

T H E R M A L E F F E C T S
O N T H E P E R F O R M A N C E
O F S C H O O L C H I L D R E N

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ABSTRACT

The effects of different thermal conditions on the performance and physiology of schoolchildren were determined. Children performed simulated school tasks in controlled indoor environments. The quality and speed of their performance on the task was recorded, as were weight, height, oral temperature, finger skin temperature and unprepared reaction time. The influence of personal parameters such as socioeconomic status was also investigated.

Children of three educational levels were tested: Grade 2 (average age eight years), Standard 3 (average age eleven years) and Standard 6 (average age fourteen years). The children taking part in an experiment were randomly assigned to one of two groups of equal size: the control group which performed at a control temperature of 24°C and the stress group which performed at either 14, 19, 29 or 34°C. Boys and girls were tested together in groups of 30 to 40. In total, 1642 Caucasian children took part and each child was exposed to only one temperature condition.

To avoid the disturbances of an artificial test environment, the children were tested in a classroom of their own school, the temperature of which was controlled by a mobile air conditioning unit.

A battery of multiple-choice-type tests included Classification, Comparison, Mathematics, Memory, Writing Speed, Number Series and Pattern Completion. In addition, a finger dexterity test and two tests of unprepared reaction time

were performed. The tests were explained to the children by video films to assure a constant quality of presentation.

The performance of each child was recorded with an answer box with five buttons assigned to the five possible answers. A digital counter on each answer box showed the number of the question to be answered. The individual answers and the time intervals between the answers were recorded and transmitted to a central unit. The answer boxes were also equipped to measure air temperature at the child's working place, finger temperature and unprepared response time.

Significant effects of temperature on performance were found. The performance of Grade 2 children was clearly impeded at 14°C. Standard 6 children showed a significant improvement in performance at all stress temperatures except 29°C. A drop in performance at a warm temperature (29°C) was found only for the Standard 6 children. The effects of temperature on the performance of Standard 3 children showed no distinct pattern. Performance on the Writing Speed and the O'Connor Peg Test was significantly reduced in the cold.

Unprepared reaction time showed little correlation with the performance of cognitive tests. Room temperature was the best predictor of the effect of temperature on performance. Finger temperature and oral temperature predicted less variation in the results and subjective comfort vote had no predictive value. Interactions between the effect of temperature and sex of subject, time-of-day when the test was performed, socioeconomic status of the children's parents or nutritional patterns were not significant.

Three types of score were obtained from each cognitive performance test: power, speed and accuracy. Scores of one type, for example speed, from different tests were usually more highly correlated than the different score types from the same test. The effects of temperature on scores of one type showed greater similarity than those on the different score types of the same test. In all age groups the working speed of the children was more strongly affected by temperature than the percentage of correct responses.

APPROVAL

The Thesis

THERMAL EFFECTS ON THE PERFORMANCE OF SCHOOL CHILDREN
was approved by the Committee for Research on Human
Subjects, University of the Witwatersrand, protocol
number 11/11/88.

DECLARATION

I declare that the Thesis

THERMAL EFFECTS ON THE PERFORMANCE OF SCHOOL CHILDREN
has not been submitted for a Degree at any other
University.

This thesis is based on a multi-disciplinary project.
Besides my coordinative function as a project leader
the following parts of the project were my own work:

- the design of the experiment,
- the principal design of the data collection system,
- the concept and initial testing of the video system,
- part of the field work, and
- the analysis and interpretation of the data



Roland Schiefer

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Parts of this thesis have appeared in the following publications:

Meese G B and Schiefer R E (1983).

Thermal effects on the performance of school children:
outline of a proposed project.

South African Journal of Science, vol 79, p 172.

Schiefer R E, Meese G B and Wentzel J D (1985).

The effect of temperature on aptitude test performance of
black pupils in Standard 10.

South African Journal of Science, vol 81, pp 213-214.

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M I (1986).

Effects of temperature on test scores of Standard 3 and
Standard 6 school children.

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7-9, Thaba'Nchu, South Africa. Abstract published in South
African Journal of Science 84(6): 527.

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An integrated system for the collection of multiple-choice-
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C O N T E N T S

ABSTRACT	
APPROVAL	
DECLARATION	
ACKNOWLEDGEMENTS	
CONTENTS	
LIST OF FIGURES	
LIST OF TABLES	
LIST OF ABBREVIATIONS	

1	INTRODUCTION AND LITERATURE REVIEW	1
1.1	STRUCTURE OF THE INTRODUCTION AND LITERATURE REVIEW	1
1.2	BACKGROUND INFORMATION ABOUT THE RESEARCH PROJECT	2
1.2.1	Reasons for undertaking the project	2
1.2.2	Rationale for literature search and discussion for the present study	4
1.2.3	History of the project	7
1.3	EFFECTS OF TEMPERATURE ON HUMAN PHYSIOLOGY	7
1.3.1	Thermoregulation	7
1.3.2	Physiological responses to heat	13
1.3.3	Physiological responses to cold	15
1.3.4	Measures of thermal stress	17
1.3.5	Acclimatisation and acclimation	21
1.3.6	Thermoregulation in children	23
1.4	EFFECTS OF TEMPERATURE ON PERFORMANCE	26
1.4.1	Effects on the performance of practical work ...	26

1.4.2	Psychological explanations	29
1.4.3	Effects on cognitive performance	33
1.4.3.1	Overview	33
1.4.3.2	Decrease of performance due to heat	37
1.4.3.3	Heat exposures with no effect on performance	41
1.4.3.4	Improvement of performance due to heat	43
1.4.3.5	Effects of cold conditions	45
1.4.3.6	Separating physiological and behavioural aspects	48
1.4.3.7	Comparison of findings	52
1.4.4	Effects on finger dexterity and sensitivity	56
1.5	THERMAL COMFORT AND PERFORMANCE	62
1.5.1	Comfort conditions and comfort vote	62
1.5.2	Thermal comfort as predictor of performance	68
1.5.3	Conclusion	70
1.6	EFFECTS OF TEMPERATURE ON THE PERFORMANCE OF CHILDREN	71
1.6.1	Background	71
1.6.2	Effects of hot conditions	73
1.6.3	Arousal and moderate heat stress	78
1.6.4	Effects of cold conditions	82
1.6.5	Clothing	83
1.6.6	Adverse effects of thermally controlled environments	84
1.6.7	Conclusion	86
1.7	OTHER ENVIRONMENTAL EFFECTS ON THE PERFORMANCE OF CHILDREN	89
1.7.1	Purpose of discussing non-thermal effects	89
1.7.2	Noise	89
1.7.3	Nutrition	95
1.7.4	Time-of-day effects	98
1.7.5	Physical school environment	105
1.7.6	Stressor interaction	108

1.8	TESTS AND TEST DEVELOPMENT	113
1.8.1	Multiple-choice-type performance tests	113
1.8.1.1	Introduction	113
1.8.1.2	Inter-individual differences in test performance	114
1.8.1.3	Effects of experimental conditions on test performance	120
1.8.1.4	Problems of testing	122
1.8.2	Reaction time tests	124
2	METHODS AND EQUIPMENT	133
2.1	EXPERIMENTAL DESIGN	133
2.1.1	Requirements for an experimental design	133
2.1.2	Discussion of alternatives	133
2.1.2.1	Meeting of experts as a forum for discussion	133
2.1.2.2	Evaluation of school marks versus a controlled experiment	134
2.1.2.3	Alternatives for a controlled experiment	135
2.1.2.4	Exposure temperatures.....	140
2.1.2.5	Time-of-day effects	141
2.1.2.6	Effects of age	142
2.1.3	Details of the experimental design selected	143
2.1.4	Pilot studies and improvements	146
2.2	DATA COLLECTION SYSTEM	147
2.2.1	Requirements for a data collection system	147
2.2.2	Investigation of alternative data collection systems	151
2.2.2.1	Feasibility study	151
2.2.2.2	Comparison of products available	154
2.2.3	Description of the automated data collection system (ADCS)	157

2.2.3.1	Overall system configuration	157
2.2.3.2	Answer boxes	158
2.2.3.3	Communication interface	160
2.2.3.4	SHARP MZ-80B microcomputer system	161
2.2.3.5	Telecontrol unit	161
2.2.3.6	Initial NEERI software	162
2.2.4	Pilot studies, modifications and additional developments	163
2.2.4.1	Preliminary tests of the new system	163
2.2.4.2	Children getting out of step	163
2.2.4.3	Reliability problems with the cable system ..	172
2.2.4.4	Reliability of the counter	176
2.2.4.5	Transport and overheating problems	178
2.2.4.6	Control software	182
2.2.4.7	Calibration of temperature sensors	193
2.3	THE MOBILE AIR-CONDITIONING UNIT	198
2.3.1	Requirements for a controlled thermal environment.	198
2.3.2	Comparison of different options	199
2.3.2.1	The NBRI mobile climate laboratory	199
2.3.2.2	Feasibility study: extended climate chamber	200
2.3.2.3	Feasibility study: power supply at schools ..	201
2.3.2.4	Feasibility study: access at schools	202
2.3.2.5	Alternative uses of the climate chamber	203
2.3.3	Description of the air-conditioning solution ...	204
2.3.4	Field experience and improvements	208
2.3.4.1	Modifications of the air-conditioning plant	208
2.3.4.2	Extended ducting	208
2.3.4.3	Quality of temperature control	211
2.4	PERFORMANCE TESTS	213
2.4.1	Requirements for performance tests and co-operation with the HSRC	213
2.4.2	Description of the performance tests	215
2.4.2.1	Classification	215
2.4.2.2	Comparison	216

2.4.2.3	Mathematics	217
2.4.2.4	Memory	218
2.4.2.5	Number Series	219
2.4.2.6	Pattern Completion	220
2.4.2.7	O'Connor Peg Test	221
2.4.2.8	Writing Speed	222
2.4.2.9	Simple Reaction Time Test	224
2.4.2.10	Choice Reaction Time Test	225
2.4.2.11	Figure Analogies	226
2.4.2.12	Personal Questionnaire	227
2.4.3	Presentation of the tests	228
2.4.3.1	Test booklets	228
2.4.3.2	Test instructions	229
2.4.4	Field experiences and improvements	230
2.4.4.1	Elimination of the Figure Analogies Test	230
2.4.4.2	Elimination of unsuitable test items	231
2.4.4.3	Duration of tests and number of questions ...	232
2.4.4.4	Improving the results for the O'Connor Peg Test	233
2.4.4.5	Special problems with Grade 2 children	234
2.5	VIDEO SYSTEM FOR TEST INSTRUCTION	235
2.5.1	Requirements for test instructions	235
2.5.2	Comparison of different ways of explanation	235
2.5.2.1	Feasibility study: instruction via video film	235
2.5.2.2	Alternative ways of presenting standardised test instructions	236
2.5.3	Description of the video system for test instructions	237
2.5.3.1	Video studio	237
2.5.3.2	Presentation unit with telecontrol	239
2.5.3.3	Transport equipment	241
2.5.4	Pilot studies and modifications	243
2.5.4.1	Production of the films	243
2.5.4.2	Use in the classroom	243
2.5.4.3	Secondary uses of the presentation unit	244

2.6	DETAILS OF THE EXPERIMENTAL ROUTINE	245
2.6.1	Additional measurements	245
2.6.1.1	Noise level measurement	245
2.6.1.2	Height measurement	245
2.6.1.3	Weight measurement	246
2.6.2	Control of the thermal environment	246
2.6.2.1	Standardisation of clothing	246
2.6.2.2	Reduction of temperature gradients	247
2.6.2.3	Acclimation	247
2.6.3	Organisation of the experiments	249
2.6.3.1	Approval, acceptance and site selection	249
2.6.3.2	Preparation of the test groups	250
2.6.4	Structure of an experimental day	250
2.7	DATA HANDLING AND PREPARATION	253
2.7.1	Data collection, transfer and conversion	253
2.7.1.1	Overview	253
2.7.1.2	Input of additional data	254
2.7.1.3	Data transfer	254
2.7.1.4	Conversion of the data structure	255
2.7.2	Preparation of results of the multiple-choice-type tests	256
2.7.2.1	Filtering of incorrectly entered data	256
2.7.2.2	Identification of unsuitable test items	257
2.7.2.3	Calculation of standardised performance test scores	259
2.7.2.4	Identification of uncooperative children	261
2.7.3	Preparation of results of the O'Connor Peg and the Writing Speed Test	263
2.7.3.1	O'Connor Peg Test	263
2.7.3.2	Writing Speed Test	264
2.7.4	Preparation of results of the reaction time tests	265
2.7.5	Oral temperature	266
2.7.6	Finger temperature	268
2.7.7	Ponderal index	268

2.8	STATISTICAL METHODS	269
2.8.1	General linear model (GLM)	269
2.8.2	Sign test	271
2.8.3	Facet Analysis	273
3	RESULTS	275
3.1	STRUCTURE OF THE RESULTS PRESENTATION	275
3.2	DESCRIPTION OF SAMPLE SIZES	276
3.3	DIFFERENCES IN PERFORMANCE ON STRESS AND CONTROL DAYS	279
3.4	EFFECTS OF ROOM TEMPERATURE ON TEST PERFORMANCE	281
3.4.1	Aim of the analysis	281
3.4.2	Significance of the temperature effect	281
3.4.3	Effects of other variables on performance	284
3.4.3.1	Noise levels	284
3.4.3.2	Sex differences	286
3.4.3.3	Time-of-day	287
3.4.3.4	Pupil data	289
3.4.3.5	Personal Questionnaire	290
3.4.4	Percentage of variation attributed to room temperature	292
3.4.4.1	Attributing variation to variables	292
3.4.4.2	Results	293
3.4.4.3	Summary tables	294
3.5	PREDICTIVE VALUE OF BODY TEMPERATURES AND COMFORT VOTE	298
3.5.1	Aim of the analysis	298
3.5.2	Oral temperature	298

3.5.3	Finger temperature	302
3.5.4	Comfort vote	305
3.5.5	Comparison of predictive values	307
3.6	INTER-INDIVIDUAL VARIATION AT DIFFERENT TEMPERATURES	309
3.6.1	Aim of the analysis	309
3.6.2	Calculation of the coefficient of variation	309
3.6.3	The coefficient of variation at different temperatures	310
3.7	FACET ANALYSIS	314
3.7.1	Aim of the analysis	314
3.7.2	Data structures at the control temperature	315
3.7.3	Data structures at different stress temperatures	316
3.8	EFFECTS OF ROOM TEMPERATURE ON COMBINED SCORES	329
3.8.1	Aim of the analysis	329
3.8.2	Calculation of combined scores	329
3.8.3	Temperature effect on combined scores	330
4	DISCUSSION	334
4.1	STRUCTURE OF THE DISCUSSION.....	334
4.2	TEMPERATURE EFFECTS ON THE PERFORMANCE OF MULTIPLE- CHOICE-TYPE TESTS	335
4.2.1	General	335
4.2.2	Comparison with the results of other studies ...	336
4.2.3	Comparison of thermal effects on different performance tests	353
4.2.4	Differences in thermal effects on speed and accuracy	356

4.2.5	Summary	358
4.3	TEMPERATURE EFFECTS ON WRITING SPEED AND THE O'CONNOR PEG TEST	363
4.4	TEMPERATURE EFFECTS ON REACTION TIME AND ITS USE AS A PREDICTOR OF PERFORMANCE	366
4.4.1	Reaction time as a predictor of performance	366
4.4.2	Effect of temperature on reaction times	368
4.4.3	Writing Speed as an alternative predictor of performance	370
4.5	THE ROLE OF CONCOMITANT VARIABLES	373
4.5.1	General	373
4.5.2	Time-of-day effects	374
4.5.3	Effects of sex	381
4.5.4	Effects of nutrition	384
4.6	CRITICAL ASSESSMENT OF THE METHODS USED	386
4.6.1	Purpose of the discussion of methods	386
4.6.2	Experimental design	387
4.6.3	Adaptation to thermal conditions	390
4.6.4	Sensitivity of the present study	392
4.6.5	Effects of noise	393
4.6.6	Experimental conditions	394
4.6.7	Selection of schools and subjects	397
4.7	POSSIBLE IMPROVEMENTS IN THE PREDICTION OF THERMAL EFFECTS ON PERFORMANCE	398
4.7.1	General	398
4.7.2	Body temperatures and subjective comfort vote as predictors of performance	399
4.7.3	Information about the individuals	402
4.7.4	The use of indicators for performance prediction	403

4.8	RECOMMENDATIONS FOR SCHOOL BUILDINGS	405
4.8.1	Relevant effects of temperature on performance	405
4.8.2	Air-conditioning and pupils' scholastic performance	407
4.8.3	Air-conditioning and teachers' morale	409
4.8.4	Appropriate design for classrooms	410

5	CONCLUSION	412

APPENDICES:

A	Control program for ADCS	417
B	Control data file for ADCS	429
C	Personal Questionnaire	430

REFERENCES	440

LIST OF FIGURES

- Figure 1.4-1: Effect of temperature on performance.
Data were taken from Table 1.4-1
- Figure 2.1-1: Sequence of events in an experiment.
- Figure 2.2-1: Children working with answer boxes of the ADCS.
- Figure 2.2-2: Answer box of the ADCS clamped onto a desk and an ID-disk.
- Figure 2.2-3: Schematic drawing of the ADCS system
- Figure 2.2-4: Drawing of the front panel of an ADCS answer box.
- Figure 2.2-5: Drawing of ADCS microcomputer screen (questionnaire mode).
- Figure 2.2-6: Initial cable system of the ADCS.
- Figure 2.2-7: Improved cable system of the ADCS.
- Figure 2.2-8: Connection between cable ducts of the ADCS.
- Figure 2.2-9: ADCS answer boxes installed in a classroom.
- Figure 2.2-10: Control system of the ADCS mounted in an aluminium container.
- Figure 2.2-11: ADCS control system and cable connections in a classroom.
- Figure 2.2-12: Flow diagram of operations from the ADCS main menu.

Figure 2.2-13: Flow diagram of operations from the ADCS "questionnaire" menu.

Figure 2.2-14: ADCS initialisation dialogue.

Figure 2.2-15: Warming curve of a temperature sensor in contact with a fingertip.

Figure 2.3-1: Caravan containing the air-conditioning unit connected to a classroom.

Figure 2.3-2: Schematic drawing of the link between air-conditioning unit and classroom.

Figure 2.3-3: Air distribution box for temperature control in classroom.

Figure 2.3-4: Air distribution boxes installed in classroom.

Figure 2.3-5: Caravan containing air-conditioning unit connected to classroom with extended ducts.

Figure 2.3-6: Frequency distribution of all room temperature measurements at a target temperature of 14°C during the performance of the Classification Test.

Figure 2.4-1: First page of Classification Test for Grade 2.

Figure 2.4-2: Item from the Comparison Test for Grade 2.

Figure 2.4-3: Item from the Mathematics Test for Grade 2.

Figure 2.4-4: Item from the Memory Test for Grade 2.

- Figure 2.4-5: Examples from the Number Series Test for Standard 6.
- Figure 2.4-6: Item from the Pattern Completion Test for Standard 6.
- Figure 2.4-7: Pegboard for O'Connor Peg Test.
- Figure 2.4-8: Top of page one from the Writing Speed Test.
- Figure 2.4-9: Item from the Figure Analogies Test for Standard 6.
- Figure 2.5-1: View of the video studio.
- Figure 2.5-2: Presentation unit in a classroom.
- Figure 2.5-3: Loading of the presentation unit into a truck.
- Figure 2.7-1: Collection and transfer of experimental data.
- Figure 2.7-2: Frequency distribution for the POWER scores of the Classification Test for Standard 6 at 24°C.
- Figure 2.7-3: Frequency distribution for the SPEED scores of the Classification Test for Standard 6 at 24°C.
- Figure 2.7-4: Frequency distribution for the ACCURACY scores of the Classification Test for Standard 6 at 24°C.
- Figure 2.7-5: Frequency distribution of oral temperatures of Standard 6 children at 24°C measured during the late morning.

- Figure 3.5-1: Oral temperature of Standard 6 children at five experimental temperatures (14, 19, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)
- Figure 3.5-2: Oral temperature of Standard 3 children at five experimental temperatures (14, 19, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)
- Figure 3.5-3: Oral temperature of Grade 2 children at five experimental temperatures (14, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)
- Figure 3.5-4: Finger temperature of Standard 6 children at five experimental temperatures (14, 19, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)
- Figure 3.5-5: Finger temperature of Standard 3 children at five experimental temperatures (14, 19, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)
- Figure 3.5-6: Finger temperature of Grade 2 children at five experimental temperatures (14, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)
- Figure 3.5-7: Comfort vote of Standard 6 children at five experimental temperatures (14, 19, 24, 29 and 34°C) expressed as percentage of the children who voted either: too hot, just right or too cold.

- Figure 3.5-8: Comfort vote of Standard 3 children at five experimental temperatures (14, 19, 24, 29 and 34°C) expressed as percentage of the children who voted either: too hot, just right or too cold.
- Figure 3.5-9: Comfort vote of Grade 2 children at five experimental temperatures (14, 24, 29 and 34°C) expressed as percentage of the children who voted either: too hot, just right or too cold.
- Figure 3.7-1: Facet Diagram of the test scores of Standard 6 children at 24°C (Coefficient of alienation: 0.24).
- Figure 3.7-2: Facet Diagram of the test scores of Standard 3 children at 24°C. MEMspe falls outside the region of speed scores (Coefficient of alienation: 0.21).
- Figure 3.7-3: Facet Diagram of the test scores of Grade 2 children at 24°C (Coefficient of alienation: 0.17).
- Figure 3.7-4: Facet Diagram of the test scores of Standard 6 children at 14°C (Coefficient of alienation: 0.19).
- Figure 3.7-5: Facet Diagram of the test scores of Standard 6 children at 19°C. CLApow falls outside the region of power scores (Coefficient of alienation: 0.23).
- Figure 3.7-6: Facet Diagram of the test scores of Standard 6 children at 29°C (Coefficient of alienation: 0.24).
- Figure 3.7-7: Facet Diagram of the test scores of Standard 6 children at 34°C (Coefficient of alienation: 0.23).
- Figure 3.7-8: Facet Diagram of the test scores of Standard 3 children at 14°C (Coefficient of alienation: 0.25).

Figure 3.7-9: Facet Diagram of the test scores of Standard 3 children at 34°C. MEMspe falls outside the region of speed scores and the SRT scores do not form a region with the CRT scores (Coefficient of alienation: 0.22).

Figure 3.7-10: Facet Diagram of the test scores of Grade 2 children at 14°C (Coefficient of alienation: 0.21).

Figure 3.7-11: Facet Diagram of the test scores of Grade 2 children at 34°C (Coefficient of alienation: 0.18).

Figure 3.8-1: Percentage change of performance on stress days as compared with control days for the combined power speed and accuracy scores of Standard 6 children.

Figure 3.8-2: Percentage change of performance on stress days as compared with control days for the combined power speed and accuracy scores of Standard 3 children.

Figure 3.8-3: Percentage change of performance on stress days as compared with control days for the combined power speed and accuracy scores of Grade 2 children.

Figure 4.2-1: Effect of temperature on performance of an addition task (ADD) and a reading test (RD) by 11-year old boys under quiet conditions (Wyon, 1969a).

Figure 4.2-2: Effect of temperature on performance of an addition task (ADD) and a reading test (RD) by 11-year old boys under noisy conditions (Wyon, 1969a).

Figure 4.2-3: Effect of temperature on performance of the MAT and NUM test (Table 3.3-1) by Standard 3 children in the present study.

- Figure 4.2-4: Effect of temperature on performance of the MAT and NUM test (Table 3.3-1) by Standard 6 children in the present study.
- Figure 4.2-5: Effect of temperature on performance of the COM and MEM test (Table 3.3-1) by Standard 3 children in the present study.
- Figure 4.2-6: Effect of temperature on performance of the COM and MEM test (Table 3.3-1) by Standard 6 children in the present study.
- Figure 4.2-7: Effect of temperature on performance of a multiplication task by 12-year-old children (Ryd and Wyon, 1970). "L" refers to low and "H" to high performers of two classes at each condition.
- Figure 4.2-8: Effect of temperature on learning a programmed instruction text by college students (Pepler and Warner, 1968). "eff" is an abbreviation for "effort rating" by the students.
- Figure 4.2-9: Effect of temperature on performance of the CLA and PAT tests (Table 3.3-1) by Standard 3 children in the present study.
- Figure 4.2-10: Effect of temperature on performance of the CLA and PAT tests (Table 3.3-1) by Standard 6 children in the present study.
- Figure 4.2-11: Effect of temperature on performance of the CLA, COM, MAT and MEM tests (Table 3.3-1) by Grade 2 children in the present study.
- Figure 4.2-12: Facet Diagram of the effects of temperature on test scores of all children (Coefficient of alienation: 0.21).

Figure 4.2-13: Means plus and minus one standard deviation of the differences in performance between stress and control days (Table 3.3-1) for the power scores of all tests. Standard 6 children only.

Figure 4.2-14: Means plus and minus one standard deviation of the differences in performance between stress and control days (Table 3.3-1) for the power scores of all tests. Standard 3 children only.

Figure 4.2-15: Means plus and minus one standard deviation of the differences in performance between stress and control days (Table 3.3-1) for the power scores of all tests. Grade 2 children only.

LIST OF TABLES

- Table 1.4-1: Overview of thermal studies (parts 1 and 2).
The following abbreviations were used:
perf: performance, vigil: vigilance,
rep.acq: repeated acquisition, wk: work,
add: addition, cort: cortical temperature.
- Table 1.4-2: Significant decreases(-) and increases (+) in performance found in thermal studies (data taken from Table 1.4-1).
- Table 1.6-1: ASHRAE guidelines for heat stress.
- Table 2.3-1: Means and standard deviations of temperature measurements at different planned temperatures and % of values within ± 2 °C.
- Table 2.4-1: Number of test items without X-questions and maximum work time in minutes for different tests. For the Personal Questionnaire and the Memory Test in Grade 2 no time limit was set.
- Table 2.6-1: Schedule of an experimental day for a Standard 6 class.
- Table 2.6-2: Sequence of tests in three different schedules for Standard 3 and Standard 6 children.
- Table 2.7-1: Means of the number of X-key mistakes per child during one test, by test and by standard.
- Table 2.7-2: Means of the item difficulty values (%) and item response times (IRT in seconds) on control days.

- Table 2.7-3: Percentage of all oral temperatures measured at 24°C air temperature above a given level.
- Table 3.2-1: Number of children who took part in performance tests on stress and control days.
- Table 3.2-2: Number of children who took part in experiments at different conditions.
- Table 3.2-3: Means of the ages, weights and heights of boys and girls in Grade 2, Standard 3 and Standard 6.
- Table 3.3-1: Percentage increment or decrement of performance on stress days as compared with control days.
- Table 3.4-1: Significance levels of performance differences between stress and control days in abbreviated format: "043" stands for " $p < 0.043$ ". For $p < 0.01$ the levels were printed bold and for $p \geq 0.05$ they were replaced by a hyphen. A dot indicates that no experiments were performed.
- Table 3.4-2: Means and standard deviations of five noise level measurements on stress and control days at four temperature conditions. The results are given in dB(A) and "n" is the number of experimental days on which noise measurements were performed.
- Table 3.4-3: Percentage of variation attributable to room temperature.
- Table 3.4-4: Mean percentage of variation attributable to room temperature for different score types.

- Table 3.4-5: Mean percentage of variation attributable to room temperature for score types at different educational standards.
- Table 3.4-6: Mean percentage of variation attributable to room temperature for score types of different performance tests and for reaction times
- Table 3.5-1: Significant relationships ($p < 0.01$) between oral temperature and test performance
- Table 3.5-2: Significant relationships ($p < 0.01$) between finger temperature and test performance.
- Table 3.6-1: Means of coefficients of variation of scores on all control days at different temperatures and standards.
- Table 3.6-2: Number of experiments where C.V. was higher on the stress day (left of colon) versus number of experiments where C.V. was smaller on the stress day (right of colon).
- Table 3.6-3: Number of test applications where the C.V. was higher on the stress day ($S > C$) and where the C.V. was smaller on the stress day ($S < C$) for different score types and experimental conditions.
- Table 3.8-1: Significance levels of differences in combined scores between stress and control days in abbreviated format: "043" stands for " $p < 0.043$ ". For $p < 0.01$ the levels were printed bold and for $p \geq 0.05$ they were replaced by a hyphen. A dot indicates that no experiments were performed.
- Table 3.8-2: Percentage increment or decrement of performance on stress days as compared with control days (combined scores).

- Table 4.3-1: Spearman rank order correlation between the Writing Speed score and the power scores of cognitive performance tests for different age groups. The values shown are the means of the correlations at 14, 19, 24, 29 and 34°C.
- Table 4.5.1: Maximum daily variation of different physiological measures (MAX) expressed in the dimensions described and the variation of these measures between 10:00 and 13:00 expressed as a percentage of the maximum variation (%PP).
- Table 4.5.2: Daily variation of physiological parameters described as indicators of sensitivity to thermal stress.
- Table 4.5.3: Daily variation of subjective alertness.
- Table 4.5.4: Daily variation in the performance of some cognitive tests.
- Table 4.6-1: Details of the smallest difference in performance between stress and control days that was significant at $p < 0.05$, for different educational levels.
- Table 4.6-2: Design air temperature and associated humidity for 10% design day in summer and winter for Pretoria, Lynnwood (Wentzel et al. 1985).

LIST OF ABBREVIATIONS

ACC	Accuracy test score
A/D	Analog to Digital conversion (in electronic circuits)
ADCS	Automated Data Collection System, designed and built for the present study
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
CET	Corrected Effective Temperature
CLA	Classification Test
COM	Comparison Test
CRT	Choice Reaction Time (choice between four options)
CRT1	first measurement of CRT on an experimental day
CRT2	second measurement of CRT on an experimental day
CRT3	third measurement of CRT on an experimental day
CSIR	Council for Scientific and Industrial Research
C.V.	Coefficient of Variation
DB	Dry Bulb temperature
DBT	Division of Building Technology, the former NBRI

EEG	Electroencephalogram
EPA	Environmental Protection Agency (USA)
ET	Effective Temperature
GRD2	Grade 2: second year of schooling; the children were on average eight years old
HSRC	Human Sciences Research Council (South Africa)
MAT	Mathematics Test
MEM	Memory Test
NBRI	National Building Research Institute
NIOSH	National Institute of Occupational Safety and Health (USA)
NUM	Number Series Test
PAT	Pattern Completion Test
PEG	O'Connor Peg Test
POW	Power test score
PP	"performance phase": part of the experimental day during which the performance tests were completed
reaction speed	inverse of reaction time

RH	Relative Humidity: the amount of water vapour in the air at a given temperature expressed as a percentage of the maximum amount of water the air can hold at that temperature.
RT	Reaction Time
SABC	South African Broadcasting Corporation
SAS	Statistical Analysis System (produced by the SAS Institute Inc., Box 8000, Cary, North Carolina 27511, USA)
SPE	Speed test score
SRT	Simple Reaction Time (no choice)
SRT1	first measurement of SRT on an experimental day
SRT2	second measurement of SRT on an experimental day
SRT3	third measurement of SRT on an experimental day
STD3	Standard 3: fifth year of schooling; the children were on average eleven years old
STD6	Standard 6: eighth year of schooling; the children were on average fourteen years old
SYSTAT	program package for statistical data analysis, produced by Systat Inc., Illinois 60201, USA
T	Temperature
TED	Transvaal Education Department (South Africa)

1 INTRODUCTION AND LITERATURE REVIEW

1.1 STRUCTURE OF THE INTRODUCTION AND LITERATURE REVIEW

PART	HEADING AND CONTENT
1.2	<u>Background information about the research project</u> Reasons for undertaking this project, its history and the rationale for discussion of relevant literature.
1.3	<u>Effects of temperature on human physiology</u> Principles of thermoregulation, heat balance, sweating and shivering; discussion of thermal experiments in climate chambers and in the field; physiological differences between adults and children.
1.4	<u>Effects of temperature on performance</u> Size and relevance of temperature effects in industrial and office work; discussion of laboratory tests on adults and of theories on the impact of temperature.
1.5	<u>Thermal comfort and performance</u> How to determine comfort temperature; inter-individual differences in the response to the thermal environment; the use of comfort vote as a predictor of performance.
1.6	<u>Effects of temperature on the performance of children</u> Focus on the performance of school work and the effects of moderate heat stress conditions; discussion of laboratory tests and field studies; beneficial and detrimental effects of air-conditioning.
1.7	<u>Other environmental effects on the performance of children</u> Methods used and problems encountered in the investigation of other stressors such as noise, nutritional deficiencies and time-of-day.
1.8	<u>Tests and test development</u> Problems in selecting appropriate tests; background on multiple-choice-type tests and reaction time tests; reaction time as a predictor of cognitive performance; effects of experimental conditions on the test score.

WB	Wet Bulb temperature
WBGT	Wet Bulb Globe Temperature
WRI	Writing Speed Test
**	mathematical operator for exponentiation

1.2 BACKGROUND INFORMATION ABOUT THE RESEARCH PROJECT

1.2.1 REASONS FOR UNDERTAKING THE PROJECT

It is important that the time spent in school should be profitable and productive for both children and teachers. Schools in tropical and subtropical climates are often of light-weight construction and their thermal conditions vary considerably.

In Southern Africa and in most of the third world many children do not have a school building that would satisfy even minimal requirements. This implies on the other hand that most of the schools that will be used in 20 years time are not yet built - providing a unique chance to improve their usefulness in the design phase, where modifications are still fairly inexpensive compared with later alterations. The main purpose of this project was to determine whether thermal effects on the performance of school children are of sufficient magnitude to warrant an input during the classroom design phase.

Little research has been done on the effect of heat and cold stress on children. This means that building guidelines are based on the requirements of adults. The thermal response of a child, however, is not the same as that of an adult. A child's greater surface area in relation to his metabolically active tissue means that he can become extremely cold, and Araki et al. (1982) have shown that children in cold conditions maintain a lower skin temperature than adults. Under conditions of mild heat stress children are also at a disadvantage and tend to have

higher rectal temperatures, higher heart rates, lower sweat rates and a later onset of sweating (Löfstedt, 1966). For these reasons data obtained from adults, in most studies fit young males, are not necessarily relevant for children.

Temperature effects on the performance of children have been found; for example, Wyon et al. (1979) have shown that memory, mathematical ability, reading speed and comprehension, cue-utilisation and creativity of children are affected by temperature. Most studies on children have been conducted under laboratory situations, where the conditions could be tightly controlled, but where the physical and social environment was totally alien to the children. As the effect of mild stress on performance depends on a variety of factors (Wyon, 1974) it cannot be concluded that the effects found in such studies are representative for everyday school work.

In long term field studies, often focused on the impact of a newly installed air-conditioning system, the children worked in their natural environment, but the experimental conditions were at best loosely controlled (McNall and Nevins, 1967; King and Marans, 1979).

The main aim of this study was to combine careful control of experimental conditions with working in the natural environment so that the results of the study could be a relevant contribution to the design of better schools. The study was further intended to contribute to the knowledge of the relationships between physiological parameters such as oral temperature and various measures of performance for children under mild thermal stress.

1.2.2 RATIONALE FOR LITERATURE SEARCH AND DISCUSSION FOR THE PRESENT STUDY

A review of the relevant literature concerning the effects of mild thermal stress on cognitive performance did not reveal a coherent structure of findings and theories. Results were in many cases contradictory and the major theoretical concept in this field, the concept of "arousal", was too vague to be the target of an experiment that would either strongly support or reject it (Wyon, 1970).

One way of dealing with this kind of complexity is to find a criterion for selecting a sub-set of studies with fairly homogeneous results and to structure the proposed work to support or reject these results. This was seen as inappropriate for the present study for the following reasons:

- all studies discussed were performed by reputable researchers at well-established organisations. None of them involved outdated measurement techniques that did not conform to modern standards. No study could be excluded for lack of quality;
- the present study was one of the largest ever undertaken in this field. Given the number of test subjects, manpower and equipment, it seemed inappropriate to attempt anything less than to describe an overall pattern of the effects of temperature on the performance of school children; and
- it had to be considered that the effects of moderate stress and of the experimental conditions in general were highly non-linear. It is possible that small

factors such as a hardly audible background conversation or some minor elements in the presentation of the tests could have changed the outcome of an experiment. In this case it would be necessary to study a wide range of results in order to detect a pattern embedded in the "noise" of non-linear effects.

Therefore, all relevant studies were deliberately presented with comparable depth, emphasizing common findings, but without any attempt to criticise results that did not fit the findings shown by other studies. All findings, including those of the present study, were used as elements in a pattern with the goal of determining crucial features in this pattern. In this activity more importance was given to the extent to which these findings support each other than to the level of statistical significance of each of the findings. Nevertheless, the level of statistical significance is quoted for many of the findings discussed and is given for all results of the present study.

The research problem of thermal effects on the performance of school children has physiological, psychological, educational, architectural and practical aspects. The only criterion for discussing any aspects was their relevance for the research problem. I did not attempt to focus on aspects pertaining to one academic discipline as this would have reduced the value of the discussion.

The literature for the present study was obtained in the following ways:

During the early stages of the project a computerised, retrospective literature search was undertaken on a

series of databases in the USA by the CSIR library service. As a result well over one thousand relevant articles were received and used for the planning and development of the project.

An ongoing literature search based on a keyword profile relating to temperature and children was established on the databases ERIC (Educational Resources Information Center, Washington, D.C. 20208) and PA (Psychological Abstracts) for the duration of the study.

In 1989 the library service of the HSRC (HUMINS) performed a retrospective search over the last three years in the Psychological Abstracts database, focusing on the names of authors who had previously published relevant articles as determined by the literature sources described above.

All issues of the following journals during the last three years were reviewed in the first quarter of 1990: Applied Physiology, Aviation Space and Environmental Medicine, Ergonomics, Human Factors, Applied Ergonomics and Ergonomic Abstracts.

Dr David Wyon from the National Swedish Building Research Institute conducted a search for literature pertaining to the effects of temperature on children early 1990. Dr Wyon has published extensively in this area and was a guest researcher at the National Building Research Institute of the CSIR who helped to establish the mobile climate laboratory used in the present study.

1 searches indicated that little research relevant for the present study had been undertaken in the last five years.

1.2.3 HISTORY OF THE PROJECT

The National Building Research Institute (NBRI) of the Council for Scientific and Industrial Research (CSIR) had a well-equipped thermal laboratory and a team with several years of experience in thermal physiology. Most of the work focused on factory workers, but some effort had been made to investigate the effects of temperature on children. Wentzel and Meese (1983) investigated the decrease of finger dexterity under cold conditions in primary school children. Schiefer et al. (1985) analysed the percentage of variation explained by temperature in 48 000 vocational guidance tests conducted with black Standard 10 children.

The production of the "Guidelines for Factory Building Design" (NBRI, 1982) showed a demand for a major study into the effect of temperature on the performance of school children. Ideally the work should have been conducted on black children, who constitute the majority of school children in this country, but the unrest situation that pertained at that time in the black areas made such research very difficult.

1.3 EFFECTS OF TEMPERATURE ON HUMAN PHYSIOLOGY

1.3.1 THERMOREGULATION

Humans usually maintain a stable deep body temperature within narrow limits, although the environmental temperature

may fluctuate, and although physical activity may vary greatly. In hot surroundings a large proportion of the body tissue may have temperatures close to that of the core. In the cold the zone of core temperature shrinks and the limbs and the peripheral tissues become colder. Marked departures from the zone of maintained core temperature occur only when thermoregulation fails, either because it is overloaded in a thermally extreme environment, or due to drugs, disease or injury. A few aspects of thermoregulation that might aid in the understanding of the present study are given below. For more detailed reviews concerning thermoregulation see Mount (1979), McIntyre (1980) and Mitchell and Laburn (1985).

The human body requires energy to stay alive, so there is a minimum essential energy production even in the absence of conscious muscular activity. The minimum rate of energy production is termed the "basic metabolic rate", and is measured on a resting, awake, fasting subject. It decreases with age from about 60 Watt per square meter of body surface for children to $50 \text{ W}\cdot\text{m}^{-2}$ for teenagers and $40 \text{ W}\cdot\text{m}^{-2}$ for the elderly. When external mechanical work has to be performed the heat production increases. The efficiency of the human body in performing work varies with the task, but is usually lower than 20%, which means that for every 20 W of external work at least 80 W of additional heat are produced in the body. Heavy industrial work causes the body to produce about $250 \text{ W}\cdot\text{m}^{-2}$ of heat (McIntyre, 1980).

The heat produced in the human body has to be dissipated to avoid a continuous increase in core body temperature. The metabolic heat production and all 'heat gains of the body from the environment, for example by exposure to sunlight, must balance against all heat losses to maintain equilibrium. There are various mechanisms for heat transfer:

radiation: all bodies emit and absorb thermal radiation, a form of electromagnetic radiation. The net flow of energy is from hotter to cooler bodies;

convection: the layer of air in contact with skin and clothing will be warmed or cooled, depending on the temperature gradient. This layer may be blown away, or it may rise or fall due to the different densities of cool and hot air;

evaporation: the production and evaporation of sweat is the body's most powerful temperature control mechanism. When water changes from liquid to vapour, heat is required to facilitate the phase change. This heat comes partially from the body, which results in a cooling effect. One gram of sweat evaporated per minute is equivalent to a heat loss of 41 Watt. (McIntyre, 1980).

The physical properties of the clothing worn, especially the insulation value, play an essential role in heat transfer.

Thermoregulation depends on nervous control that is only imperfectly understood. There are peripheral temperature receptors in the skin, and central temperature receptors in the body core. The peripheral receptors fall into two groups: those that initiate nerve impulses under cold conditions and those that do so under warm conditions. The control of body temperature is centrally mediated by the hypothalamus which has its own temperature receptors and takes account of information coming from other deep areas and from the skin. The thermoregulatory system aims to maintain a certain core body temperature, sometimes referred to as the set point temperature (Werner, 1980). Deviations

of body temperature from the set point temperature lead to physiological and behavioural responses.

When the set point temperature is exceeded, heat dissipation is increased by sweating or panting, and heat conservation is decreased by peripheral vasodilation: the dilation of blood vessels near the surface of the skin. When the core temperature falls below the set-point temperature, heat production is increased by shivering or non-shivering thermogenesis. Heat dissipation is reduced and heat conservation is increased by peripheral vasoconstriction: the closure of blood vessels. Behavioral responses to temperature include change of posture and changes of position in relation to the microclimate, for example moving into the shade (Mount, 1979).

The term set-point for thermoregulation is sometimes a source of confusion (Werner, 1980), because it can be understood in terms of technical control: the incoming measurement signal is subtracted from a reference signal which defines the set point. The resulting error signal stimulates the effectors to respond. This model may lead to a fruitless search for a neuronal reference signal. According to Werner (1980) there is no need for such a reference signal. The regulated variable in human thermoregulatory control seems to be a "... flexible and adaptable integrative temperature signal according to a distributed parameter control strategy". Set-point in this context is the balance reached by the controlling and the controlled processes in a closed control loop.

The body's heat storage capacity is low compared to the metabolic heat production during exercise. A fraction of an

hour of severe exercise would lead to lethal core temperatures, were all the heat produced stored in the body. Skin blood flow transfers heat to the body surface where it is dissipated. The blood leaves the cutaneous capillaries at skin temperature. If the skin temperature can be kept low by a cool environment or by the evaporation of sweat, the cardiovascular adjustments required for maintenance of thermal balance are relatively minor. If the skin temperature cannot be kept low, more skin bloodflow is required for the same heat transport. Thus cardiovascular regulation and the thermoregulatory system are interdependent. Brengelmann (1983) compared the results of ten publications concerned with circulatory adjustments to exercise and heat stress. All investigators used esophageal temperature as their measure of core temperature and recorded forearm blood flow to determine changes in skin blood flow. The following conclusions were drawn:

- At low core temperatures the increase in skin blood flow is approximately linear with core temperature. An increase of core temperature from 37.0 to 37.8°C caused an average increase of skin blood flow from about 4 to 16 ml of blood per 100 ml of tissue per minute. Much smaller increments of skin blood flow are associated per unit core temperature increment at higher ranges of core temperature.
- Change from a supine to an upright position, exercise and hypo-hydration lead to a lower skin blood flow at a given core temperature. Acclimation and an increase in skin temperature lead to a higher skin blood flow at a given core temperature.
- Exercise intensity does not change the relationship between skin blood flow and core temperature. This is surprising, because there is a marked difference in

skin blood flow between rest and performing any form of exercise. This finding was confirmed by several studies.

As most school work is traditionally performed in a sitting position, the effects of posture and exercise level were not relevant for the present study.

Thermoregulation is affected by time-of-day. Faria and Drummond (1982) found a sine wave pattern over 24 hours in resting heart rate and oral temperature. The changes were in phase, reaching their peak at 18:00 (66 beats, 37°C) and their lowest value at 06:00 (60 beats, 36°C). The differences between the peak and lowest values were significant for both parameters ($p < 0.05$).

Marotte and Timbal (1981) found a similar pattern for rectal temperature, but described it as non-sinusoidal with a day-time plateau (highest value 36.4°C at 18:00) and a night-time minimum (36.4°C at 04:00). Seven resting subjects were monitored over 24 hours at constant air temperature. Mean skin temperature followed a circadian asymmetric rhythm with a maximum at 23:00 (34.2°C) and a minimum at 06:00 (33.9°C). The skin temperatures of the extremities showed an even more pronounced circadian pattern.

Hildebrandt (1984) writes that the circadian pattern of body temperature is the result of a heat-up phase in the morning, when perfusion of the skin of the extremities (and therefore heat loss) is low, and of a cool-down phase in the afternoon, which is associated with high peripheral perfusion. The organism seems more responsive to cold stress

and less responsive to heat stress in the morning whereas the opposite is the case in the afternoon.

Marotte and Timbal (1982) investigated the effects of circadian rhythms on thermoregulation by exposing four subjects to hot (90 minutes at 40°C) and three to cold conditions (75 minutes at 20°C after a 45 minute cool-down from environmental temperature to avoid instant shivering). Each subject participated in eight experiments equally spaced over the 24 hour span. The time before the onset of sweating showed a sinus pattern with a maximum at 13:00 ($p < 0.001$), indicating a low sensitivity to heat in the morning. The time before the onset of shivering showed no clear pattern.

The dependence of thermoregulatory processes on time-of-day implies for the present study that a possible influence of time-of-day on the effect of room temperature on performance had to be investigated.

1.3.2 PHYSIOLOGICAL RESPONSES TO HEAT

The effect of a given thermal environment on the body's physiological response depends strongly on the clothing the subject is wearing. The transport of heat from the skin of a dressed subject to a cooler environment is a complex process. Warm air can be pressed through the fabric layers of the clothing and through small and large openings of the clothing to the surrounding environment, and cold air can be sucked into the clothing. Within the clothing, mixing of air

layers of different temperatures can be caused by extension and compression of air-filled cavities. Nielsen et al. (1985) found that intrinsic clothing insulation and surface air insulation can be reduced by up to 50% by physical activity such as bicycling or walking. In the present study clothing and the type of physical activity (sitting) were therefore standardised.

Heat stress is significantly increased when subjects are hypo-hydrated. When exercising in the heat it is essential to replace the water lost by sweating. Francesconi et al. (1984) measured the concentration of stress hormones in the blood of subjects exercising in either hot dry or hot wet conditions. Increments in circulating plasma cortisol levels were only found when the subjects were hypo-hydrated by 5% of their body weight. When eu-hydrated, only more subtle effects on the normal circadian variation of plasma cortisol levels occurred. Effects on circulating levels of growth hormone were less consistent, but hypo-hydration ordinarily elicited elevated concentrations of this stress hormone. In the present study temperature levels and physical activity were far too low to lead to serious hypo-hydration. During the school breaks the subjects had sufficient opportunity to drink, although they were not encouraged to do so.

Males and females react differently to heat stress. Wyndham et al. (1965) compared the heat reactions of 30 male and 26 female Caucasians in an unacclimated state. Females showed stronger physiological and psychological reactions than males, they reached the exposure limit of 40°C rectal temperature or 180 heartbeats per minute faster and sweated less. Burse (1979) also found that women under heat stress show greater heart rate increases, lower maximal sweat rates and higher skin temperatures with higher body heat storage

than do males. Kenney (1985) stated in a review of comparative responses of men and women to heat stress that:

- women as a population are less tolerant to a given heat stress but if cardiovascular fitness level, body size and acclimation state are standardised, differences between the sexes tend to disappear;
- women have a lower sweat rate than men of equal fitness, size and acclimation, which is disadvantageous in hot, dry environments, but advantageous in hot, wet environments; and
- that menstrual cycle effects are minimal.

This implies for the present study that differences in the effect of temperature on the performance of boys and girls must be investigated.

1.3.3 PHYSIOLOGICAL RESPONSES TO COLD

In the cold the body reacts with an increase of metabolic rate; at 5°C it is about twice as high as at 25°C. This was demonstrated by Wyndham (1965) on subjects resting naked for two hours. At the human knee joint and inter-phalangeal joints the predominant type of movement is a gliding motion. The increase in viscosity of the synovial fluid due to cold means that for a given speed of movement muscles must exert a greater force to overcome the increased resistance to shear. Hunter et al. (1952) investigated the effect of cold on joint movement and found that it was difficult or

impossible to maintain maximum speed of movement on exposure to cold.

A study of temperature effects on time estimation by Baddeley (1966) found a positive relationship between oral temperature and speed of counting ($p < 0.01$). Twenty male scuba divers were tested during a week of scuba diving in cold sea water. Before and after the dive they were asked to count up to sixty at what they considered a rate of one count per second. According to the author the findings support the hypothesis that the speed of counting is controlled by a chemical clock that runs slower in the cold and faster in the heat. Baddeley (1966) discusses also the findings of other researchers. The combined data cover a range of body temperatures of about 1.5°C and show a linear dependency of time estimation on body temperature, with the time judged to be one minute increasing by about 30% for every degree decrease in body temperature. This effect could result from the reduced speed of bodily chemical reactions at lower temperatures. In every chemical reaction the reacting molecules have to reach an energy-rich transition state. A rise in temperature increases thermal motion and energy and thereby the number of molecules that can reach the transition state. In many reactions the reaction speed is approximately doubled by a 10°C rise in temperature (Lehninger, 1970). Goodman et al. (1984) also found that reaction time increased when the arm that had to respond was immersed in cold water. When the arm was heated, reaction time decreased as intramuscular temperature increased.

Differences in the physiological reactions of Caucasian females and males to cold were investigated by Wyndham et al. (1964). Increases of metabolic rate per square meter of body surface from 27°C to 5°C environmental temperature were

similar for both sexes. Females were found to have a greater subcutaneous insulation against heat flow, which was associated with greater average skinfold thickness and lower average skin temperatures. The rectal temperatures in both males and females were increased at 5°C environmental temperature, as compared with 27°C. These findings agree with those of Burse (1979) who found females under cold stress to have less capability for heat production either by exercising or by shivering, a more extensively vasoconstricted periphery, lower hand, foot and mean skin temperatures, greater heat losses, especially from the geometrically thinner extremities, and a relatively greater risk of cold injury.

These findings provide a physiological background for the effects of cold on the performance of dexterity tasks such as writing, of reaction time tests and of school work, and indicate that the effects of cold on the performance of boys and girls might differ.

1.3.4 MEASURES OF THERMAL STRESS

To investigate the effects of different environments on humans a reliable and relatively easy measure of thermal stress is required. Piekarski (1984) did not find the normally used parameters such as heart rate and rectal temperature sufficient. He suggested using rate of increase in core temperature from 38°C to 38.5°C as a reliable indicator, and recommended the change of aldosterone concentration in the plasma and the reduction in oxygen consumption as indicators for the "physiological costs" of

thermoregulation. Such measurements are obviously aimed at severe thermal stress and require a physiological laboratory. For the moderate thermal stress encountered in the present study, simpler measures have to be found.

Core temperature is closely linked to arterial blood temperature. Carlsten and Grimby (1958) showed that the esophageal temperature follows the arterial blood temperature variations with relatively little lag. When body temperature has to be measured in everyday life, preference is commonly given to other sites of measurement because of the difficulties of inserting an esophageal probe. Mairiaux et al. (1983) investigated the use of rectal and oral temperature for the estimation of esophageal temperature. During heavy work load conditions, rectal temperature seemed to be as good or better than oral temperature as an index of core temperature. Under resting conditions oral temperature provided a better estimation of core temperature, both during exposure to steady environmental conditions and during exposure to air temperature variations.

Strydom et al. (1965) measured the body temperatures of approximately 950 men undergoing heat acclimation. With increasing work rate the difference between oral and rectal temperature increased, and the authors write that: "The present findings certainly emphasise the fallacy and danger of relying on oral temperature in heat and/or work situations". Although oral temperature has little value as an indicator of core body temperature at high work rates, it seems to be at least an acceptable indicator at low work rates and at rest. In the present study all tests were performed at a very low level of physical work (sitting at a desk), and measurement of rectal temperature was not

possible. Oral temperature was therefore the only choice available.

After eight minutes of mouth breathing, a stabilisation time for oral temperature of four (at 50°C) to eight (at 23°C) minutes was determined by Mairiaux et al. (1983). In the present study, where prolonged mouth-breathing was an exception, the use of oral temperature with a minimum stabilisation time of five minutes seemed to be appropriate.

It would obviously aid research and industrial planning if environmental parameters could be used directly to calculate the level of stress a human would experience in a given environment. An early attempt to combine the different environmental parameters was the Effective Temperature index. It was developed in the 1920s on subjects moving between two rooms with different thermal conditions. An Effective Temperature of 40°C means that this condition was subjectively equivalent to slow moving, fully saturated air at 40°C (McIntyre, 1980).

Rohles et al. (1967) exposed eight subjects to six different temperatures at four humidity levels each. The time required to increase the subject's rectal temperature by 2°F (1.1°C) was recorded. None of the subjects exhibited such an increase in less than four hours when the Effective Temperature was below 33°C, whereas above 36°C Effective Temperature all subjects showed this increase in less than four hours. The rank order correlation between Effective Temperature and the time required for the rectal temperature to increase by 2°F was -0.987. These findings indicate that Effective Temperature is a useful index under certain conditions, but it does not take radiation effects

into account. Vernon and Warner (1932) applied a correction for thermal radiation by using the globe temperature in place of the dry bulb temperature. This led to the Corrected Effective Temperature (CET) scale. The CET was adopted during the second world war by the Royal Navy as an index of warmth (Bedford, 1946).

A large number of combined heat stress indices has been developed over the years. In 1972 the US National Institute of Occupational Safety and Health (NIOSH, 1972) recommended the Wet Bulb Globe Temperature (WBGT) index, a weighted mean of wet bulb, dry bulb and globe temperature. It has been widely implemented in standards and regulations, although it underestimates the level of heat stress at high humidities (Kok et al. 1989) and other indices such as the Botsball are claimed to be much easier to use in the field (Beshir, 1981). Various indices continue to be used , for example Sohar (1982) used the Discomfort Index, the arithmetic mean of dry bulb and wet bulb temperature, to compare the heat loads in different Israeli cities.

Different heat stress indices have proved their value in special environments, but no single index is applicable in all environmental conditions. Heat stress indices try to combine the effects of temperature, humidity, radiation and wind speed. In the present study humidity was low in all experiments, radiation effects were largely eliminated by screening the windows where necessary, and the wind speed was regulated by the air-conditioning to be low and constant. As far as description of the results and data analysis was concerned, there seemed to be no need for using any combined index. Dry bulb temperature was therefore used throughout to describe environmental conditions.

1.3.5 ACCLIMATISATION AND ACCLIMATION

The human body can adapt to a certain extent to the thermal environment. This adaptation is referred to as acclimatisation in case of a response to changes in the natural climate and as acclimation in case of a response to experimentally induced changes (IUPS Thermal Commission, 1987).

Physiological adaptation to cold has been documented by Brück et al. (1976). Caucasian subjects exposed to cold for a prolonged period reacted by lowering their mean body temperature levels at which increased metabolic rate and shivering occurred. In most cases humans are capable of behavioural protection from the cold and no cold acclimatisation occurs. Eskimos can live comfortably at temperatures as low as -50° because their clothing offers extremely high insulation. Inside their clothing they live in a tropical microclimate.

Whereas protection from cold is relatively easy, protection from a hot environment is usually expensive. Man also has a greater ability to adapt to hot than to cold conditions without suitable protection. This may explain why more work has focused on adaptation to heat. Acclimation for hot conditions is reached by exercising in the heat. Mere exposure to heat is not sufficient. Wyndham and Strydom (1969) describe the acclimation procedure for underground workers in the South African gold mines where the selected workers exercised for nine days, 4 hours a day in a climate chamber at 31.7°C , the air being almost saturated with water vapour. During the acclimation the workers improved their physical condition. Their average maximum oxygen consumption

increased from 2.4 to 2.8 litre per minute and they became mechanically more efficient.

A certain percentage of the population is unable to adapt physiologically to hot environments. According to Strydom (1980) 3-5% of the 300 000 mainly black males undergoing heat acclimation for the South African gold mining industry each year are heat intolerant. Heat intolerance is diagnosed when the subject exhibits a high body temperature for five consecutive days during the heat acclimation procedure. Anyone with this limitation engaging in physical work in a hot environment is likely to develop a dangerously high body temperature and is thus at an unacceptably high risk of developing heat stroke.

The findings of Hori and Ihzuka (1985) indicate that long term acclimatisation might be different from short term acclimation. They compared young males born and raised in subtropical Okinawa with residents of Okinawa who were born and raised in Japan but had lived in Okinawa for less than two years. The native group showed less sweat volume, lower Na concentration in sweat, less rise in rectal temperature and less increase in heart rate during heat exposure. They also showed less seasonal fluctuation in these parameters.

In the present study heat tests were performed in summer and cold tests in winter, so seasonal changes in acclimatisation were not relevant. Most subjects did exercise, at least during the prescribed school sport lessons, and a certain degree of adaptation to heat can be expected. The subjects were all selected from a single geographical region, the Transvaal Highveld in South Africa. Possible differences in the level of heat acclimatisation should therefore be

considered, when results are compared with those of children from other regions.

1.3.6 THERMOREGULATION IN CHILDREN

Small children are especially at risk under severe thermal stress. At temperatures found in cars parked in the open a baby can lose 8% of its body weight by dehydration within four hours (King et al. 1981), which would lead to cerebral manifestations of heat stroke. Even older children are more susceptible to thermal stress than adults. Araki et al. (1982) exposed 11 boys (8 years old) and 11 adults to heat and cold for 60 minutes. In the boys physiological responses were found at smaller deviations from comfort temperature than in adults. Boys' rectal temperature increased more rapidly than that of adults in the heat. In the cold it decreased progressively in boys but increased in adults due to an increase in metabolic rate. It was presumed that boys have functional and morphological disadvantages in thermoregulatory abilities against heat and cold.

These findings are also supported by Davies (1981), who tested the thermal responses of eight boys (average age 12.8 years) and of five girls (average age 13.8 years). Compared with adults, their evaporative sweat loss was lower and their skin temperature was approximately 3°C higher under the same environmental conditions, but they were able to loose an equal amount of their total heat production. Davies writes that:

"... due to the possible advantage of their high body surface area to weight ratio, it would seem that young children are excellent convectors and radiators of heat, and in consequence have a relatively poorly developed and/or insensitive sweat mechanism".

Wagner et al. (1974), who tested males between 10 and 67 years old under thermally neutral and cold conditions found, that thermoregulatory mechanisms are significantly affected by age. Differences between juvenile and adult thermoregulation are not surprising, as the metabolism undergoes significant changes during the growth process (de Wijn, 1968).

Fitness seems to have little effect on children's tolerance of heat stress. Araki et al. (1981) found in thermal stress experiments with 11 year old boys that there were no significant differences between a group of very fit individuals (members of a soccer team) and boys with no participation in sport. Obesity must be considered as a concomitant variable. Haymes et al. (1975) found that obese boys tended to exhibit more physiological strain while exercising in the heat than lean boys, and that both, lean and obese boys, tended to be more tolerant of exercise at 32.2°C effective temperature than lean and obese girls.

Children react differently to thermal stress than adults. This is one of the reasons for undertaking this study. Besides obvious variables such as sex and educational standard it seemed necessary to note:

- the exact age of each child, and
- height and weight, to calculate an indicator of the level of obesity.

The effort to assess the level of children's involvement in sports with high cardiovascular activity seemed unnecessary.

1.4 EFFECTS OF TEMPERATURE ON PERFORMANCE

1.4.1 EFFECTS ON THE PERFORMANCE OF PRACTICAL WORK

The present study is concerned with the effects of temperature on performance in a real-life situation. It is therefore of primary interest to establish the magnitude and nature of temperature effects on performance that have been demonstrated outside the laboratory.

Motivation, performance incentives and job pressures can induce people to perform in thermally adverse conditions better than would otherwise be expected. Temperature effects on the work in a hospital laundry were investigated by Woods et al. (1981). The performance of eleven female workers on tasks such as folding of clothes was recorded. Temperature conditions between 13.5 and 28.5°C occurred in a timespan of ten weeks. Performance changed with the time of the day and the day of the week, but no significant effects of temperature were determined. The results suggest that the laundry employees worked harder when the work demanded, independently of the thermal conditions to which they were exposed. Such adjustments to work demand are only possible if the workers do not perform at their physiological limit and thus have the choice to work harder.

Even without undue performance pressure, temperature can make working more dangerous. Ramsey et al (1983) studied unsafe work behaviour and its relationship to temperature. Subjects in two industrial plants were observed for short periods of approximately 30 seconds each to characterise their work behaviour according to a taxonomy of unsafe

behaviours. Over a period of 14 months, 17 000 observations were made. Ambient temperature had a significant effect on unsafe behaviour. The relationship was an inverted U-shaped curve with the minimum occurring in the temperature zone between 17 and 23°C WBGT. Unsafe behaviour was significantly higher in the afternoon and was generally higher on tasks with a higher workload.

The findings of Meese et al. (1981, 1984) suggest that temperature effects on performance in the cold seem more consistent over a wide range of tests than temperature effects in the heat. They used a mobile climate laboratory to test South African factory workers at the factory site. The workers performed activities designed to simulate light manual labour involving various tests of finger dexterity, motor performance and inspection tasks. The study was therefore a hybrid between a laboratory and a field study. Black and white males and females were tested in a cold series at 6, 12, 18 and 24°C and in a hot series at 22, 26, 32 and 38°C. In the cold a linear relationship between performance and temperature was significant for 52% of the tests. Best performance was at 18°C or at 24°C for 81% of the tests. In the hot series a linear relationship between performance and temperature was only significant in 25% of the cases, as the performance usually did not follow a monotonic function but peaked at 32°C. Of all tests 62% were performed best at 32°C and all groups did best at 32°C except the white females, who did best at 26 and 38°C. Their low performance at 32°C could be attributed to their delayed onset of sweating or to a value system that rates sweating as socially undesirable.

A comparison between the effects found in the large-scale study of Meese et al. (1981) and observed industrial tasks

was undertaken by Senior et al. (1987). Output measurements of production tasks in several South African factories were taken each hour and environmental temperatures were recorded continuously. A total of about 30 000 man-hours was monitored. The performance decrement in cold conditions was even more marked than in the climate chamber studies. At one factory the performance at 6-9°C was found to be 20% lower than the top performance monitored. In the factories as well as in the climate chamber the performance decrement in hot conditions was found to be smaller than in cold conditions.

Results specifically focused on children are discussed in 1.6. The studies reviewed above show that temperature has an influence on work performance in real life as well as in formal laboratory experiments. However, the magnitude of the effect depends on the type of task (Meese et al. 1981) and is affected also by economic and motivational factors (Woods et al. 1981). This implies for the present study that:

- temperature effects on performance have been demonstrated outside the laboratory. The present study does not have to break new ground in this respect;
- the tests should be perceived by the subjects as routine activities in order to reduce the inevitable stimulation of novel tasks; and
- a wide range of tests should be used so that one may extend the findings.

1.4.2 PSYCHOLOGICAL EXPLANATIONS

The field studies described in 1.4.1 have proven an effect of temperature on performance in the heat and cold. An overview of studies on thermal effects is presented in 1.4.3 to 1.4.5. The following short outline of the theories concerning performance changes under moderate stress will aid the understanding of patterns in the results of the temperature studies.

Performance in the cold deteriorates largely for physiological reasons. Fingers become numb, joints become less flexible and the ability to perform skilled tasks is therefore reduced. Heavy muscular work in hot conditions is limited by the accumulation of heat within the body. These effects are described in 1.3. In the zone of mild heat stress, however, where the body can maintain its equilibrium by thermoregulation, there is no obvious physiological reason for the deterioration of performance, yet studies have shown this to occur. Other studies show performance to be reduced at mild levels of heat stress, but to be improved at higher levels of heat stress (Wilkinson et al. 1964). Similar effects have been documented for other stressors, for instance Poulton (1976) lists 38 experiments by a number of researchers that suggest that noise can reliably improve performance.

The concept of arousal can be used to explain many of these findings. The state of activation of an individual can be described on a continuum running from sleeping, through the state of alertness, to frantic excitement. Performance on a given task is at its best at some specific level of arousal. At low levels of arousal the individual is not alert enough

to perform properly, while at high levels of arousal he is over-excited and not able to pay attention to the task at hand. Several factors contribute to the level of arousal. The general state of the individual from sleep to alertness is the basis. The normal level is different between individuals and extraverts have a lower resting level of arousal than introverts. This explains why an extravert seeks arousal from additional stimulation, while an introvert tends to avoid it. The task may also contribute to the arousal level. A difficult and complex task is itself arousing and is better performed with little external stimulation, because if the total arousal is too great, performance deteriorates. Simple and boring tasks are not arousing, and their performance can be improved by additional stimulation, e.g. background music. Indeed, levels of pure noise loud enough to be unpleasant will reliably improve performance of some tasks (Poulton, 1970).

Thermal stimulation is bi-directional, in the sense that stimulation increases in both hot and cold conditions. Wyon (1970) found that mild heat is de-arousing. This is linked to the common experience that mild heat makes one drowsy and relaxed. The conditions for minimal arousal seem therefore to be slightly to the warm side of comfort conditions.

There is as yet no established way of obtaining an absolute measure of arousal other than by its effects on performance. Vigilance tests are good indicators of arousal. Wilkinson et al. (1964) exposed test subjects to a series of tones and at infrequent intervals a slightly longer tone was played, which the subjects were required to detect. The body temperature was controlled by means of a vapour barrier suit. They found a reduction of performance at slight

increases of body temperature, followed by an improvement at higher temperatures.

Arousal effects and therefore effects of mild thermal stress can differ between main tasks and peripheral tasks. Bursill (1958) demonstrated that high arousal reduces the ability to detect occasional signals which are peripheral to the main task. Subjects carried out a central tracking task in a control climate and in a hot environment of 41°C (35°C wet bulb). They were also asked to respond to occasional peripheral light signals. Under hot conditions there was a considerable decrement in peripheral awareness, which was greatest for the lights placed furthest from the central tracking task. This has its practical significance in that a given level of heat stress may have only a small effect on the performance of a task, but a person's ability to notice and respond to unexpected signals, such as danger warnings may be considerably reduced.

The level of skill of an operator can also modify the impact of stressors. The resistance to stressor effects of the more experienced performers is due to the automated nature of the task in which the operator is skilled (Hancock, 1986). This had been shown earlier by Mackworth (1946) who measured the number of errors made by operators in telegraphic reception as a function of temperature. The number of errors increased for all groups with temperature, but the weakest performers showed the highest increase.

There is also evidence that extraverts and introverts tend to adopt different attitudes towards exposure to stress. Zaky (1984) assessed ten healthy male subjects with a personality inventory and exposed them to severe heat stress

(50°C, 30% RH). The extraverts assigned significantly more positive meaning to the heat stress situation and tended to be more confident of completing the experiment. They tended also to suffer from higher physiological stress than introverts. Zaky speculates that this might be caused by their higher expectations of success.

From the reviewed literature it can be concluded that the predicted variation of performance with temperature for a complex task has the form of an inverted "U", with the optimum performance at the temperature of minimal arousal. For a simple task the graphical representation should be similar to an "M", where the performance has a local minimum at the point of lowest arousal, increases for slightly cooler or hotter conditions, and falls off in the extreme heat as well as in the extreme cold.

The results for a homogeneous group of subjects can be expected to depend on skill and the prevailing type of personality. For very heterogeneous groups of subjects the effects of moderate stress are likely to be inconclusive, as it is hard to devise a task that is difficult for most subjects without being impossible for some and easy for the more able.

1.4.3 EFFECTS ON COGNITIVE PERFORMANCE

1.4.3.1 OVERVIEW

A series of studies of thermal effects on cognitive performance are discussed below, with the purpose of identifying a pattern in the results. This served as a guide to the present study and helped relate its findings to other work. To aid the perception of an overall pattern, a table of the results of the studies discussed is presented.

Table 1.4-1 lists author, year of publication, type of task, thermal condition, the change of performance in percentage, and the significance level. In some cases, when the mean performance at the different temperatures was not given in the publication, the change in performance was derived from a graph in the publication. Performance under comfort conditions, or the thermal condition closest to comfort in each study, was used as a baseline and performance at other conditions was calculated relative to the baseline performance expressed as a percentage increase or decrease relative to the baseline.

All temperatures are given in degree Celsius ($^{\circ}\text{C}$). Results published in degree Fahrenheit were converted and rounded to the nearest $^{\circ}\text{C}$. Temperatures in brackets refer to a relative change of body temperature, such as: (-1.7°C CORE) indicating a drop in core temperature of 1.7°C .

Where not provided by the authors, the WBGT index was calculated for the environmental conditions to allow

comparisons between the studies. It was assumed that radiant temperature was equal to the dry bulb temperature:

$$\text{WBGT} = 0.7 * (\text{wet bulb}) + 0.3 * (\text{dry bulb})$$

This formula is also appropriate when a forcibly ventilated wet bulb thermometer was used. Where the wet bulb temperature was not given, it was derived from a psychrometric chart based on dry bulb temperature and relative humidity (RH) (Mount, 1979).

For cold conditions, when relative humidity was not given as in the papers of Ellis (1982) and Ellis et al. (1985), WBGT was set equal to the dry bulb temperature. This seemed a fair approximation, as the impact of cold is more a function of dry bulb temperature and wind speed than humidity of the air (McIntyre, 1980).

The studies are discussed below, sorted according to the environmental conditions during the tests and the impact of these conditions.

AUTHOR(S)	TASK	THERMAL ENV	WBGT	PERF
Azer et al. (1972)	peripheral RT	35 DB 50 %RH	29	ns
Azer et al. (1972)	peripheral RT	35 DB 75 %RH	32	- 6%
Azer et al. (1972)	peripheral RT	38 DB 50 %RH	32	ns
Azer et al. (1972)	tracking	35 DB 50 %RH	29	ns
Azer et al. (1972)	tracking	35 DB 75 %RH	32	-18%
Azer et al. (1972)	tracking	38 DB 50 %RH	32	ns
Beshir et al. (1981)	tracking	26 WBGT	26	-34%
Beshir et al. (1981)	tracking	30 WBGT	30	-40%
Bursill (1958)	peripheral vigil	41 DB 35 WB	37	-76%
Bursill (1958)	tracking	41 DB 35 WB	37	-12%
Coleshaw et al. (1983)	add.acc 1 digit	(-1.7 CORE)	.	ns
Coleshaw et al. (1983)	add.acc 2 digit	(-1.7 CORE)	.	ns
Coleshaw et al. (1983)	add.spe 1 digit	(-1.7 CORE)	.	ns
Coleshaw et al. (1983)	add.spe 2 digit	(-1.7 CORE)	.	-21%
Coleshaw et al. (1983)	memory learning	(-1.7 CORE)	.	-31%
Coleshaw et al. (1983)	memory recall	(-1.7 CORE)	.	ns
Curley & Hawkins (1983)	rep.acq.learning	33 DB 29 WB	30	-50%
Curley & Hawkins (1983)	rep.acq.perf.	33 DB 29 WB	30	ns
Ellis (1982)	choice RT error	-12 DB	-12	-55%
Ellis (1982)	choice RT lags	-12 DB	-12	ns
Ellis (1982)	simple RT	-12 DB	-12	ns
Ellis (1982)	verbal reasoning	-12 DB	-12	+11%
Ellis (1982)	word colour	-12 DB	-12	ns
Ellis et al. (1985)	choice RT error	-5 DB	-5	-58%
Ellis et al. (1985)	choice RT lags	-5 DB	-5	ns
Ellis et al. (1985)	choice RT error	8 DB	8	ns
Ellis et al. (1985)	choice RT lags	8 DB	8	ns
Ellis et al. (1985)	Raven's matrix	8 DB	8	ns
Givoni & Rim (1962)	multiplication	39 DB 30 WB	33	ns
Hancock & Dirkin (1982)	choice RT error	(+2.6 CORT)	.	+34%
Hancock & Dirkin (1982)	choice RT speed	(+2.6 CORT)	.	- 6%
Hohnsbein et al. (1984)	visual acuity	50 DB 10 %RH	30	- 5%
Hohnsbein et al. (1984)	visual acuity	39 DB 65 %RH	35	- 5%
Langkilde et al. (1973)	addition	19 DB 50 %RH	15	ns
Langkilde et al. (1973)	addition	27 DB 50 %RH	21	ns
Langkilde et al. (1973)	cue-utilisation	19 DB 50 %RH	15	ns
Langkilde et al. (1973)	cue-utilisation	27 DB 50 %RH	21	ns

Table 1.4-1: Overview of thermal studies (part 1).

AUTHOR(S)	TASK	THERMAL ENV	WBGT	PERF
Langkilde et al. (1973)	word memory	19 DB 50 %RH	15	ns
Langkilde et al. (1973)	word memory	27 DB 50 %RH	21	ns
Mortagy & Ramsey (1972)	vigilance, 20min	33 DB 24 WB	27	- 4%
Mortagy & Ramsey (1972)	vigilance, 40min	33 DB 24 WB	27	- 4%
Mortagy & Ramsey (1972)	vigilance, 60min	33 DB 24 WB	27	- 5%
Mortagy & Ramsey (1972)	vigilance, 20min	39 DB 30 WB	33	- 4%
Mortagy & Ramsey (1972)	vigilance, 40min	39 DB 30 WB	33	- 7%
Mortagy & Ramsey (1972)	vigilance, 60min	39 DB 30 WB	33	-12%
Pepler (1958)	tracking	29 DB 24 WB	26	ns
Pepler (1958)	tracking	34 DB 28 WB	30	-23%
Pepler (1958)	tracking	38 DB 32 WB	34	-23%
Pepler (1958)	vigilance	32 DB 27 WB	29	+44%
Pepler (1958)	vigilance	49 DB 29 WB	35	ns
Pepler (1958)	decision, slow	32 DB 27 WB	29	+18%
Pepler (1958)	decision, slow	35 DB 29 WB	31	ns
Pepler (1958)	decision, slow	38 DB 32 WB	34	- 6%
Ramsey & Beshir (1980)	perceptual motor	40 DB 29 WB	32	ns
Ramsey & Beshir (1980)	perceptual motor	46 DB 34 WB	38	+ 2%
Ramsey & Beshir (1980)	perceptual motor	52 DB 40 WB	43	+ 6%
Ramsey et al. (1983)	safety: light wk	30 WBGT	30	-25%
Ramsey et al. (1983)	safety: heavy wk	30 WBGT	30	-26%
Reddy & Ramsey (1976)	maze track	20 DB 45 %RH	15	+ 4%
Reddy & Ramsey (1976)	maze track	29 DB 45 %RH	23	ns
Reddy & Ramsey (1976)	multiplication	20 DB 45 %RH	15	+ 5%
Reddy & Ramsey (1976)	multiplication	29 DB 45 %RH	23	- 4%
Reddy & Ramsey (1976)	RT	20 DB 45 %RH	15	ns
Reddy & Ramsey (1976)	RT	29 DB 45 %RH	23	ns
Shapiro et al. (1974)	Raven's matrix	45 DB 22 %RH	32	ns
Shapiro et al. (1974)	digit symbols	45 DB 22 %RH	32	ns
Wilkinson et al. (1964)	addition	(+2 ORAL)	.	ns
Wilkinson et al. (1964)	vigilance: sound	(+2 ORAL)	.	+20%
Wyon (1974a)	typewriting	20 DB 50 %RH	16	-40%

Table 1.4-1: Overview of thermal studies (part 2).
The following abbreviations were used:
perf: performance, vigil: vigilance,
rep.acq: repeated acquisition, wk: work,
add: addition, cort: cortical temperature.

1.4.3.2 DECREASE OF PERFORMANCE DUE TO HEAT

A variety of studies have shown a reduction of performance in hot conditions. One of the most commonly used tests of performance is tracking; basically following the irregular movements of one pointer with another pointer. Bursill (1958) exposed 18 heat acclimated young male subjects to temperatures of 21°C dry bulb (16°C wet bulb) and 41°C dry bulb (35°C wet bulb). They performed a central tracking task and a peripheral vigilance task. In the tracking task a pointer performed irregular movements and the subjects had to keep another pointer just in front of the "object pointer" by operating a handle with their right hand. For the peripheral task six small neon bulbs, three on each side, were placed at angles of 20, 50 and 80 degrees from the point of fixation where the tracking task was placed. The subjects had to respond by pressing a key on a key-pad corresponding to the activated light. Heat led to a significant drop in performance in the tracking as well as in the vigilance task. Signals at a greater eccentric angle had a higher probability of being missed in hotter conditions. The longer the previous exposure to heat, the higher was the probability of missed signals.

In a study of Azer et al. (1972) three groups of seven young male subjects were exposed to either:

35°C and 50% RH;
35°C and 75% RH; or
38°C and 50% RH.

The subjects performed a central tracking task on a screen and a peripheral reaction time task. Six lights were placed at angles of 20, 60 and 80 degrees from the central task and

the subjects had to press a single button when any of the lights came on. The arrangement was very similar to that of Bursill (1958). Each group performed the same tests in a control environment of 24°C and 50% RH. A significant deterioration in tracking performance could only be found at 35°C and 75% RH. The peripheral field of awareness was not affected by any of the conditions, i.e. the light signals at an 80 degree angle had the same chance to be missed as the light signals at a 20 degree angle. This did not change with temperature. These results do not agree with those of Bursill (1958), but Azer et al. pointed out that Bursill used much more strenuous conditions (41°C at 70% RH) than their study.

Six male undergraduate students performed a one-dimensional vertical compensatory tracking task in a study by Beshir et al. (1981). The tests were performed at 20, 26 and 30°C WBGT. At 26°C the number of errors was found to be approximately doubled as compared to 20°C, while the rise in ambient temperature from 26 to 30°C WBGT did not produce much further reduction in tracking performance. A significant deterioration occurred after about 25 minutes on the task. This deterioration was significantly more pronounced in the heat.

Mortagy and Ramsey (1972) used 108 male college students to study the effect of temperature, length of work period and work/rest ratios on the performance of a vertical tracking task. The subjects had to watch a screen and indicate when a central light point moved and how much it moved (either 6.4 or 12.7 mm). Exposure temperatures were:

23°C Effective Temperature (27°C dry bulb,
19°C wet bulb)
28°C Effective Temperature (33°C dry bulb,
24°C wet bulb), and
32°C Effective Temperature (39°C dry bulb,
30°C wet bulb).

Three work periods were adopted: 20, 40 and 60 minutes. Each work period was repeated to reach a total work duration of 120 minutes per experiment. For each period length two work/rest ratios were used: 2/1 and 3/1. Temperature reduced performance significantly. The reduction in performance due to length of work period and work/rest ratio was only significant at 32°C ET.

Pepler (1958) investigated the effect of warmth on young European men living in the tropics (Singapore). In the first experiment six subjects performed a vertical tracking task for about two hours in indoor climates with the following dry bulb / wet bulb combinations: 24/18, 29/24, 34/28 and 38/32°C. The mean error of alignment on the tracking task was significantly higher at the 34/28 and the 38/32°C conditions. In a second experiment subjects were exposed to Effective Temperatures of either 22, 26, 29 or 33°C, which were either achieved with 20% RH or with 80% RH. The humid conditions tended to decrease performance more, but the effect was not significant.

A further experiment described by Pepler (1958) aimed at determining the effect of temperature on tasks with a heavy mental load. The test apparatus consisted of a rotating belt that carried twenty small cards at irregular intervals, each showing six different symbols. Five pairs of similar cards were mounted besides the belt; one to the right and one

left. The subjects had to report the number of different symbols on two cards whenever two cards passed. The belt could be adjusted to three different rotating speeds: slow, medium and high. The test was carried out at the following dry bulb / wet bulb combinations: 29/24, 32/27, 35/29 and 38/32°C. The number of omissions in reporting differences increased significantly with the rotating speed of the belt, but only at the slow speed did heat have a significant effect. The best performance was found at the 32/27°C condition. The proportion of wrong responses was only significantly higher at high speed and at the highest temperature. The principal source of errors was the failure to make comparisons, the omissions, which are given in Table 1.4-1.

Sixteen healthy male subjects were tested at comfort temperature (25.6°C), at the lower end of the comfort range (20.0°C) and at the higher end of the comfort range (28.9°C) by Reddy and Ramsey (1976). The temperatures refer to dry bulb temperatures at 45% relative humidity. The subjects performed a maze task, a multiplication task, a reaction time task and a rotor pursuit task. The data for the rotor pursuit were not considered reliable. No significant effects were found on reaction time. The performance of the maze task was improved under cool and under warm conditions, although the effect under warm conditions was not significant. The multiplication task was performed better under cool and worse under warm conditions. These results illustrate how different tasks can be affected by temperature in a different way.

The adverse effects of heat on performance can be summarised as follows:

- a decrease in performance of some tasks such as tracking has been shown reliably and repeatedly;
- different tasks are affected in different ways;
- central and peripheral tasks might be effected in different ways;
- at a given level of heat stress as expressed by a heat stress index such as ET, humid conditions might reduce performance more than dry conditions; and
- effects of heat might only become apparent when additional stressors such as a fast pace of work or long exposure time are applied.

1.4.3.3 HEAT EXPOSURES WITH NO EFFECT ON PERFORMANCE

Some studies did not demonstrate a significant effect of heat on performance. Shapiro et al. (1974), for example, tested 48 high-school boys from either Bedouin, Moroccan or Eastern European descent with Raven's progressive matrices and a digit-symbols task (part of the Wechsler Intelligence Scale for Children). The tests were performed at 25°C with 50% RH and at 45°C with 22% RH. No significant effect of temperature was found for any group.

Langkilde et al. (1973) established the preferred ambient temperature of six male and six female students while performing cognitive tests. The subjects were then tested at

their preferred temperature, at a temperature 4°C higher and at a temperature 4°C lower. The following tests were used:

- an addition test where two five-digit numbers had to be added;
- a word memory test in which the subjects had to learn 25 words and recognise them in a list of 50 words thereafter; and
- a cue-utilisation test, a version of the Tsai-Partington test (Ammons, 1955), which requires joining 25 circles, marked by letters or numbers and placed at random on a page. The circles had to be linked by joining "A" to "1", "1" to "B", "B" to "2", "2" to "C" and so on.

No significant effects of temperature were shown for any of these tests. The authors speculate that although the subjects did not report that they had exerted themselves more at the higher temperature, they might subconsciously have done so. The average preferred temperature for the subjects was 22.6°C. For simplicity the test conditions are described in Table 1.4-1 as 19, 23 and 27°C.

Curley and Hawkins (1983) acclimated six young males by treadmill exercise in the heat (33°C dry bulb, 29°C wet bulb). The regimen lasted for 10 days, 150 minutes per day. The results on a "repeated acquisition" task was recorded three times during the daily acclimation. The task had two components: learning, where a sequence of keystrokes had to be followed 10 times according to the instructions on a digital display, and performance, where the learned sequence had to be reproduced. No effect was found on the performance component, but both completion time and number of errors on

the learning component increased significantly during the acclimation, reaching a maximum on the seventh day.

Although these studies did not show any effects on performance they suggest that:

- subjects might maintain performance in the heat by exerting themselves more than under comfort conditions;
- if the effect on a certain test score such as number of correct items is not significant it cannot be concluded that this test is not affected by temperature. Other scores such as time for completion might be affected; and
- different components of a test, such as learning how to perform it and performing it repeatedly, might be affected in different ways.

1.4.3.4 IMPROVEMENT OF PERFORMANCE DUE TO HEAT

For some performance tests the results were found to be better under moderate or even fairly severe heat stress than under comfort conditions. The performance of 12 male volunteers in an adding test and a test requiring prolonged vigilance was measured by Wilkinson et al. (1964). The subjects performed at four different thermal conditions: at comfort temperature and while the oral temperature was held constant at levels of 37.3, 37.9 and 38.5°C in a hot and humid environment. Each temperature exposure took place on a separate day and the four exposures constituted a

measurement cycle which was repeated four times. The detection of an auditory signal in the vigilance test was not significantly effected by temperature in the first cycles, but in the fourth cycle performance was significantly better at 38.5°C oral temperature than under comfort conditions. Although no other significant effect was found, the adding test shows a trend to lower performance in the heat. The authors speculate:

- that the challenge of raised body temperatures stimulated the subjects to greater efforts, improving performance on a simple task such as vigilance, while failing to prevent the more complex task of adding from being debased; or
- that as the level of arousal increases through an outside stimulus, performance improves up to a certain point and thereafter declines (Duffy, 1957). The optimal point for vigilance may occur at a higher temperature than that for adding.

Ramsey and Beshir (1980) tested perceptual-motor performance of 31 male and 15 female subjects at 23, 32, 38 and 43°C WBGT. Relative Humidity was held constant at 45%. The subjects performed a reaction time test, a rotor-pursuit task, a hand-eye coordination task and a multiplication test. As the performance of the four tasks showed the same basic pattern, the authors combined them into a single score, which is given under perceptual-motor in Table 1.4-1. Performance increased with temperature. This might be due to increased arousal under stress and the fact that the exposures were relatively short: 120 minutes for the coolest and 30 minutes for the hottest condition.

Pepler (1958) tested 18 male subjects with a visual watch-keeping task at dry bulb / wet bulb combinations of 24/18, 32/27 and 49/29°C. They had to observe a rotating pointer, jumping in small steps, and to detect infrequent larger jumps. Performance was equal at the lowest and the highest temperature, but at the 32/27°C condition the performance was better! This would suggest that low arousal aids performance of this task.

Performance improvements under moderate stress are usually discussed in terms of the arousal theory which was described in 1.4.2. As this theory has little predictive value it can only be stated that:

- performance on some tests does improve under heat stress;
- tests showing a decrease and tests showing an increase in performance do not fall into obvious groups; and
- there is no apparent difference such as exposure time or age of subjects between the experiments showing a decrease and those showing an increase in performance.

1.4.3.5 EFFECTS OF COLD CONDITIONS

The effect of severe cold on performance was investigated in two experiments of Ellis (1982), who exposed six and eight males between 17 and 31 years of age to -12°C air temperature. The exposure time was 1.5 hours for the first and 2 hours for the second experiment and performance was

tested before, during and after the exposure. In a serial choice reaction time test the subjects had to classify numbers between 1 and 8 as odd or even by pressing one of two buttons. A response taking longer than 1250 ms was classified as a "lag". The number of errors increased significantly in the cold, and recovered much faster than rectal temperature after the exposure. It showed a much better correlation with skin temperature than with rectal temperature. The number of lags tended to decrease in the cold, but the results were not conclusive. A test of verbal reasoning was performed better during exposure in experiment two. Simple reaction time and the time required to name colours (word colour test) increased during exposure, but the results were not significant.

The impact of different cooling speeds was described by Ellis et al. (1985). In the first of two experiments the subjects were cooled quickly (one hour at -5°C). They performed a serial choice reaction time task which required pressing of the correct key according to a given light stimulus, for example pressing key number three when light number three comes on. The task is called "serial" because a new stimulus is supplied as soon as a subject has responded. Errors on the serial choice reaction time task increased significantly in the cold. The errors on the 8-choice version increased significantly more than on the 4-choice version. The number of lags was unaffected for the 4-choice and had a tendency to drop for the 8-choice in the cold, but this was not significant. In the second experiment of this study the subjects were cooled more slowly (3.25 hours at 8°C). Under these conditions no effects of the exposure on the serial choice reaction time test were found. Performance on Raven's progressive matrices was also unaffected. This indicates that the speed of cooling changes the impact of

cold on performance. The author speculates that fast cooling might increase the level of arousal.

A study of Wyon (1974a) deals with moderately cool conditions. He reanalysed data from a report of the New York State Commission on Ventilation in 1923. The report described four climate chamber experiments in which 47 subjects typed for several days in either 20 or 24°C, in both cases at 50% RH. The experiments were originally undertaken to investigate the effect of temperature on appetite, the performance aspects were secondary. In contrast to most performance testing the typewriting task was administered in a very relaxed manner, so that the work situation was very much that of a modern office. By using non-parametric statistical methods that were not available at the time when the experiments were performed, Wyon could show a significant effect of temperature. Typing performance was about 40-50% higher at 20°C than at 24°C. The author points out that the subjects could not adapt their dress, as they had to wear standard clothing. In a manual task such as typewriting, the most immediate way to reduce body heat production is to type less fast.

The findings on the effects of cold on performance can be summarised as follows:

- as in the heat, direction and size of the effect depend on the task and perhaps on non-thermal parameters of the experiment;
- the speed of cooling can alter the effect of cold;
- under work conditions with little performance pressure the effect of temperature on performance could be

magnitudes higher than that found in tightly controlled laboratory studies.

1.4.3.6 SEPARATING PHYSIOLOGICAL AND BEHAVIOURAL ASPECTS

To improve the predictive quality of any stress theory it would be helpful to separate direct physiological effects such as changes in neural signal transmission from behavioral effects such as decreased motivation or discomfort. The identification of physiological effects could be aided by using parameters of strain such as rectal temperature instead of parameters of stress such as environmental temperature as predictor variables. It would further be helpful to use simple, elementary tests that avoid interaction between several components of performance.

Coleshaw et al. (1983) focused on the effects of low core temperatures and tried to eliminate the effects of low skin temperatures and discomfort from their experiment. The body core temperatures of 27 male and 10 female volunteers were lowered by immersion in 15°C cold water. After rewarming had started in 41°C warm water and the subjects felt comfortable while their core temperatures were still low, aspects of their cognitive function were tested. Memory registration was found to be impaired progressively when core temperature fell below 36.7°C. At core temperatures of 34- 35°C the impairment caused a loss of about 70% of the data that could be retained under normal conditions. The recall of previously learned data was not impaired. Speed on a two-digit calculation test (adding 4 two-digit numbers) was impaired by 50%, but accuracy of performance did not drop

when enough time was given. No effect was found on a single-digit calculation test (adding 5 one-digit numbers).

Hancock and Dirkin (1982) investigated the effect of increased cortical temperatures of six male subjects. The increase of about 2.6°C was achieved by warming the head selectively with a heated helmet. Increased cortical temperature caused an increase in reaction time and a decrease in errors on a serial choice reaction time task.

Hohnsbein et al. (1984) found a significant correlation between rectal temperature and visual acuity. Nine males between 19 and 34 years of age were exposed for five hours to:

29°C, 40% RH;
39°C, 65% RH; and
50°C, 10% RH.

Visual acuity was measured using Landolt's circles, which have a small gap that can occur at eight possible positions (at angles of 0°, 45°, 90°, etc.). Acuity was determined by the smallest gap that could still be identified. Tests in dim (5 cd·m⁻²) and bright (450 cd·m⁻²) light both showed a linear decrease of visual acuity with rectal temperature.

All three studies showed significant correlations between a physiological strain parameter and the performance of a fairly simple task. This approach will definitely contribute to a better understanding of the effects of thermal stress. In a work situation or in a school temperature effects on the behaviour of people are as important as effects on the workings of the body. Mild stress might not cause any

measurable physiological effect but might nevertheless lead pupils to take things easy. Motivation is of major importance. Givoni and Rim (1962) exposed 4 subjects to thermal conditions ranging from comfortable to hot (39°C DB, 30°C WB). The exposures lasted for two hours. A multiplication test was performed, and the subjects were paid according to the number of correct answers. No effect of temperature on performance was found, indicating that it is possible to maintain a maximal degree of mental ability in hot environments for short periods, provided that high incentives are offered.

Pepler (1958) demonstrated the importance of incentives with 16 subjects performing a manual tracking task in the following dry bulb / wet bulb combinations: 29/24, 32/27, 35/29 and 38/32°C. Half of the subjects were rewarded by information about their scores and by praise and encouragement. The rewarded group performed significantly better, but there was no evidence that the size of the temperature effect relative to the performance level at comfort temperature was influenced. It is interesting to note that the rewarded group performed better in the worst environment than the unrewarded group did in the most favourable environment. In the present study no rewards were given and the subjects were not informed about their test scores.

Adjustments to given situations must also be taken into account. In some cases such adjustments may eliminate the performance decrement. This is shown by a study of Wyon et al. (1975) on the effect of heavy clothing on performance. Sixteen male and sixteen female subjects performed sedentary work in a climate chamber. Each subject was exposed singly for 2.5 hours and the temperature was continuously adjusted

to suit the subject's request. The subjects performed a numerical addition task, a recognition memory task and a cue-utilisation test either with light clothing ($0.6 \text{ clo} = 0.093 \text{ K}\cdot\text{m}^2\cdot\text{W}^{-1}$) or with heavy clothing ($1.15 \text{ clo} = 0.178 \text{ K}\cdot\text{m}^2\cdot\text{W}^{-1}$). No significant difference in performance could be found, indicating that the impact of the thermal environment can be minimised if the subjects are allowed to adjust.

Adjustments of work behaviour to thermal conditions can be dangerous. Incidences of unsafe work behaviour were recorded by Ramsey et al. (1983). A total of 17 000 observations was collected over 14 months. Temperature increased unsafe behaviour significantly in the heat and in the cold. The lowest incidence of unsafe behaviour occurred in the zone of preferred temperature between 17 and 23°C WBGT. The study discriminated between three workloads: light, medium and heavy. At the preferred temperature there were twice as many incidences of unsafe behaviour for heavy work as for light work. The authors fitted second order polynomials to the data in the three workload categories. The entries for work safety in Table 1.4-1 were derived from these polynomials.

Physiological as well as behavioural studies on the effect of thermal stress on performance offer partial explanations for the responses of humans, but the parts have not yet been integrated into a convincing theory.

1.4.3.7 COMPARISON OF FINDINGS

Table 1.4-1 lists mainly significant results. For inconclusive studies results were only added for the most extreme conditions. The significant results stretch over a wide range of changes in performance, from 2% change to 76% change.

Table 1.4-2 shows the significant findings in different groupings of percentage change in performance. The data were derived from Table 1.4-1. Most results fall into the lowest group, with a performance change in the range of 1-5%. All except one study in this group showed a change of either 4 or 5%. Only one study, Ramsey and Beshir (1980), shows a significant effect for a performance change of 2%, and in this case the score was derived as a mean of the scores of four sub-tests. In all other studies the smallest change in performance that produced a significant effect was at least 4%. This seems to be the lower limit, given the variation in the results due to uncontrollable factors and the number of subjects that can usually be handled in such a study. The results indicate that significant effects of temperature on performance are likely to be small.

In total, decrements in performance due to thermal stress outnumber improvements in performance by 27 to 9. It should be noted that the studies do not cover the spectrum of thermal stress equally. Of all significant results 28 were effects of heat and only 8 effects of cold.

% range	significant results	
	HEAT	COLD
1- 5	- - - - - - - +	+ +
6-10	- - - - +	
11-15	- -	+
16-20	- + +	
21-25	- - -	-
26-30	-	
31-35	- +	-
36-40	-	-
41-45	+	
46-50	-	
51-55		-
56-60		-
>60	-	

Table 1.4-2: Significant decreases(-) and increases (+) in performance found in thermal studies (data taken from Table 1.4-1).

Figure 1.4-1 shows the effect of different thermal environments on performance. The horizontal axis gives the temperature in °C WBGT at which an experiment was performed. On the vertical axis the tests are ranked to the size of change in performance. The data were taken from Table 1.4-1, but studies that aimed at specific physiological effects such as heating of the head (Hancock and Dirkin, 1982) were excluded.

Several clusters can be identified in Figure 1.4-1. The first shows a moderate decrease (5-10%) of performance in the heat. It includes: vigilance, peripheral reaction time, speed of choice reaction time and visual acuity. The second cluster shows a massive decrease of performance in the heat (>20%) and includes tracking, safety behaviour and peripheral vigilance. A third cluster is made by massive decrements in performance due to severe cold.

There are also improvements in performance, in several cases on tests that had shown decrements in performance under similar thermal conditions in other studies. As can be seen in several publications, it is always possible to fit a version of the arousal theory to a given set of results. Unfortunately, this flexibility of the arousal theory makes predictions almost impossible - making arousal more an ingredient in essays than a useful scientific tool.

It seems that stress research in the present situation can be undertaken in a useful manner in two ways:

- 1) Focus on overcoming the present dilemma. The parameters measured in most studies of thermal strain, namely core temperature, heart rate, skin temperatures and sweat rate are obviously not sufficient to predict cognitive performance. A new type of parameter is needed. It should predict performance on cognitive tasks and it should be possible to measure it on-line like heart rate. A possible contender would be a parameter derived from pattern recognition procedures applied to EEG recordings. Work that aids the identification of such a parameter (or a set of them) is one major branch of future stress research.
- 2) Solve real-life problems in a pragmatic manner while the knowledge base in stress research is insufficient to give an elegant solution based on modeling or a few elegant key experiments.

	-10°C WBGT	0°C	+10°C	+20°C	+30°C	+40°C
more than +20%				type writing	vigilance	
+11% to +20%				C O M F O	decision, slow	
+6% to +10%				R T Z O		perceptual motor
+1% to +5%				N E	multiplication maze track	perceptual motor
-1% to -5%				multiplication	vigilance, 20min vigilance, 20min vigilance, 40min vigilance, 60min	visual acuity
-6% to -10%				C O M F O	decision, slow peripheral RT vigilance, 40min	
-11% to -20%				R T Z O	vigilance, 60min tracking tracking	
less than -20%				N E	tracking	tracking safety: light work safety: heavy work tracking perip. vigil
				choice RT error	choice RT error	rep. acq learning

Figure 1.4-1: Effect of temperature on performance.
Data were taken from Table 1.4-1.

The purpose of the present study is more in line with the second approach: solving a practical problem. This includes:

- choosing experimental conditions as close as possible to the real conditions, even if this leads to a less elegant experiment. Small differences, such as the speed of the temperature change or the length of exposure time, can change the outcome drastically and no present theory can predict the direction or magnitude of such a change reliably;
- choosing the performance tests to be as similar as possible to the real tasks in question. This can include complex tasks that contain a variety of performance components. Such an approach might have limited value for generalisation, as it is difficult to identify which component of a complex task has actually been affected, but it can be advantageous to answer a specific problem.

1.4.4 EFFECTS ON FINGER DEXTERITY AND SENSITIVITY

Most studies on finger dexterity centre around light manual labour in industry. Children obviously do not perform such work in school, except in handicraft classes. Nevertheless, nearly all of the central school tasks such as mastering languages or mathematics involve finger dexterity as an auxiliary task. Children have to write, to draw and to turn their pages. Young children, for whom writing is not yet a familiar skill but a task to be mastered, would seem most likely to be affected by conditions that reduce finger dexterity.

Besides the wide and complex array of psychological factors such as arousal, motivation and fatigue, finger dexterity is directly affected by finger temperature, and it is mainly cold that produces performance decrement. This is partially due to an increase in viscosity of the synovial fluid in the cold (Hunter et al. 1952).

Heat leads to dilation of the peripheral blood vessels and to the onset of sweating. At some point the presence of sweat and the distracting effects of sweating and discomfort will affect performance. As with cold, high temperatures may bring about increased arousal (Meese, 1980). Sweating fingers might impede some sensitive dexterity tests, but they will hardly disable children from holding a pen. When assessing the impact of heat on school work, finger dexterity can therefore be conceptually fused with effects on cognitive performance in general.

In the cold the effects are quite different. Low environmental temperatures lead directly to low finger temperatures. In a study by Meese (1980) a drop in finger temperature from about 30 to 20°C led to a reduction in performance of 10%. Finger temperatures of 20°C were produced by environmental temperatures between 13 and 16°C. The subjects performed a modified O'Connor peg test, a repetitive task in which they had to pick up three pegs about the size of a cigarette filter and insert them in holes in a board.

The decrease in dexterity follows a fairly predictable function for males and females, Blacks and Whites and for a variety of tests such as tactile discrimination, finger strength and speed (pencil rolling), threading of perforated

blocks on a rope, knot tying, hand steadiness, arm steadiness, O'Connor peg test, screw plate, inserting pegs in a moving assembly line and even for simulated spot welding (Meese et al. 1981; 1984). The size of the change in performance varied for the different tests. The drop in environmental temperature from 24 to 18°C sometimes resulted in a significant drop in performance; from 18 to 12°C the effect was almost always significant. Best performance in most cases was at 32°C; at 12°C performance was on average approximately 90% and at 6°C approximately 80% of that at 32°C.

Riley and Cochran (1984) exposed 35 male and 35 female subjects to temperatures of 2, 13 and 24°C. They performed manual dexterity tasks such as pegboard, fine pencil tapping, large pencil tapping and a fine manipulative task in which small lead balls of 2 mm diameter were used to fill a tube. A considerable performance drop was found between 24 and 2°C but little difference was found between 24 and 13°C. This seems to be in conflict with the results of Meese et al. (1984) who found significant impairment of most dexterity tasks already at 12°C. The differences might result from different experimental procedures. Meese et al. (1984) exposed their subjects for a whole work day and did not administer performance tests in the first hour of exposure, while the results of Riley and Cochran were collected after 15 minutes of exposure.

Clark and Cohen (1960) showed that decrease in dexterity is not only a function of finger temperature, but also of the way the cooling was achieved. Twenty men performed a knot-tying task while putting their hands in a cooling box. After fast cooling of their hands to 7°C at a rate of 1.5°C per minute their performance was less impaired than when the

cooling was achieved more slowly (0.5°C per minute). It was further found that the hands rewarmed significantly faster following a fast cooling than a slow cooling.

The effects of cold depend also on previous exposure. Clark and Jones (1962) used 30 male subjects to investigate the effects of thermal conditions during training on subsequent performance. The subjects were randomly allocated to three groups: one trained on a knot tying task for 15 days while their hands and forearms were cooled with -12°C air; the second trained on the same task, on odd days under normal conditions, on even days with cooled hands as group 1; group 3 performed for 10 days with warm hands and for the remaining five with cooled hands. Groups 1 and 2 performed equally well in the cold at the end of the experiment, but group 3 was significantly worse, although it had the same duration of training. This indicates that the thermal conditions of training are important: if tasks are to be performed in the cold then training must be given in the cold.

Although the effects of cold on dexterity are largely physiological and can therefore be predicted with reasonable accuracy, they can be modified by psychological factors. Hugdahl et al. (1984) observed an interaction between cold and mental stress in the drop of finger temperature. The requirement to count backwards under cold conditions with the threat of an electric shock made the finger temperature of their physically normal control subjects fall faster than did cold alone.

While finger dexterity seems to be influenced by fairly small temperature drops, finger sensitivity is only affected

by severe cold. Provins and Morton (1960) immersed the index fingers of ten subjects in cold water near the freezing point. They determined how close two plastic edges could be placed while the subjects could still feel their being apart (V-test). Down to a finger temperature of 6°C no effect was found. Below this temperature finger numbness increases rapidly and at 2°C the fingers are totally numb.

Mills (1956) also found that tactile discrimination decreases with finger temperature. If the finger was rewarmed by a phase of spontaneous vasodilation, which generally developed after about 15 minutes of exposure to -20°C, tactile discrimination recovered with the rise in finger temperature. If spontaneous rewarming did not occur at that temperature, frostbite usually ensued.

The studies on the effects of cold on manual and finger dexterity present a clear and convincing pattern. The effects under severe cold conditions are mainly physiological and therefore less dependent on uncontrollable concomitant variables than are the effects on cognitive performance. The studies described above deal with the effects on adults, but Wentzel and Meese (1983) have shown that air temperatures of around 10°C also have a significant effect on the performance of a manual dexterity test (O'Connor peg test) by primary school children. The coldest conditions of 14°C in the present study would appear to be on the borderline where significant effects can be demonstrated.

Dexterity tests were not a focal point in the present study, but were to be included if sufficient time could be found during the experimental day. Although the lowest

temperatures in the present study might not show a significant drop in dexterity due to physiological reasons, performance might change significantly for psychological reasons. This would allow interesting comparisons with results of cognitive performance tests.

1.5 THERMAL COMFORT AND PERFORMANCE

1.5.1 COMFORT CONDITIONS AND COMFORT VOTE

Hippocrates, in 400 BC was one of the earliest authors to mention the main factors involved in human comfort. In his book "On Airs, Waters and Places" he lists them as: temperature, humidity, wind and radiation (Webb, 1959).

Fanger (1972) uses the same parameters, adding activity level of the person and the thermal resistance of the clothing worn. All parameters were integrated in an equation that produces the "Predicted Mean Vote" (PMV). A comfort vote is obtained by asking a person to select a response on a comfort scale. Different thermal comfort scales with different semantic formats are in use (McIntyre, 1980). Fanger used the seven-point scale developed by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) ranging from "cold" via "neutral" to "hot". The PMV is the vote one would expect to get by averaging the thermal sensation votes of a large group of people in a given environment. Fanger (1972) based his equation on the following three conditions for comfort:

- the body must be in thermal balance, so that the rate of heat loss to the environment is equal to the heat production of the body;
- the skin temperature should be appropriate for comfort. The skin temperature required for comfort is lower at higher metabolic rates; and

- the rate of sweating should be appropriate for comfort. The preferred rate of sweating is a function of metabolic rate. Only for sedentary activity do people prefer not to sweat.

McIntyre (1980) notes that Fanger's equation "gives good results for the standard conditions of sedentary activity and light clothing, as indeed it must, since it is based very firmly on experimental data. However, information on thermal sensation at higher metabolic rates is less satisfactory." This seems to imply only a small restriction in the usefulness of the comfort equation, as for high work rates and high thermal stress it would be more appropriate to work directly with physiological strain as comfort is largely irrelevant.

Fishman and Pimbert (1978) monitored the reactions of 26 subjects to their thermal environment in a commercial building. Results were collected throughout the working day for one year. The preferred temperature of the occupants was 22.0°C which is in good agreement with that of 22.6°C predicted by Fanger's comfort equation. Subjects were a little less tolerant of the thermal environment than the equation predicts.

A series of environmental factors were investigated by Fanger (1977, 1977a) for their potential influence on people's preferred temperature. He found no differences in preferred temperature in 16 winter swimmers who had been exposed to cold shock daily for two consecutive seasons by bathing in the sea (0-6°C). Sixteen meat packers, who had been working for 6 months, 8 hours a day at 8°C, also showed no significant differences. Effects of colour and noise were

also investigated. Sixteen subjects were exposed in a climate chamber to two types of coloured light: extreme red and extreme blue, and to two noise levels: 40 dB(A) and 85 dB(A), in all four combinations. Each subject adjusted the ambient temperature according to his wishes. No effect of noise was found, but the preferred temperature was 0.4°C lower in the extreme blue light ($p < 0.05$). The difference seems too small to be of practical importance.

Fanger (1980) wrote that preferred temperature:

- showed only small differences between people living in relatively cool Copenhagen and people who arrived there from tropical areas and were tested within 48 hours;
- did not alter significantly over a 24 hour cycle;
- was not different for males and females and did not change with age; and
- varies between individuals, so that it is not possible to satisfy more than 95% of individuals with any given temperature.

He noted further that effects of air movement are independent of their direction. An airflow of a certain speed has the same effect when coming from above, below or towards the side of a person. Cyclical variations of the room temperature with durations between 4 and 32 minutes and amplitudes up to 6 and 8°C were also investigated. They were found to have a mildly stimulating effect but were not perceived as pleasant by the subjects.

This, however, does not imply that a constant thermal environment is "optimal". On the matter of variations of the indoor climate Wyon (1974) notes: "... Human senses have developed in such a way that they pay particular attention to changes in space and time, and by designing our buildings so that such changes are minimised or even totally absent, we have very greatly reduced the resultant stimulating effect of the built environment" and further "... some of the most aesthetically successful design solutions seem to rely on the tension between two or more factors balanced in opposition to each other, each departing from the condition that would be optimum (i.e. neutral) if considered in isolation ..."

A mathematical model to predict thermal comfort during cyclical temperature variations has been produced by Rohles et al. (1980) and the human response to temperature drifts in a simulated office environment was investigated by Rohles et al. (1985). Eighty-four subjects were exposed to seven different patterns of mild temperature changes, similar to those that could be expected when an air-conditioning plant is shut down an hour, or alternatively half an hour, before the departure of office employees. Rohles' model predicted their response to within 0.3 of the predicted mean comfort vote.

In some industrial environments workers are exposed to major changes in air temperature. Mairiaux et al. (1984) looked at the effect of cyclic temperature changes, alternating between 23 and 31°C with cycle times of 10, 20 and 30 minutes over a total time of 120 minutes. Core temperatures and body heat storage did not differ significantly, but the subjects found the 10 minute cycle least strenuous. This might be due to the time constant of the sweating response,

which led to lower sweating rates and skin wettedness for the 10 minute cycle.

Extreme ambient conditions are bound to produce fairly distinct responses. Reactions to small deviations from comfort conditions seem to depend more on the expectations and attitudes of the subjects. Stramler et al. (1983) exposed a group of students to two temperatures: 21.1 and 23.9°C. The thermal vote increased by about 0.6 units. Thereafter another group was exposed twice to the same temperature (22.8°C), but they were told that the second exposure had happened at a higher temperature. The increase in thermal vote was comparable with that of the first group. The experiment was repeated a year later with similar results: perceived comfort shifted by comparable amounts whether the actual or the purported temperature was raised.

Rohles (1980) lists several examples of non-thermal influences on the thermal comfort vote:

- modifying a stark, sterile room with carpets, wood panels and comfortable furniture made people feel warmer under identical thermal conditions;
- secretaries working at 18.3°C felt warmer when they were told that a radiant heater worked in the modesty panel of their desks;
- people who were told that the temperature of a room was 23.3°C were found to be equally comfortable at 23.3, 22.2, 21.1 and 20.0°C; and
- cool temperatures are preferred over warm temperatures in summer and the opposite is true in winter.

Carlton-Foss and Rohles (1982) attempted to identify the personality factors involved in creating the inter-individual variation in thermal comfort. From 41 people they obtained the scores on a self-definition test. The higher the score the more people tend to have a history of coping well with personal and environmental demands. Thereafter the thermal condition at the people's work place and their comfort ratings were obtained. The findings indicate that people with higher self-definition scores adapt more easily to deviations from comfort conditions.

A number of workers have found that sex plays a role in the determination of thermal comfort. Beshir and Ramsey (1981) found a significant difference between the preferred comfort temperature of males (22°C) and females (25°C). Thirty-one male and 15 female subjects were exposed to temperatures between 23.3 and 43.3°C. They wore standardised clothing and performed a perceptual motor task. This finding supports Pepler and Warner (1968) who write that a significant sex by temperature interaction in their study in schools was due to the fact that female students reported feeling colder than males at low temperatures and warmer than males above 27°C. Both findings on the effects of sex on thermal comfort seem to be contradicted by Fishman and Pimbert (1978), who monitored people for one year in their work environment and found that females preferred slightly lower temperatures (21.7°C) than males (22.0). Although American children usually have no strict dress code at school, it was found that little adaptation to moderate temperature changes took place within one day. Rather more took place from day to day and the process of adaptation would be virtually completed within one week (Humphreys, 1973). Thermal comfort can be expected to have a similar time lag after a change in indoor climate.

1.5.2 THERMAL COMFORT AS PREDICTOR OF PERFORMANCE

Beshir and Ramsey (1980) found that people are not efficient in judging how thermal stress influences their performance. They exposed 43 males and 15 females to temperatures between 23.3 and 43.3°C. The subjects performed a perceptual motor task and had to judge how their performance was influenced by temperature. While they thought that increasing temperature reduced their performance, it actually enhanced it.

In a study of Meese et al. (1986) air temperature proved to be a better predictor of performance than comfort vote. The tests simulated factory skills and were performed at 6, 12, 18 or 24°C at low water vapour pressures. At each temperature four groups of about 30 workers were tested: black men, black women, white men and white women. Comfort vote predicted about 6% of the total variation, air temperature about 11%. Few differences between the groups were found.

Comfort vote seems to be a bad predictor of performance not only for industrial workers but also for school children. McCardle (1965) recorded the comfort vote of upper elementary school pupils in two classrooms. One he termed "ideal", the other represented a typical thermal environment as found in Iowa schools:

- ideal:
21-23°C, 35-61% RH, 0.10-0.20 m·s⁻¹ air movement,
- normal:
22-27°C, 26-48% RH, 0.08-0.13 m·s⁻¹ air movement.

Students in the ideal environment reported themselves comfortable more often; 66% of the responses from the ideal environment and only 34% of those in the typical environment indicated comfort. They also found that many of the students in the ideal thermal environment reported feeling cool in the morning, but said they felt comfortable in the afternoon. Generally, girls reported feeling cooler than boys. In the ideal environment no significant difference in achievement was noted between students reporting feeling comfortable and those reporting feeling slightly warm or cool. This indicates that the physical or mental differences that lead to differences in perception of a given thermal environment are not correlated with performance.

Pepler and Warner (1968) found that comfort ratings were not directly related to learning efficiency measures. Also Pepler (1971) found little evidence that students' test performance could be predicted by their sensations of thermal comfort. It is surprising that comfort vote is of so little use in predicting performance, as the sensitivity to both measures is increased by climate control. Pepler (1971) found that students in schools which were not climate controlled gave neutral thermal comfort ratings over a wider range of temperature than students in climate controlled schools. A similar trend could also be seen in the performance levels which were affected by much smaller temperature fluctuations in climate controlled schools. Climate control produced a higher sensitivity to small temperature changes, for comfort vote as well as for performance.

Pepler (1971a) investigated the thermal comfort of teachers in schools with and without climate control. The predicted "neutral" temperatures, derived from the regression of

temperature versus teachers' ratings, ranged from 22.2 to 24.4°C for schools without climate control and from 22.7 to 23.3°C for schools with climate control. This corresponds to the results found for the pupils' comfort ratings and performance and illustrates that climate control increases sensitivity to temperature changes.

1.5.3 CONCLUSION

The mean thermal comfort vote can be predicted reasonably well, at least as long as the conditions are not too far removed from comfort conditions. The individual comfort votes at a given temperature show a considerable variation of which little can be explained or predicted. Several studies have shown that comfort vote has only a small predictive value for performance. However, in the present study, which deals primarily with thermal effects on performance, comfort votes were collected for completeness and to confirm or deny others' findings.

1.6 EFFECTS OF TEMPERATURE ON THE PERFORMANCE OF CHILDREN

1.6.1 BACKGROUND

Indoor climate has a definite influence on well-being and performance. An example of the effects of indoor climate on the well-being of children is given by Green (1975), who compared the results of several studies on the effect of relative humidity on absenteeism in schools attributable to upper respiratory diseases. He found a linear decrease of absenteeism with increasing humidity, at least in the dry region between 15 and 35% RH and linked this finding to the reduced survival rate of airborne micro-organisms at relative humidities between 30 to 50%. The author lives in Canada, where very dry conditions are often produced by heating in winter. As the relatively mild climate of South Africa requires a much smaller heating effort, this problem will be of a much lower importance. The present study therefore did not deal with pathogenic effects of indoor climate.

Even healthy children can be expected to be more sensitive to heat stress than healthy adults. Under conditions of mild heat stress children are at a disadvantage as their thermoregulation does not work as efficiently as that of adults. Children have lower sweat rates and a later onset of sweating and tend therefore to have higher rectal temperatures and higher heart rates in hot environments (Löfstedt, 1966). The heat dissipation of children is aided by their larger surface-to-volume ratio, which helps them to cope with heat but is a disadvantage in the cold. Araki et al. (1982) have shown that children in the cold maintain

lower skin temperatures than adults. Severe reductions in children's finger temperature as a reaction to cold school environments and its effect on finger dexterity was shown by Wentzel and Meese (1983). Primary school children, 8 years of age, performed a version of the O'Connor peg test in their classroom in summer and in winter. The children's performance at 7.6°C in winter was 20% lower than at 25.5°C in summer. The classroom temperatures in South African schools during winter can be especially chilling in the early morning. As a result of the usually mild climate heating is often not available and teachers insist that children need "fresh air".

Kevan and Howes (1980) note that in the past most research efforts which have been made to determine the effect of the thermal environment upon mental performance were undertaken by placing subjects in standardised clothing in a controlled climate chamber. Kevan and Howes (1980) state that:

"More often than not the subjects were volunteers, either young, healthy military personnel or college students, who were motivated by monetary rewards. Unfortunately, much less research has been conducted using the more realistic conditions encountered by teachers, that is, a typical assortment of healthy and not-so-healthy schoolchildren, who have no real dress code, who are distracted rather easily and who tend not to be motivated too highly."

It was therefore the objective of the present study to test children in their natural environment without additional incentives.

The difficulty of such a task was illustrated by Wyon (1970) who listed arousal, attention, effort, acquired skill and fatigue as time variant factors closely linked to strain and writes that: "At present, the complexity of their interaction makes it impossible even to predict the direction of a stress-induced change in performance in the moderate stress region ...". He elaborates further that:

"It appears to be necessary to test quite specific abilities if a clear-cut effect of temperature is to be demonstrated. It is plausible that different abilities may be differently affected by temperature, even to the extent of being affected in opposite directions, and if this is so the total effect may be zero for a test whose performance depends on too many of them."

1.6.2 EFFECTS OF HOT CONDITIONS

Most studies on the effect of temperature on the performance of school children focus on the impact of heat. One of the first investigations was published by Hines (1909). Describing "conventional wisdom" of the time he writes that:

"It is the commonest kind of an observation that when a school room becomes too warm, the pupils become dull and listless. They do not work so readily nor so accurately. Usually the higher the temperature, the poorer the results. On the other hand, if a room is allowed to become too cold, the results are almost as poor. There is that happy medium which many efforts have been made to find."

Hines (1909) exposed children to different temperatures in a classroom and gave them spelling and arithmetics tests. While admitting that his tests were somewhat crude, he states that the best school room work can be done in a temperature ranging between 18 and 21°C, and that the more the temperature rises above 21 or falls below 18°C, the poorer will be the work done in that room.

The behavioral effects of temperature described by Hines (1909) have been verified by systematic observations. Wyon and Holmberg (1972) studied children performing school-type work at 20, 27 and 30°C. The children were observed through one-way mirrors, and their behaviour, posture and clothing was rated by four observers. The results showed a significant change in posture, clothing and appearance with increasing air temperature. At higher temperatures the children tended to adopt a more relaxed and open posture which maximised body surface area. Moderate heat stress caused boys to display decreased concentration and girls increased restlessness. Both effects were more marked at 27°C than at 30°C.

An array of studies supports the general findings of Hines (1909) that performance decreases in the heat. Schiefer et al. (1985) analysed the results of 5347 black adolescents, 17 to 18 years of age, who took part in a vocational guidance programme. Each subject performed a battery of nine tests: non-verbal reasoning, verbal reasoning, English vocabulary, English reading comprehension, number comprehension, Afrikaans vocabulary, Afrikaans reading comprehension, squares (similar to Raven's matrices) and spatial perception. They performed the test battery once only. The tests were conducted in school classrooms. At the beginning of each test the dry bulb temperature was measured

with a mercury-in-glass thermometer by the test administrator. The temperatures ranged from 11 to 30°C, with a mean temperature of $22.0 \pm 2.6^{\circ}\text{C}$ at 10:00. The effects on performance of the six known variables (temperature, geographical region, school where the test was performed, sex of the child, date and time-of-day) were quantified by an analysis of co-variance. A small but significant effect of temperature was found on mathematical ability, verbal skill, verbal reasoning and nonverbal reasoning. In each case the percentage of variation that could be attributed to temperature was below 1%. Cooler conditions favoured a better performance.

Nolan (1960) compared the performance of matched groups of military students on two courses in summer and in winter. Attention was given to controlling factors that influence learning such as quality of instruction, visual aids and lesson plans. In all groups, students earned higher academic grades during the winter month (properly heated classrooms) than in the summer month (conditions fairly hot). Nolan concludes that: "physical discomfort resulting from high temperature conditions does have an adverse influence on academic learning." This conclusion, however, can hardly be derived from his study. Even if the academic factors are stringently controlled, there is a wide variety of physiological, psychological and social factors that undergo seasonal changes. Concluding that differences in performance in summer and in winter are due to temperature differences alone is not warranted by the data.

McNall and Nevins (1967) summarised the findings of a comparison of the performance of children in air-conditioned and non-air-conditioned schools and found trends favouring the climate controlled schools, though the effect was often

non-significant. Pepler and Warner (1968) write that there is evidence that the superior performance in the air-conditioned schools was due to better pupils, more highly trained teachers and possibly better supervision.

Johannsen (1975) exposed 24 ten-year-old children to air temperatures of 30, 36 and 41°C in a climate chamber. The experimental group was compared to a control group of 12 subjects. Increases in room temperature had an adverse effect on simple mathematical skills.

In a survey of research into the physical environment and the learning process, King and Marans (1979) conclude their chapter on climate by stating: "Cooler temperatures, whether created by mechanical means or not, were associated with increased comfort, activity and productivity. Results are based on studies of teachers' perceptions as well as studies of students' performance and assessments."

The guidelines for heat stress from the "Handbook of Fundamentals" of the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) are summarised in Table 1.6-1. They are also applicable for schools.

CATEGORY	°C ET	HEAT STRESS EFFECTS
danger	≥35	heat stroke or sun stroke likely
extreme caution	29-34	heat stroke, heat cramps, heat exhaustion possible with long exposure
caution	24-28	learning skills decrease with long exposure
maximum comfort	18-23	optimal

Table 1.6-1: ASHRAE guidelines for heat stress.

Most studies look at different performance levels at different temperatures. Peccolo (1962) looked at the effects of temperature on improvement of performance. A two-classroom experimental school building was constructed. The thermal conditions in the classrooms were set at:

15-23°C, 40-60% RH, 0.10-0.20 m·s⁻¹ air movement, and
 22-27°C, 35-67% RH, 0.05 m·s⁻¹ air movement.

Each classroom was occupied by 22 matched students. Matching was by intelligence, achievement, age and sex. The experiment was repeated with a second set of students, whose only significant difference was a higher mean achievement score. The students took a series of tests which were classified into three categories: reasoning tasks, clerical tasks and new concept tasks. At every task the students in the more comfortable environment improved more in performance than those in the control groups, with especially significant differences at the reasoning and some clerical tasks. Peccolo's results suggest that temperature affects the learning of new skills in a similar way than the performance of familiar tasks.

The essence of these studies is that the performance of most tasks deteriorates when the room temperature increases above comfort level.

1.6.3 AROUSAL AND MODERATE HEAT STRESS

A number of studies deals with a special phenomenon: for many tasks performance does not decline monotonically with temperature. Performance is often lowest at moderate heat stress corresponding to an environmental temperature of approximately 27°C. At higher levels of heat stress the task is performed better. Attempts to explain this phenomenon usually centre around the concept of arousal, which was described in 1.4.2.

Wyon (1969) found in a language test with 13 year old children at 20 and 27°C that only the weaker performers were significantly affected; they performed worse at 27°C. In another test series involving reading speed and comprehension, the supplying of opposites, multiplication and comparison of numbers he reports a consistent tendency for performance to be worse at 27°C than at 30°C. He speculates that this could be caused by lower arousal, caused by adaptive muscular relaxation resulting in lower metabolic rate in the heat.

Wyon (1969a) tested 48 eleven-year-old Swedish pupils at air temperatures of 20, 23.5 and 27°C. A battery of mental performance tests was administered in a climate chamber over two hours. Background noise was set at two levels: 65-70

dB(A) and 85-90 dB(A), but noise was not found to influence performance. Results indicate that increased temperature tended to inhibit performance in concentration tasks (addition and reading). No significant deterioration of speed or accuracy in these tests could be found, but a significant decrease in sinus-arrythmia ($p < 0,004$) indicated that increased effort had been exerted to maintain performance. For tasks requiring relaxation (Tsai-Partington creativity test) it was found that performance was significantly higher at 27° than at the two lower temperatures. This indicates that the 27°C condition produced the lowest arousal.

In a study of Holmberg and Wyon (1969) 9-year-old children were exposed to 20, 27 and 30°C, and 11-year-old children to 20 and 30°C. In both groups reading speed and comprehension deteriorated significantly at 30°C as opposed to 20°C. The decrement in performance at 27°C was greater than at 30°C. The experiment also examined the effect of time-of-day for the older children. The interaction between temperature and time-of-day was significant for reading speed and showed a clear trend for comprehension. The performance decrement caused by temperatures above the comfort range was greater in the afternoon.

Langkilde et al. (1973) found that at 4°C above thermal comfort (22.6°C) student subjects thought they had performed better at a memory test, but they had in fact performed at the same level as during exposure to the comfort temperature. The authors attribute this changed perception of performance to lowered arousal. Wyon and Holmberg (1972) also used arousal theory to explain the poorer performance of 8 to 11-year-old children at 27°C when compared with 20 and 30°C. A temperature slightly above comfort is assumed to

produce low arousal and inattentiveness and thus a lower performance overall than a much higher temperature.

Third and fifth year Swedish pupils participated in two studies of Ryd and Wyon (1970) on temperature effects. In the first study the pupils were exposed to 20, 27 and 30°C room temperature in an observation classroom at the School of Education in Malmö. They performed the following tests: reading speed, reading comprehension, opposites, multiplication, addition, highest number, equivalent numbers and false statements. Increasing the temperature from 20 to 27°C for the third year pupils led to a significant reduction in reading speed and comprehension. A non-significant improvement in performance was obtained between the tests at 27 and 30°C. A possible explanation is that elevated temperatures reduce arousal, but that the feeling of discomfort that occurs at room temperatures that are much too high (30°C) counteracts the reduced arousal.

The second experiment was conducted in a normal school classroom and examined performance at 23, 25 and 27°C on a similar test battery. Four parallel classes from the fifth year course were used. The results indicate that even a slightly raised temperature (25°C) can have an unfavourable effect on performance. The tendency was for temperature to have a greater effect on the least able. Intra-individual comparisons between parallel versions of the multiplication test for the less able sections of the classes showed a deterioration throughout at high temperatures, a significant decrease in the correct answers and the number of answers submitted and an increase in the percentage of mistakes.

The effects of temperature on learning and on test performance were studied by Pepler and Warner (1968). As a measure of learning they used the change in performance from session to session during exposure to different thermal conditions. Thirty-six male and 36 female students worked on a programmed text book on psychology. They worked in a climate chamber and were exposed to six temperatures between 17 and 33°C. The study lasted six weeks and it was found that temperature had a significant effect on error rate, time to completion and the effort the students experienced. The relationship between temperature and performance was an inverted U-shaped curve with best performance at 27°C. In the hot conditions (30 and 33°C) they learned less efficiently in the sense that although their accuracy and speed of learning did not change significantly, they experienced a greater sense of effort in completing their assignments. The performance peak at 27°C seems to contradict the findings of other studies such as Ryd and Wyon (1970).

A series of studies indicates that environmental temperatures around 27°C do affect performance, and that this effect is not just a milder form of the effects encountered at more severe heat stress conditions. Speculations centre around the concept of arousal, but the findings are inconsistent and do not allow predictions of the magnitude or even the direction of changes in performance.

1.6.4 EFFECTS OF COLD CONDITIONS

Few studies have been conducted on the effects of cold on performance of children. This may result from the fact that cold is obviously an undesirable condition and that it is easily avoided by heating the class room - at least in the relatively wealthy countries of the northern hemisphere where most studies have been performed. An exception is a study in South African schools by Wentzel and Meese (1983) who investigated the effects of cold (down to 7°C) on the finger dexterity of children and found a deterioration of performance in the range of 20%.

A mainly detrimental effect of cold on performance has been reported by Pepler and Warner (1968) who investigated the effect of temperature on learning. The study has been described above. In the two cool conditions (17 and 20°C) the students showed a learning behaviour different to that at comfort temperature. They completed their assignments more quickly and had a higher rate of errors. In the coolest condition they also reported having experienced more effort in completing the task.

Langkilde et al. (1973) did not find any decline in performance under moderately cool conditions. Student subjects were tested individually at their personal comfort temperature, 4°C below their comfort temperature and 4°C above their comfort temperature. The subjects complained about the warm condition, where they felt more sleepy and fatigued and that the air was more stuffy, but mentioned no complaints about the cool condition.

An improvement of performance in the cold was found by Murrain (1983) for some of her test subjects. She evaluated 268 seventh- grade pupils with a learning style inventory, which analyses the preferred learning style. It diagnoses also the preferred temperature, an environmental element of learning style. All subjects were tested twice on a word recognition test: in a cool room (16°C) and in a warm room (27°C). Those diagnosed as preferring cool conditions performed better in cool conditions, and those diagnosed as preferring warm conditions performed better under warm conditions, but the statistical significance of these findings was fairly low ($p < 0.1$).

As in the heat, the findings in the cold are inconsistent.

1.6.5 CLOTHING

Clothing requirements for children might differ from those for adults. Kevan and Howes (1980) point out that: "As schoolchildren tend to have slightly higher metabolic rates and are often more active in the classroom than military personnel or university students, it is thought that slightly lower Effective Temperature, within the region of 22 to 24°C ET would be more appropriate for a schoolroom." Such recommendations must also pay attention to such factors as local customs regarding normal clothing. British schoolchildren, for example, tend to wear much warmer woollen clothing than do the Americans who tend to wear much thinner and cooler cottons.

Children have the option to adapt to the classroom temperature by modifying their clothing. Humphreys (1973) recorded classroom temperatures and children's clothing during 987 lessons. As noted in 1.5.1 he found that little adaptation took place in response to temperature changes within a day and that adaptation required up to a week. Performance decrements can therefore be expected, especially when temperature conditions vary strongly during the day, when strict rules for school uniforms do not allow adaptation of clothing, or when the temperature in the class reaches extremes that cannot be compensated for by clothing adaptation.

1.6.6 ADVERSE EFFECTS OF THERMALLY CONTROLLED ENVIRONMENTS

In many studies on the effects of heat on performance air-conditioning is described as the best solution for heat problems, provided it can be afforded. Some findings contradict this view.

The correlation between variations in students' test performance and in classroom temperatures in schools with and without climate control was investigated by Pepler (1971). The study was conducted in two grade schools, two junior high schools and two high schools, where one of each pair was climate controlled. Performance was recorded in spelling, Spanish, social studies, Latin, geometry and general mathematics. In the non-climate controlled schools during spring, students did less well in their course work when classroom temperatures were high. Temperature

variations were in the range of 4-6°C. In autumn when ambient temperatures were lower, the students were generally unaffected by temperature. It was a surprising result that the performance of the students in the three climate controlled schools was correlated with variations in temperature, although the temperature variation in this schools was only in the range of 1-2°C. This association was found in spring and autumn, but in two cases in spring and in four cases in autumn the students tended to do better at higher classroom temperatures. Calculations based on the product moment correlation coefficients given in the paper indicate that the proportion of the total variation in the data that can be attributed to temperature variation, is on average over all tests 2.0%. Over all tests the mean is 3.5% ($p < 0.05$).

Pepler speculates that people become accustomed not only to a particular temperature level, but also to the range of variation to which they are habitually exposed. Students in climate controlled schools got used to a stable temperature and reacted more sensitively to small changes. This is supported by the finding that students in non-climate controlled schools gave neutral comfort ratings over a wider range of temperature than students in climate controlled schools. Pepler suggests the following explanation: for the positive correlations between temperature and performance in autumn, where most of the positive correlations were found, lower classroom temperatures occurred mostly on days with lower outside temperatures. The contrast between inside and outside temperatures was likely to be greatest when room temperatures in the climate controlled schools were lowest. If all, or a significant portion of the children, were negatively affected by marked contrasts between inside and outside temperatures, they could be expected to perform

worse when the inside temperatures were lower. This would explain the positive correlations.

The findings indicate that climate control may introduce more problems than it solves. By reducing temperature variation it makes the pupils more sensitive to smaller temperature variations within the controlled environment and it also creates problems due to the unavoidable gradient between the controlled and the outside environment. This effect might be amplified by the increased sensitivity to temperature changes mentioned above.

Exposures during the present study lasted only for a few hours and were therefore much too short to create any adaptation effects, but the drawbacks of air-conditioning must be kept in mind when recommendations for an ideal school environment are made.

1.6.7 CONCLUSION

From the publications discussed above, the following conclusions can be drawn:

- deviations to either side of the comfort zone (about 22-24°C) have been shown to reduce mental performance. Studies have focused on the hot side, as it requires less effort to heat a room than to cool it;
- tasks requiring concentration are performed worst at about 27°C. Performance improves at hotter and cooler

conditions. Tasks requiring relaxation are performed best around 27°C;

- poor performers are hit harder by adverse environmental conditions;
- local customs regarding normal clothing, the readiness to adapt it to temperature changes and the level of temperature and temperature variation to which people are accustomed, must be taken into account;
- individual characteristics, such as preferred learning style, might modify the impact of certain temperature conditions;
- economic considerations apart, maintaining a constant artificial indoor climate might NOT be the best solution to thermal problems, as it changes the way people react to temperature variations. Additional problems might be created by the required transitions between indoor and outdoor climate;
- the interaction between several moderate stressors and their effects on complex tasks are not yet understood.

The following guidelines can be derived for the present study:

- the present study is worth undertaking, as regional variations in climate and customs may affect the outcome;
- equal attention should be paid to heat and cold, as the effect of cold is traditionally neglected and

appropriate heating facilities are not common in a country with a usually mild climate;

- one temperature level should be around 27°C (low arousal), a further level should be significantly above that temperature;
- a variety of tasks should be used, as different tasks are likely to be affected in different ways;
- the tasks should be as simple as they can be made while still being recognised as worthwhile by educational authorities; and
- using the children as their own controls should be considered whilst making allowance for individual differences in learning style and performance level.

1.7 OTHER ENVIRONMENTAL EFFECTS ON THE PERFORMANCE OF CHILDREN

1.7.1 PURPOSE OF DISCUSSING NON-THERMAL EFFECTS

The reason for discussing the effect of factors other than temperature is that:

- they could appear as concomitant variables. Their effect has to be eliminated in the experimental design or it has to be compensated for in the analysis of the data;
- they could interfere with the effect of temperature and therefore be part of an appropriate description of the temperature effect; and
- methods used and problems encountered in the investigation of other stressors and their interactions can aid the work on thermal effects.

1.7.2 NOISE

Studies on the effect on noise on people tend to focus either on short term exposures such as tests in a laboratory or on the impact of long term exposure, for example on tenants living close to an expressway. In both areas the results are varied, sometimes contradictory and tend to increase the complexity rather than to provide explanations.

In a literature review on the effects of noise Lambert and Hafner (1979) concluded that noise usually causes no change in work performance, as the human system can adapt to noise quite well, ignoring steady or periodic stimuli and using reserve processing capacity to provide constant performance. Therefore noise often has no measurable effect on work performance, even when it is annoying. They refer to two documents of the US Environmental Protection Agency (EPA (1973) and EPA (1976)) which summarise a large volume of experimental literature and conclude that steady, meaningless noise does not seem to interfere with human performance unless the level exceeds about 90 dB(A).

Edmonds and Smith (1985) tested 289 sixth grade students with Standard Progressive Matrices and a reading test. They were exposed to noise levels of either 40 dB(A) or 70 dB(A) during the test. No evidence of sex differences was found on either test. On the matrix test students scored generally better under quiet conditions ($p < 0.03$). On the reading test a significant interaction ($p < 0.01$) between noise and intelligence indicated that students with above average intelligence performed better with low noise than with high noise, while students with below average intelligence scores performed better in 70 dB(A) noise than in 40 dB(A) noise. The authors speculate that noise might affect the concentration of elementary grade students both of high and low intelligence on relatively unfamiliar tasks such as matrices. However, on familiar tasks such as reading, noise appears to interfere with the performance of students of high intelligence but not the performance of students with low intelligence.

Hambrick-Dixon (1986) tested 5-year-old black children attending day care centres near or far from elevated

subways. They completed a battery of tests including a psycho-motor task, serial memory for words and pictures, incidental memory, visual recall, learning of paired associates, perceptual learning and coding performance. The children performed the test either with 80 dB(A) noise from a tape or without noise. Only performance of the psycho-motor task was significantly ($p < 0.04$) impaired by noise. A significant interaction between the noise at the day care centre and test results was found on the coding task ($p < 0.001$), with children from relatively noisy day care centres performing best under noisy test conditions, and their counterparts under quiet conditions. This indicates that the effect of noise is not universal, but varies with the nature of the task and previous exposure to noise.

The effects of music and task difficulty on performance of a visual vigilance task were investigated by Davies et al. (1973) with 20 male and 20 female undergraduate students. The subjects had to detect brightness changes of a lamp. For the "easy" test the brightness changes were relatively big, for the "difficult" test they were smaller. This task was performed either with music at an average of 75 dB(A) or with white noise of the same intensity. When the task was "easy", music or noise made little difference to performance, but for the "difficult" task, performance was significantly ($p < 0.05$) higher with music.

Research on the impact of long term exposure focuses mainly on community noise. Sources of community noise include aircraft overflights, railways, road traffic and industrial machinery as well as neighbours, children and pets. Continued exposure to noise levels considered disturbing or uncomfortable raises the question whether or not noise affects health and work performance.

Long term effects of aircraft noise on the scholastic performance of children were studied by Ko et al. (1981) in Hong Kong. Two hundred and fifty-six children from three quiet schools were compared with 241 children from three schools under an airplane flight path and very near an airport. They were exposed to up to 80 overflights per day. The peak noise levels measured at the three schools had means of 90, 92 and 94 dB(A) while the maxima were 102, 105 and 107 dB(A). The children could be closely matched by their scores on the Secondary School Entrance Examination, which they complete when they are about twelve years old. A comparison of their scores on the Certificate of Education Examination five years later did not indicate a long term effect on their average academic performance in public examinations. This absence of any long term effect on pupils in the age group from 12 to 17 years was found for mathematics, English and Chinese. The authors suggest that the children learn to adapt to the noise.

Cohen et al. (1973) tested auditory discrimination and reading ability of 54 children living in a 32-storey apartment house near an expressway in New York City. The noise from the expressway decreased with increasing floor level. The building of the houses was subsidised, and admission limited to "middle income" families. This made the apartment house an excellent experimental site, where a population with fairly homogeneous socioeconomic background was exposed to various levels of long term noise. After compensating for socioeconomic variables such as "father's income" the variable "floor level" explained 19% of the variation in auditory discrimination results. Only 2-4% of the reading ability score could be attributed to floor level.

In a study by Cohen et al. (1980), 120 third and fourth grade children from quiet schools and 142 children from noisy schools were compared. The noisy schools lay in an air corridor with over 300 overflights per day. The highest reading in a noisy classroom was 95 dB(A) whereas the highest reading in a quiet classroom was 69 dB(A). A regression technique was used to compensate for differences between the noise and the quiet sample on factors such as racial distribution. It was found that children from noisy schools:

- had higher blood pressure by 2-5 mm Hg ($p < 0.05$). The longer the children had attended the school, the smaller was the difference between them and children from the quiet school;
- quit difficult tasks more readily ($p < 0.025$). The difference tended to increase with years of exposure;
- did better in a test of distractibility when they had been less than two years at a noisy school, but children who had attended a noisy school for more than two years did worse than children at a quiet school ($p < 0.03$).

One interpretation of the data is that they indicate some habituation of the physiological stress response but show no effect of adaptation to noise on cognitive performance or motivation.

The children still enrolled in their schools one year later were retested by Cohen et al. (1981). It was found that:

- the differences in blood pressure between children at quiet and noisy schools tended to disappear with length of exposure;
- the increased "giving-up" of children at noisy schools was not found in the second sample;
- children who had been at a noisy school for less than two years did better on a test of distractibility, but with longer exposures performance was equal to that of children at quiet schools.

The authors attribute the different results to changes in the sample by children leaving their school and conclude, rather surprisingly, that the retest data provide strong support for the stability of the effect of noise.

For an overview of noise research the summary of Loeb (1981) seems still valid. After an extensive review of 68 articles he wrote:

"... it is very difficult to predict the effect [of noise] in a given situation. This occurs partly because it is necessary to consider complex interactions with such variables as the personality and task proficiency of the subject, time-of-day, drugs and food ingested, and task difficulty. Another is that we have not sufficiently considered the significance and meaning of the noise for the subject and his/her previous history of exposure, including the degree to which it interferes with work and recreation, whether it signifies a threat (as it might be the case with overflying aircraft) or whether it is interesting or enjoyable to the listener. We must answer questions of this kind before generalising about the nature of noise

effects. To a degree, similar considerations will apply for other stressors."

1.7.3 NUTRITION

Nutrition can effect the performance of children:

- when they are malnourished or suffer from nutritional deficiencies, or
- by their patterns of food intake in general and especially on the day of the performance test.

Malnutrition can have drastic effects on health and therefore also on the ability to perform mental tasks. Stoch and Smythe (1963) compared 21 malnourished Cape Coloured children between ten months and three years old with a control group matched in age and socioeconomic background. In terms of IQ the malnourished group was well below that of the well-nourished group. Nelson and Dean (1959) found abnormal electroencephalogram (EEG) activities in 17 of 47 children between one to three years old, suffering from kwashiorkor, a form of protein-calorie malnutrition. These findings suggest that the effects of malnutrition on behaviour and performance might be traced back to neural determinants.

Among the children selected for the present study (white children in the Pretoria-Johannesburg area) severe malnutrition was unlikely to be found, but the composition

of food and the pattern of food intake can also affect physiology and behaviour.

Dauncey and Bingham (1983) showed that the composition of nutrients has a significant effect on metabolic rate. Six subjects were given either a high-protein, low-carbohydrate diet, or a low-protein, high carbohydrate diet. Each subject lived for 28 hours in a whole-body calorimeter. The high-protein diet led to a 24 hour energy expenditure that was 12% higher ($p < 0.001$) than that of the low-protein diet.

Dallosso and James (1980) exposed six young men to two diet regimens. The exposure lasted for two weeks for each regimen. One, labeled "gorging", consisted of two big meals a day. The other, labeled "nibbling", consisted of six small meals of equal energy content. The energy expenditure during the sleep period was 10% ($p < 0.1$) higher for "gorging", while the energy expenditure during the waking hours was higher for "nibbling". This effect, only marginally significant, suggests a possible effect of food intake pattern on the pattern of energy expenditure.

In a study of Capani et al. (1981) two groups of four obese subjects were given a low-energy meal of about 2900 kJ either in one or in three portions a day. It was found that the time of meals induced very little change in the circadian rhythm of energy expenditure.

As most of the normal school day takes place before lunch, breakfast is the meal that might influence school performance most. Dickie and Bender (1982) found no performance differences attributable to the omission or

consumption of breakfast. Two hundred and twenty-seven school children with an average age of 12.5 years, and 260 school children with an average age of 15.3 years performed a short-term memory test (discover paired letters in a random sequence of letters). They were asked if they had breakfast or a mid-morning snack. Presence or absence of either had no significant effects on performance. In another study, described in the same article, boarding school pupils who were used to a daily breakfast performed memory and search tests, simple addition tests or a sentence verification task. Two groups (average age 16.3 and 17 years) of 108 pupils were tested. Depriving them of their breakfast did not have a significant effect on their test performance. Dickie and Bender concede that subjects tend to be more motivated during a test, and that omission of breakfast could possibly have an effect on normal daily performance.

In contrast, the work of Connors et al. (1982) indicates that the attentional mechanism in children can be affected by omission of breakfast. Ten boys were studied for two days without and two days with breakfast. During the morning they performed three times on a warned reaction time task and on an arithmetic task. Omission of breakfast increased variability but did not affect the mean score on the reaction time task, and resulted in a reduced cardiac acceleration in response to the warning tone. Performance on the computerised arithmetic task improved throughout the morning after breakfast, but not after missing breakfast.

Heavy lunch can reduce performance in the afternoon. In a study by Craig et al. (1981), 40 university students performed a visual discrimination task before and after the mid-day interval. Performance was significantly impaired

after a three course lunch but did not alter when no food was ingested.

Smith and Miles (1986) tested the effect of a three course lunch on 48 university students. They found that lunch impaired performance on cognitive vigilance tasks and produced a general impairment of efficiency.

In the present study most tests were scheduled in the morning, and schoolchildren usually do not eat a heavy lunch. Most children came from families that could afford to give them money for snacks or to provide them with food to take to school. Significant findings concerning the impact of nutrition on performance were therefore unlikely. Therefore only a few questions relating to nutritional habits were included in a personal questionnaire.

1.7.4 TIME-OF-DAY EFFECTS

It is now well established that there are circadian or 24-hour rhythms in the efficiency with which various tasks are performed. Such rhythms result in fluctuations of performance over the normal waking day which are generally referred to as time-of-day effects (Monk and Conrad, 1979).

Rutenfranz and Colquhoun (1979) discussed a variety of circadian effects on performance. They relate these effects to the daily cycle of "sleep need", where the largest negative decreases in performance are normally observed when

the sleep need is greatest. Hellbrügge et al. (1959) counted the percentage of children awake at different times of the day. Three groups of children were investigated: 3-5, 6-10 and 11-15 years old. Although the awake periods for older children are obviously longer, the overall pattern is very similar for all age groups. The pattern shows:

- an awake phase in the morning between 06:00 and 12:00,
- a lunch-time dip between 13:00 and 14:00 in which over 80% of the youngest and still over 40% of the oldest age group were found asleep,
- an awake phase in the afternoon between 15:00 and 20:00, and
- a sleep phase between 21:00 and 05:00.

This pattern corresponds closely with the number of automobile drivers who admitted to "falling asleep over the steering wheel" (Prokop and Prokop, 1955). Twenty-five percent of them reported having fallen asleep between 12:00 and 15:00, 58% between 23:00 and 05:00. It corresponds also to the number of mistakes made by meter readers in a gas works, as determined from checks on their records (Bjerner et al. 1955).

The circadian variation in rectal temperature follows a similar sequence: low during the night, morning peak, lunch-time dip and afternoon peak (Marotte and Timbal, 1981). Resting heart rate follows a similar pattern according to Faria and Drummond (1982), with peaks at 12:00 and 18:00. Conclusions about cause and effect are tempting but may be

premature at the present state of research. A variety of other factors interferes with the basic sleep-wake pattern.

Circadian rhythms have been shown to have effects on a variety of mental activities, for example a study by Davis (1987) supports the hypothesis that long term memory functions better in the afternoon than in the morning. Beginner readers who received their instruction in the afternoon benefitted more in terms of reading achievement gains than beginner readers who received instruction in the morning. One hundred first grade pupils were used. The time-of-day differences were significant ($p < 0.003$). Monk and Conrad (1979) found afternoon performance to be superior in speed of information extraction, in accuracy of proof reading and complex date sorting. Of eight clerical tasks and a typing test given to 34 secretaries three showed afternoon superiority, the rest did not show a time-of-day effect.

A decrease in immediate memory recall over the day was found by Gunter et al (1983). Eighty adults were presented with television news at 09:30, 13:30 and 17:30. Unexpected tests of free recall and recognition of news content were given immediately following presentation. Results showed significant decrements in memory performance on all tests across the day.

Craig and Cordon (1984) tested 48 subjects on a battery of six predominantly perceptual tasks that were relevant to bridge operations on a ship at sea. Tests were performed between 08:00 and 24:00. The authors found a shift towards faster but less careful performance as the day progressed. They speculate that this may be due to fatigue rather than

to the time-of-day. Monk and Leng (1982) support the hypothesis that: "... there might be a tendency for people to become faster but less accurate as the day wears on". They exposed subjects to tests involving little or no "working memory" load and found that their results could not be explained by assuming a simple change of processing rate over the day. An explanation assuming a change in processing strategy seemed more suitable.

A study on 43 school children by Zagar and Bowers (1983) found that pupils performed better in the morning on most problem solving tasks. All pupils exhibited more interference, off-task activity, noncompliance and minor motor movement in the afternoon. The pupils were diagnosed by medical examinations as having attention deficits with hyper-kinesis. The results can therefore not be generalised.

A further complication of the performance pattern is that arising from the introvert/extravert difference and was described by Gunter et al (1984). Presenting tests of free recall, cued recall and recognition, two hours after the presentation of television news, they found that "... introverts remembered more than extraverts and differences between them were most marked during the late afternoon session especially for free recall and when minimal cuing was provided".

It is assumed that each task has an optimal arousal level at which it is performed best and that tasks with low memory load are performed best with a high level of arousal, tasks with a high memory load are performed better with a low level of arousal. Monk (1982) found "a remarkably good fit" of performance results on tasks with different memory loads

and the performance predicted by an "arousal model". The model assumed that arousal follows a sinusoidal pattern during the day, increasing during the waking hours and reaching a peak in the late afternoon.

Monk et al. (1983) measured subjective alertness ratings of 36 undergraduate students at several times of the day. The students had to rate their perceived level of alertness on a "visual analogue scale", a 10 cm line labeled "drowsiest" on the one and "alertest" on the other side. The shape of the alertness function resembled an inverted U, with a peak at approximately 12:00. They also measured oral temperature, which peaked at about 20:00, and concluded that the peak of subjective alertness is clearly phase advanced relative to the peak of the temperature rhythm.

There seems to be some agreement over the circadian pattern of the subjective alertness ratings. Folkard (1983) quotes five studies, using alertness rating techniques based either on a "visual analogue scale" or on data derived from "mood adjective check lists". All found an inverted U shape with a peak around 12:00. Unfortunately this is not the arousal pattern best suited to explain performance of tasks with different memory loads (Monk, 1982), so either subjective alertness ratings are a bad predictor for arousal or arousal is a bad predictor for performance. As there is no direct physiological measure for the level of arousal, the arousal theory can be fitted to a wide variety of experimental data. In cases where a task was performed well under conditions assumed to create low arousal it can be concluded that the task requires low arousal for optimum performance. If it was performed badly it might require high arousal. If it has been performed well under high arousal conditions before one can speculate that the subjects had a high arousal level

after all, possibly caused by a combination of light, noise and temperature or by the unfamiliar task. There are enough possible combinations of such assumptions to fit most results. The arousal theory has therefore little predictive power and only limited practical use.

Some physiological measures show changes during the waking hours that could be correlated with the performance increases found in certain mental tasks. Drummond (1980) measured aerobic capacity, heart rate, body temperature and perceived exertion at various times during a twenty-four hour period. The subjects were senior college students. Aerobic capacity and perceived exertion indicated that the subjects were most active during the evening sessions. Drummond concludes that a healthy person's functional capacity is lowest in the early morning and increases during the waking hours.

There is obviously no accepted theory about time-of-day effects on performance, but there is some agreement on what such a theory should contain. Folkard (1983) points out: "... that performance of different tasks adjusts to night-work at different rates. This finding is quite impossible to account for within any theory that assumes only a single factor to mediate changes in performance and points to the need for a multi-factor theory". He states further: "... that there are at least two circadian factors responsible for time-of-day effects in performance". A similar view is supported by Colquhoun (1982).

Folkard (1979) suggested that:

"An alternative interpretation of time-of-day effects in performance is that they reflect a shift in cerebral dominance over the day, such that the dominant left hemisphere becomes less so in the evening. While admittedly speculative, such an interpretation is consistent with much of the time-of-day literature and is perhaps rather more testable than an account in terms of a multi-factor arousal theory and the dominance of different sources of information."

Morton and Kershner (1985) tested 36 school children for incidental visual memory for words and their ability to solve verbal analogies. They found an afternoon superiority for immediate recognition of superficially processed words, but no time-of-day effects were found for words that were processed at a deeper semantic level. They point out that these results cannot be accounted for by a single-factor arousal theory but may be related to greater right hemisphere activation later in the school day.

In conclusion, there is sufficient evidence that time-of-day influences performance, but there is no established theory on time-of-day effects that could be integrated in the present study. Therefore the present study was designed according to the following criteria:

- that time-of-day effects could be eliminated by having the exposure to control conditions as well as to thermal stress conditions for any performance test always conducted at the same time-of-day; and

- that pairs of control and thermal stress exposures for each performance test should be conducted at different times of the day to test for a possible interaction between the effect of temperature and the time-of-day.

1.7.5 PHYSICAL SCHOOL ENVIRONMENT

The physical school environment includes features such as classroom size and shape, number and orientation of windows, seating arrangement in the classroom, size and structure of the school and school facilities. It is obviously impossible to quantify the effects of such a variety of factors on performance. Some of these effects were selected for investigation when observation and evidence from other studies suggested that these effects might be strong. Economic reasons such as the need to build more schools on a limited budget might be the driving force for other projects.

To put the effect of the physical school environment into perspective, it has to be compared with other effects on performance. Thompson (1985) found "... overwhelmingly close associations between the home environment and variations in educational performance as compared to the minimal influences of the school and neighbourhood environments". A sample of 392 seven-year-old and ten-year-old elementary school children from 26 schools in Northern Ireland was tested on measures of intelligence, reading and mathematics. A regression analysis was used to determine the predictive qualities of certain environmental variables. Parental attitudes such as home literacy and educational ambition had

the strongest effect of all variables. Environmental variables explained less than half of the variation in the performance of the seven-year-olds and slightly more than half for the ten-year-olds. The variation explained by environmental variables could be divided as follows:

	7-year-olds	10-year-olds
school conditions	8%	4%
neighbourhood conditions	12%	5%
home environment	74%	90%

This study included formal teaching methods and personal data of teachers amongst the school variables. The effect of the school environment was nevertheless quite small. Focusing on physical school variables only would produce an even smaller effect.

The attitudes of Israeli pupils and teachers towards their schools was investigated by Levy and Guttman (1967). Pupils tended to like their school when it provided:

- a high scholastic level;
- social activity and a close relationship between pupil and teacher;
- large space for spending recess periods;
- spacious construction of such areas as the entrance and the staircase;
- appropriate room temperature, lighting and ventilation;
- facilities for decorating the classroom;
- a convenient entrance; and
- sufficient ventilation of the toilets.

Lighting proved to be a good criterion for overall evaluation of the architect's handling of school building problems. When lighting was reported to be faulty, it appeared that there were faults in the regulation of classroom temperature and ventilation as well. It is of interest to note that most of the classes with a relatively large number of satisfied pupils had windows on two opposite sides of the room, usually facing north and south. As regards academic achievement, no relationship between the pupils' grades in Hebrew, English or Mathematics and their opinions of their school were found.

Larson (1965) investigated the impact of a windowless school environment on kindergarten and primary school children. All windows of a school building in Michigan, USA, were occluded for several months. It was concluded that the school children showed very little personal interest in whether their classrooms had windows or not. No significant effects on performance were found.

Crowding or seating arrangements are also factors that could affect performance. Steyaert and Snyder (1983) investigated this by testing 40 male and 40 female college students with the Digit Span and the Digit Symbol sub-tests of the Wechsler Adult Intelligence Scale. The students also completed an anxiety checklist. Half of the subjects were in a corner-to-corner position and the other half in a face-to-face position relative to the experimenter. Seating arrangement, anxiety level and sex of the subject had no significant effect on the test scores, and anxiety was unrelated to seating arrangement or subject gender.

In extreme cases the physical environment has an obvious effect on performance, for example when there is insufficient lighting reading cannot be performed. If one focuses on the variations in the physical environment that are usual in schools of industrial countries, then few general principles can be drawn from present literature. The sample in this study was restricted to schools that allowed access to three-phase, 60 Ampere mains power for the air-conditioning unit. This ruled out schools in informal settlements or small schools in rural areas. The variation in the physical factors was therefore relatively small. Besides an experimental design to keep test conditions constant and to compensate for performance differences between different school classes and schools, no special effort concerning the physical structures of the selected schools was made.

1.7.6 STRESSOR INTERACTION

The literature is less than conclusive about the effect of single stressors on performance. In the more complex area of stressor interaction, even less consensus can be expected. Nevertheless, in real life stressors do interact. A school building in a poor neighbourhood may not only have a bad thermal design, it could also have poorer ventilation and lighting and be located in a noisier environment when compared with a school in a wealthy neighbourhood. A discussion of stressor interaction defines the context into which studies of single stressors such as the present study will ultimately have to fit.

Under moderate stress the effects of the stressor on performance will depend on how it is perceived by the subject. Gliner and Gliner (1984) investigated the relationship between environmental stressors and memory. Nine cards with descriptions of different stress situations were given to each test subject, with the request to imagine each situation and to sort the cards according to similarity. All 16 subjects worked at the Institute of Environmental Stress, University of California, Santa Barbara and were therefore experienced enough to imagine many different stresses under different conditions. A multidimensional scaling method (INDSCAL) was used to analyse the similarity between stressors. Heat stress was not closely associated with cold stress. It was perceived to be closer to breathing strongly polluted air, whereas cold stress was more associated with electric shocks. This indicates that heat stress and cold stress are different concepts in the human mind. It can therefore be expected that, apart from the difference in physiological effects, heat stress and cold stress interact differently with other stressors.

The present study deals with effects of temperature on performance, and it is of particular interest how such effects could be influenced by other stressors. Nicholl (1978) investigated the combined effects of noise and heat on performance. Male subjects with an average age of 28 years were exposed to two levels of pre-recorded traffic noise at three ambient temperatures at similar levels of water vapour pressure. Their performance on the Tsai-Partington test, a short term memory test, a simple reaction time test and an assembly line test was monitored. Performance on most tests plotted against ear canal temperature and various skin temperatures fitted into an overall pattern:

- performance in low level noise declined with temperature,
- performance in high level noise also declined with temperature, but the decline was flatter than in low level noise, and
- performance at lower body temperatures was usually better at low level noise, whereas at high body temperatures it was usually better at high level noise.

The effect of temperature on performance was therefore dependent on the noise level.

A primary pursuit rotor task and a concurrent subsidiary number processing task were performed by 72 male and 72 female paid volunteers in a study by Bell (1978). The subjects were exposed to ambient temperatures of 22, 29 and 35°C at either 55 or 95 dB(A). Neither heat nor noise showed a significant effect on the primary task. Performance on the subsidiary task decreased with heat and noise. The decrements for heat and noise were additive - a different pattern to that found by Nicholl (1978).

In a study of Grether et al. (1972) twelve males were exposed to different combinations of heat, noise and vibration stress. They performed tasks such as tracking, a reaction time test and mental arithmetic. The performance decrements relative to a control situation were greatest during vibration alone, smaller during vibration and heat and smallest during vibration, heat and noise. Generally the differences between the stress conditions were not significant, but the findings were consistent in direction. This leads to the rather unexpected conclusion that the

three stressors are antagonistic rather than additive - a pattern different to that found by Nicholl (1978) as well as to that found by Grether et al. (1972).

Combined effects of temperature and lighting on the performance of 144 school children were studied by Löfberg et al. (1975). Illuminances of 60, 250 and 1000 lux were combined with two levels of heat stress: 22 and 29°C. An addition test was presented on high and on low contrast sheets, as well as a visual test in which the children had to find gaps of different sizes in ring patterns (Landolt rings). At the neutral temperature, illuminance had no effect on the performance of the addition test with high contrast, but the expected positive effect on visually more difficult tasks such as Landolt rings with small gaps was found. During moderate heat stress visually demanding tasks still improved with illuminance, but especially in the afternoon it was found that a high level of illuminance had a negative effect on tasks where visual concentration was less essential such as the addition test with high contrast sheets. The authors speculate that the distracting effect of brightly lit surroundings may outweigh the marginal advantage of improved visual acuity for tests that are not visually demanding.

The findings on combined effects of thermal and other stressors on performance are incoherent. No existing theoretical model can predict changes in performance and a considerable amount of research will be necessary to devise such a model. In the meantime, studies that focus on one stressor and aim at practical recommendations, such as the present study, must:

- avoid the complexity of introducing combined stressors deliberately;
- perform the experiment in conditions as close as possible to the real situation to ensure that the concomitant stressors are at a realistic level;
- keep the experimental conditions as constant as possible; and
- vary certain concomitant variables such as time-of-day, if results on an overall effect are required, but no conclusive results on stressor interaction should be expected.

1.8 TESTS AND TEST DEVELOPMENT

1.8.1 MULTIPLE-CHOICE-TYPE PERFORMANCE TESTS

1.8.1.1 INTRODUCTION

Performance tests were developed to measure in a standardised and controllable way how well individuals are likely to perform in real life. The development of such tests and the discussion of their validity for predicting different types of performance is a separate area of research. The present study is not concerned with development or validation of new tests, but with the appropriate application of those already existing. The discussion of performance tests therefore takes the form of a general overview with the aim of elucidating problems of test application.

Performance tests are normally used to make statements about individuals. Results of a performance test suitable for this purpose should among other characteristics:

- have a high inter-individual variation, because if everybody scores about the same the test has little predictive ability; and
- be rugged in respect of the environmental conditions in which the test is performed, such as time-of-day or room temperature, to minimise the experimental effort and the concomitant parameters that have to be controlled.

Tests ideally suited for the present study should have just the opposite characteristics: high sensitivity to environmental effects and a low inter-individual variation to give significant findings with small numbers of test subjects. Although it might be possible to develop such tests, it would be quite difficult to prove their relevance for the prediction of performance on ordinary tasks. Therefore established conventional performance tests were used for this study. In 1.8.1 the following aspects are discussed:

- inter-individual differences in test performance, whether they are due to genetic variation, home background or schooling;
- effects of the experimental conditions (the way the test is presented) on test performance; and
- problems of testing relevant for the present study.

1.8.1.2 INTER-INDIVIDUAL DIFFERENCES IN TEST PERFORMANCE

The term inter-individual differences refers in this study to the variation in performance that cannot be ascribed to any experimental condition. The size of the smallest experimental effect that can still be detected reliably, increases with the size of the inter-individual differences (Kirk, 1968). Careful selection of the test subjects will reduce the inter-individual variation in performance. When this is not possible, as in the present study, the analysis of the data can be aided by using concomitant variables to which part of this variation can be ascribed. A discussion

of the most important variables with a potential use for reducing the unexplained inter-individual variation follows.

Intelligence

Intelligence tests are performance tests that focus on cognitive abilities. The scores people achieve on these tests are fairly consistent for each individual, and consistent differences in the mean score between population groups can also be demonstrated (Jensen, 1973).

Most researchers agree that intelligence tests have their uses as predictors of scholastic success. Barton et al. (1971) found with 311 children from a junior high school that the "Culture Fair IQ Test" (Cattell and Cattell, 1965) predicted 20% of the variation in the children's achievement scores. Two ongoing controversies, however, seem to dominate the field of intelligence testing.

The first is concerned with the role of genetics in the explanation of differences in scores. Whereas Jensen (1973) argues that a genetic explanation for differences in performance between population groups should not be excluded, others such as Farrell (1983) reject this explanation and favour cultural and educational factors. Farrell (1983), for example, argues that the syntactic grammar of a language is the basis of abstract thinking, and that the insufficient mastery of a syntactic language by minority groups or lower classes explains their lower scores

on intelligence tests. This discussion is of little relevance to the present study.

The second controversy concerns the nature of intelligence. One school postulates a variety of intelligences; this dates back to Thurstone (1938) and even earlier investigations. A modern form of expressing this idea is the concept of multiple mental processors (Gardiner, 1983). The other school upholds the importance of general intelligence that is relevant for the whole spectrum of performance (Spearman, 1927). A more recent way of arguing along this line is followed by Humphreys (1979) who sees the general part of intelligence as a result of overlapping effects of genetic and environmental factors.

A variation of the concept of multiple intelligences deals with specialisation of the cerebral hemispheres. Much of the evidence for such a specialisation was discovered when patients suffering from severe epileptic fits were treated with split-brain surgery in which the corpus callosum, the connection between the right and the left cerebral hemispheres, is cut and communication between the two halves of the brain is virtually halted. Research on the mental performance of such patients revealed that the left hemisphere specialises in sequential analytic and linear processing, as used in mathematics or language. The right hemisphere deals with multiple processing, it is holistic in nature and is associated with art, creativity and visual patterns (Kaufmann, 1979). People tend to move their eyes to the right or to the left when considering a problem. Movements to the left are believed to indicate right brain activity and vice versa (Bakan, 1971). As Kaufmann (1979) points out, most tests of mental performance involve a mixture of right and left brain activities. This is also

true for the tests used in this study. Methods such as registering the eye movement of each child during the test period were beyond the scope of this study.

The fact that each test used in this study most likely involves a variety of brain functions should be taken into account in the interpretation of the results, as effects of environmental stressors on one hemisphere will be obscured if the other hemisphere is not affected or affected in a different way.

In the context of a "general intelligence" it might be meaningful to grade the children according to a short "general" intelligence test that is performed before the main experiment. This approach was seen as too speculative. In the context of multiple intelligences it would not be meaningful to talk of "intelligent subjects" in general. The performance level has to be established for each test, which implies that the subjects have to be used as their own control. This was not feasible in the present study.

Sex

The physical differences between the sexes and the common differences in social values applied to boys and girls make sex an obvious choice as a potential concomitant variable. Hertzog and Carter (1982) tested children and their parents together with a comprehensive battery of intelligence tests. They analysed the data by using comparative factor analysis and found that the results provided little support for the

hypothesis that the organisation of abilities differs fundamentally between sexes.

In a study of psycho-motor performance Ruffer (1984) found that boys had a shorter reaction time than girls, and that girls scored better on an arm-hand steadiness test. Differences in the performance of pursuit rotor and hand tapping could not be ascribed to sex.

Jensen (1983) tested 944 males and 924 females on 13 sub-test of the Wechsler Intelligence Scale for Children. Their ages ranged from 6 to 17 years. In all but two tests the sex differences were small: below 0.2 standard deviations. In the "information" sub-test the males scored markedly better, and in the "coding" sub-test (matching geometric symbols with numbers) the females excelled.

The significance and relative influence of individual and environmental variables on achievement test scores of 439 tenth-grade students in 39 Indian Schools were investigated by Walberg et al. (1984). Self-rated motivation, IQ, peer-rated studiousness, peer group status and parent-rated home environment predicted 76% of the variation. Socioeconomic status, sex and language of instruction proved to be non-significant when the variables were controlled for one another by partial correlation, either because they were weakly correlated with performance or because they correlated with other independent variables.

The significance of sex as a predictor of performance depends on the type of test used and on the use of other parameters in the analysis. The role of sex as a concomitant

variable will therefore have to be investigated in the present study.

Other factors

The effort used to solve difficult tasks can be affected by external stimuli, but the way children react may be dependent, among other factors, on their social background. The influence of feedback on children's motivation in solving challenging tasks was investigated by Wilson (1982); 128 third grade children had to guess which lamp will light up on a test box. Correct predictions produced either no feedback, caused a bell to ring (non-material feedback), or released a marble (material feedback). Working and middle-class children were both responsive to the cognitive challenge posed by a difficult task, but working class children, especially boys, responded more strongly to a material reward. Girls showed more interest in solving a difficult task when receiving a non-material reward.

Another factor effecting performance can be the "mood" of the test person. In a study by Barton (1978) 2600 children were rated on a mood test battery, including tests for anxiety, regression, arousal, fatigue, introversion, stress and depression. Two hundred of each sex were identified as scoring high or low on each test. The children also performed a perceptual motor task in which they traced a road on a map with a pencil, staying on the road and bypassing obstacles on the road. The group scoring high on the mood test made significantly more errors than the low scoring group on a perceptual motor task, but made up for

this by covering a greater distance. The efficiency, defined here as the mean distance covered between two errors, was therefore roughly the same.

Eysenck (1976) reviewed the literature on the effect of extraversion on learning and memory. He describes as an important and replicable finding that extraverts learn more rapidly than introverts on difficult and complex tasks, but not on easy tasks. Extraverts tend to exhibit better short retention spans, but introverts perform better where long retention spans are required.

In the present study, socioeconomic status was assessed with a personal questionnaire. A mood test or an introversion-extraversion test was omitted because it would have increased the time required to administer the test battery beyond the length of a school day.

Age has such an obvious effect on the performance of children that it was included in the experimental design and the analysis without further discussion.

1.8.1.3 EFFECTS OF EXPERIMENTAL CONDITIONS ON TEST PERFORMANCE

The influence of the experimenter's race and behaviour on the performance of test subjects has special relevance for the testing of different population groups. Katz (1970) found that the race of the examiner had an effect on the

performance of black students and that this effect depends on the type of task. Sattler and Gwynne (1982) state that: "the available research literature clearly refutes the existence of race-of-examiner effects and indicates that black children's performance is not enhanced by examinations administered in black dialect".

In a study by Allen et al. (1969), eight experimenters each portrayed two roles, warm and cold. The subjects were 128 boys and 128 girls from fifth and sixth grades. The performance task required them to drop marbles in holes outlined in colours matching the marbles. When the experimenter was of the opposite sex to the children, they obtained higher scores with "warm" experimenters. With experimenters of the same sex little effect of "cold" or "warm" behaviour on the scores was found.

The effect of the experimenter on performance depends on the type of task and on social and experimental circumstances. In the present study little effect would be expected, as the subjects and the experimenters were essentially white middle class. However, for tests that require a verbal explanation, the quality of such an explanation can be expected to influence the subsequent performance. In such cases it will be appropriate to:

- keep the verbal part of the explanation to a minimum, while considering that a lengthy written test explanation introduces a component of reading comprehension;
- standardise the verbal part as far as possible by training; or

- deliver the explanation via audio tape or video film to ensure constant quality of explanation and thereby reduce the role of the experimenter and his possible influence on performance.

1.8.1.4 PROBLEMS OF TESTING

Sorensen (1985) investigated the equivalence of paper-and-pencil versions and computerised versions of cognitive ability tests. The tests were concerned with induction, number facility, general reasoning and logical reasoning. The relationship between scores obtained with the two test methods for all four cognitive tests was significant and positive ($p < 0.01$). According to Sorensen: "this relationship substantiates the validity of computerised test administration".

Verster (1983) used a computerised test battery on white males ($n=100$), white females ($n=100$) and black males ($n=173$). He found that speed and accuracy measures may represent different attributes of cognitive performance.

Bridges (1985) investigated the relationship between score and finishing time of 278 students on examinations at the end of a course on introductory psychology. No significant correlation between score and finishing time was found.

According to Poulton (1965), the sensitivity of a test to changes of an independent variable such as temperature

depends on the performance level that is achieved under the starting conditions. If, for example, the performance level is already near the maximum under neutral conditions, little improvement can be expected in more favourable conditions. A change to slightly worse conditions will also show little effect, since the task can still be performed with ease. Such a test would therefore be inappropriate under neutral conditions but might be acceptable under very adverse conditions where the performance level at the starting point is already far from the maximum. Poulton writes:

"If an S-shaped relationship is assumed to hold between performance and the independent variable for any level of task difficulty, the region which is most sensitive to small changes in the independent variable is the almost straight section on either side of the point indicating 50% performance. The most sensitive test used is thus one using a task on which the average performance of the combined control and experimental groups is about 50%."

Besides choosing an appropriate test in the first place, Poulton (1965) discusses the option of introducing an additional task to occupy the reserve capacity of the subject. The additional task should engage different receptors and effectors to ensure that competition between the tasks does not occur in the sense organ or the effector organ.

For the test application in the present study the following conclusions can be drawn:

- the use of computerised versions of conventional cognitive tests is free of problems, especially when

the exposure and the control groups are tested with the same method;

- the use of computerised testing would be desirable for reasons other than administrative ease. Speed and accuracy scores are quite independent and reflect different cognitive elements, and detailed measurement of working speed requires computerised testing;
- fine tuning of the difficulty level of tests would be possible while the test is presented. This can be achieved by the introduction of additional tasks. Because of the resulting complexity of the testing procedure and the analysis, this option should be avoided if possible.

1.8.2 REACTION TIME TESTS

Performance on a reaction time test is not obviously linked to the tasks children are required to perform at school. Reaction time tests were included in this study for two reasons:

1. Appropriate reaction to a stimulus requires mental activity. If reaction time could be shown to be temperature sensitive, it would aid in the understanding of temperature effects on the performance of mental tasks.
2. There is strong evidence that choice reaction time is correlated with performance on intelligence tests

(Jensen and Munro, 1979). If it could be shown that reaction time is affected by temperature in a way similar to that of mental tasks, further investigations of thermal effects could be based on reaction time, thereby considerably reducing the experimental effort.

The effect of temperature on reaction time, amongst a range of other factors, was investigated by Bell et al. (1982). They used paid volunteers (64 males and 64 females), who performed either an easy or a complex reaction time task, either alone or in pairs, while exposed to ambient temperatures of either 22 or 37°C. Reaction time was faster for males than for females, faster for the easy than for the complex task, and faster when working in pairs than for individually acting subjects. Heat increased reaction time, though its effect was statistically weak ($p < 0.08$). The R^2 for temperature was 0.06, indicating that about 6% of the total variation could be accounted for by heat. All of these effects were essentially additive, with task difficulty having the strongest effect. Regression analysis suggested that arousal, as measured by systolic blood pressure, could account for the effects of working in pairs, sex differences and heat.

The discussion of the correlations between measures of intelligence and measures of reaction time is strongly influenced by Arthur Jensen's work and his hypothesis on reaction time and intelligence. His approach and that of his colleagues shall therefore be described in more detail.

Jensen and Munro (1979) found a significant correlation between reaction time and intelligence as measured by

Raven's Standard Progressive Matrices, testing 39 girls with an average age of 14.7 years.

Their apparatus for measuring the subjects responses consisted of a panel of 432 mm x 330 mm, painted flat black and tilted at a 30° angle. At the lower centre of the panel was a red push-button, 13 mm in diameter, called the home button. Arranged in a semicircle above the home button were eight red push-buttons, all equidistant (152 mm) from the home button. Thirteen millimeter above each button was a 13 mm faceted green light. Different black panels could be fastened over the whole array so as to expose arrays having 1, 2, 4, 6 or 8 light/button combinations, corresponding to an information content of 0, 1, 2, 2.58 and 3 bits. A "bit" is the binary logarithm of the number of choices available. The subjects were instructed to place their index finger on the home button; then an auditory warning signal was sounded, followed, after a random interval of 1 to 4 seconds, by one of the green lights going on. The subject had to switch the light off as fast as possible by touching the micro-switch button directly below it.

The time the subject took to remove his finger from the home button after the green light came on was termed reaction time. The time from removing the finger from the home button to touching the button that turned off the green light was called movement time. The term "reaction time" is here used differently from its use in most other publications, where reaction time includes movement time.

Raven's scores were significantly correlated with reaction time and movement time for all tests, except reaction time at 0 bit. The correlation coefficients were around 0.4 with a significance between $p < 0.1$ and $p < 0.5$. Reaction time increased with the number of bits suggesting a linear

dependency. This dependency is often referred to as "Hick's law" (Hick, 1952). Movement time was not affected by the number of bits.

In a critique of Jensen's approach Longstreth (1984) mentioned among others the following points:

- unequal practise at different set sizes makes the linear increase of reaction time with decision uncertainty (in bits) look questionable;
- RT has been shown to increase with the distance of the stimulus from the foveal centre of the retina, and Jensen's apparatus is designed in such a way that the retinal displacement increases with set size; as a better alternative Longstreth suggests a computer monitor where all different stimuli are presented in the same position.

Vernon and Jensen (1984) used a computer monitor to present their RT tests. They exposed 50 black and 56 white vocational college students as well as 100 university students to eight different reaction time tests as well as to a battery of scholastic aptitude tests. The groups showed marked differences on the RT variables, the largest differences occurring on the tests that required more complex cognitive processing. The more complex RT tests also correlated most highly with the psychometric measures of ability within each group. They found the results consistent with the hypothesis that individual differences and the mean differences between groups in psychometric abilities and scholastic achievement are related to differences in speed of information processing as measured in elementary cognitive tasks.

Results obtained by Carlson et al. (1983) support Jensen's findings. Using Jensen's type of RT measurement apparatus for tests of 105 seventh-grade children both mean reaction time and standard deviation of reaction time correlated with intelligence and achievement measures used.

Smith and Stanley (1980) also used a computer screen to present the stimulus. Their choice reaction time test did not use a home button, and was therefore different from that of Jensen and Munro (1979). Testing 45 adolescent girls, they found only a weak and non-significant correlation between a verbal measure of intelligence and the "rate of reduction of uncertainty", which is derived by plotting reaction time against the information uncertainty in "bit" and drawing a regression line. The "rate of reduction of uncertainty" is the slope of the regression line, in accordance with Hick's law (Hick, 1952).

In a later study (Smith and Stanley, 1983) they tested 137 twelve- year-old students with IQs ranging from 59 to 142. Correlations of RT measures with spatial scores were not significantly greater than with verbal scores, suggesting that whatever relationship exists is with a general factor rather than only with a spatial one. Only three of the RT measures produced correlations greater than 0.25 with the general factor. These were Hick's law (-0.28), the 3-bit mean RT (-0.33) and the 3-bit RT standard deviation (- 0.41) compared with the average inter-correlation of 0.40 between the intelligence measures. They state that: "... an optimist could see promise in the correlations reported in this study".

Vernon et al. (1985) gave 81 students a battery of reaction time tests and a group test of intelligence which yielded timed and untimed scores. Multiple regression analysis indicated that speed of information processing was an equally good predictor for timed and untimed intelligence test performance. Various combinations of speed of processing variables accounted for as much as 48% of the variance in the intelligence scores.

Lunneborg (1975) reports on the results of three studies, each of which used a series of psychometric tests and a series of reaction time measures based on visible and audible stimuli. The first study was conducted with 64 high school age subjects. Motor choice and reaction time appeared to be strongly predictive of individual test performance across the range of psychometric tests. The second study was performed with 63 university freshmen and found response times only weakly correlated with psychometric performance. As the difference in findings could have resulted from differences in measurement techniques, a third study was conducted, using the tests of the second study on a sample similar to that of the first study (63 high school juniors). Significant correlations between test performance and RT were found, similar to those in study one. Lunneborg (1975) sees a possible explanation in the higher variability for choice response time found among the high school groups. This indicates that the relation between choice reaction time and performance on psychometric tests can only be defined when a particular population of subjects is specified. Narrowing the range of cognitive abilities, as in the university sample, might reduce the simple correlations and yield relations which are complex and difficult to replicate.

A comparison of reaction time findings must emphasise that each experimental apparatus provides a unique definition of reaction time. Most studies deal only with the overall measure of the time elapsed between stimulus and response. Some, such as those of Jensen, refer to a narrower definition of reaction time. According to Teichner (1954) the total time required to react to a stimulus consists of different periods. After the onset of the stimulus there is a latent period during which the receptor process is initiated and builds up to a maximum. This is followed by a second phase involving central transmission of the sensory impulses to the motor fibers, and finally there is time involved in the contraction of the muscles and the beginning of the movement of the responding member. The following factors are influenced by the design of an experimental apparatus and have a potential influence on reaction time (Teichner, 1954):

- sense modality stimulated;
- number of sense organs stimulated;
- number of receptors stimulated;
- location of the stimulus in the visual field;
- intensity of the stimulus;
- duration of the stimulus;
- pattern of onset and cessation of the stimulus.
- preparedness of the subject;
- body position;
- responding member of the body and
- prolonged state of readiness.

A part of the definition of reaction time lies also in the experimental procedure. Mowbray and Rhoades (1959) have shown that with accumulated practice, decision time and reaction time might well be reduced. Reaction time depends also on the intervals between consecutive stimuli. If they

are closely spaced, the RT to the second one tends to be longer, although both stimuli were equally unexpected (Craik, 1948). Of further interest in the design of reaction time experiments is the trade-off between speed and accuracy. Fitts (1954) suggested that the greater the accuracy of a movement and the greater its extent, the more time it will take to perform the movement. This corresponds also with the views of Hick (1952), who assumed that humans act as a constant capacity information channel.

Grice et al. (1982) developed a general theory of human reaction time, in which the strength of the excitatory tendency grows continuously from the time of stimulus onset. Response occurs when this strength reaches the value of the decision criterion. This criterion depends on motivation, attention, adaptation and individual differences. Excitatory strength may depend on either one or two processes: on detection information dependent on sensory strength and on associative strength. In simple RT only detection is involved, but in choice RT both are present. The theory was successfully tested in a series of five experiments with auditory stimuli, where differences in intensity were used as the basis of differential response. The authors reject the concept of staged processing of information, in which additional complexity implies the addition of another processing part and therefore additional complexity. They speculate that signal processing occurs in parallel, and that slower responses to a more complex stimulus might not result from the addition of an extra processing stage or from a limitation in the processing capacity. It might result from a deliberate increase of the response criterion to permit time for inhibition in case the stimulus turns out to be misleading.

The study of Grice et al. (1982) demonstrates that there is no consensus on describing RT results in the framework of a limited capacity information channel. There seems to be little sound and undisputed theory for a link between RT and mental performance, and although correlations can be used for predictive purposes, such results can only be relied upon to a limited extent. The present study is concerned with the effects of temperature on performance. As it is disputed to what extent RT is correlated with mental performance under comfort conditions, it seems rather unlikely that the effects of temperature on RT can be used to predict the effects on other mental tasks. The main reason for including reaction time tests in the test battery of the present study is the interest in the effects of temperature on reaction time itself.

2 METHODS

2.1 EXPERIMENTAL DESIGN

2.1.1 REQUIREMENTS FOR AN EXPERIMENTAL DESIGN

The experimental design should allow the derivation of valid and relevant conclusions about thermal effects on the performance of school children with a minimum of school children tested, with a minimum of disturbance of the school routine and in a labour- and cost-effective way.

2.1.2 DISCUSSION OF ALTERNATIVES

2.1.2.1 MEETING OF EXPERTS AS A FORUM FOR DISCUSSION

To aid in the selection of a suitable experimental design based on the practical experiences of educationalists and test psychologists, while taking into account special features of the educational system such as school holidays and examination periods, a meeting was arranged at the CSIR on 13 January 1983. It was attended by senior government officials, educational experts, psychologists and teachers from several population groups.

Various alternatives for the experimental design were presented to the forum, discussed and investigated for

feasibility in the educational context. It must be pointed out that the forum had only an advisory function. It should by no means be deduced that all persons involved supported a particular alternative, that any individual did so, or that anybody except the author of this thesis carried any responsibility for decisions made in this project.

2.1.2.2 EVALUATION OF SCHOOL MARKS VERSUS A CONTROLLED EXPERIMENT.

An assessment of thermal effects could have been undertaken in two principal ways:

- A) by collecting data relating to the performance of children in their school examinations during the year, and by correlating these results with the temperature conditions during these examinations; and
- B) by conducting a controlled experiment in which children would be exposed to controlled thermal conditions and would perform standardised tasks representative of school work.

Alternative A has the advantage that it resembles real life more closely and that no direct experimental effort is necessary. The field work consists only of collecting the examination results from different schools and bringing them into a computer-readable form. A fair estimate of the temperature at the time of an examination can be gained by combining local meteorological data (annually available for South Africa on magnetic tape) with a simulation program for

the thermal performance of buildings and the data for the building structures of the schools involved.

The essential disadvantage of alternative A is that it produces data with a low reliability, for example insufficiently controlled examination conditions, cheating by pupils and a high variance due to uncontrolled and often unidentifiable factors. Schiefer et al. (1985) showed that the average test performance of school classes in certain school subjects, for example mathematics, can vary by a factor of two. Much of this variation can be accounted for by differences in the educational standard of schools.

Because the curricula in all schools are synchronised over the year, it would also be exceptional to find two similar tests performed under significantly different environmental conditions. It seemed unlikely that it would be possible to compensate these shortcomings by the large amount of data that could be collected with this relatively cheap and easy data collection method. The most promising approach was therefore alternative B; the controlled experiment.

2.1.2.3 ALTERNATIVES FOR A CONTROLLED EXPERIMENT

Thermal experiments require an adaptation period in which the bodies of the test subjects can adapt to the altered temperature conditions. Haymes et al. (1975) tested lean and obese boys, walking on a treadmill at four conditions ranging from comfort temperature to 32.2°C Effective Temperature, which is comparable to 32°C WBGT. The hottest

condition in the present study was 26°C WBGT (34°C at 40% RH). A graph showing rectal temperatures versus time in Haymes et al. (1975) indicates that all lean boys had reached a state of thermal equilibrium under all conditions in less than an hour. The subjects in the present study were school children chosen by a random procedure; most of them could therefore be classified as "lean". In a study of Williams et al. (1968) most of the increase in the rectal temperature of acclimated subjects stepping at 32.7°C WBGT took place within the first hour. The skin temperatures of subjects in a study by Kok et al. (1982) reached their final value in the heat (38°C DB) and in the cold (6°C DB) within less than an hour. It was therefore assumed that an adaptation period of one hour would be sufficient.

To make the experimental procedure cost- and time-effective, a sufficient exposure period must follow the acclimation. It would be inefficient to acclimate the children and then to expose them for only half an hour. It was therefore decided to use an experimental day equal in length to an average school day for the educational level concerned, and to design the test battery so that it could be completed within one day. The following alternatives for an experimental design were then presented to the forum, discussed and compared:

- A) use the same group of children for the whole experiment, train them in the performance of the tests until they have reached the plateau of their learning curve, then expose them to different thermal environments and compare their performance under different conditions;
- B) use one group of children for about a week, expose them to different thermal conditions, and expose them

between these tests several times to a control temperature to assess the learning curve of each child for each task. Compare their performance under different conditions after compensating for the learning effect;

- C) expose one school class at a time to a certain thermal condition and compare the performance of different classes under different thermal conditions. Counteract the sometimes considerable difference in the average performance levels of school classes by testing a sufficient number of classes under the same thermal condition;
- D) test a group of children at a certain thermal condition and re-test them again after a few weeks, when the children have lost most of their familiarity with the tests, at another thermal condition. Quantify the learning effect by performing some re-tests at the same thermal condition than the first test; and
- E) split each school class randomly into halves, test one half at a control temperature, the other at a hotter or colder experimental temperature, and compare the performance of the two groups.

Experimental design alternatives A and B require children to be available as full-time test subjects for at least a week, possibly longer. It was considered nearly impossible to get permission from the educational authorities or from the parents to allow children, especially younger children, to act as test subjects for such a long time.

With a few exceptions, for example reaction time tests, the vast majority of performance tests is designed for naive subjects; people who perform the test for the first time in their lives, or at least for the first time after a long period. They are not designed to be repeated until a performance plateau is reached, as required for alternative A. To find out which tests are suitable for such an adaptation, and within which constraints, would have been a large-scale psychological research project on its own.

Whereas it is relatively easy to create test material for one exposure, the effort to create standardised test material for N exposures, as required for alternatives A and B, is much higher. Not only must the N-fold amount of items be generated; it is also necessary to ensure, by means of extensive pilot studies and item analysis, that the test packages are of an equal difficulty level and consist of a similar mix of items. It was also doubted whether it would be possible to compensate for learning effects in a meaningful way by using repeated control temperature exposures. Because of these restrictions the alternatives A and B were ruled out.

Alternative C provides the simplest experimental routine and keeps each child for only one day from the regular school syllabus, however, it introduces a large variation in the data due to factors other than temperature. Large differences between the average performance levels at different schools have been shown by Schiefer et al. (1985). This high additional variation could obscure any temperature effects.

Alternative D compensates for most of the variation in alternative C, for example the differences between schools, school classes, and the socioeconomic status of different areas. In addition it keeps each child from the regular school syllabus for only two days. After compensating for the learning effect the subjects can be used as their own control, thus eliminating inter-individual variation arising from different initial performance levels, but introducing variation due to inter-individual differences in learning. The main drawback of this alternative is the additional strain on the school's organisation, as the equipment required for the experiment has to be installed and dismantled twice at each school. This increases also the demand for manpower and the running cost of the experiment.

Alternative E compensates for performance differences between schools and school classes as well as alternative D. The subjects are not used as their own control, but no learning effects have to be handled. Each child is kept from the regular school syllabus for only one day, and the equipment necessary for the experiment has to be installed only once at each school.

The advantages and disadvantages of the alternatives D and E seemed fairly well balanced. Although alternative D was very promising with respect to data analysis, its organisational problems weighed too heavily against it. It was doubted if co-operation of school headmasters and teachers could be obtained for such an intrusive scheme. Therefore alternative E was chosen.

2.1.2.4 EXPOSURE TEMPERATURES

The exposure temperatures were to be representative of temperature conditions in schools. These conditions can be extreme. Schiefer et al (1985) found temperatures between 11.1°C and 30.2°C in a study on black Standard 10 children. Wentzel and Meese (1983) found temperatures down to 6°C in a primary school for white children. The exposure temperatures in a controlled study are of course limited by a possible health risk to the children and by acceptance problems with educational authorities, teachers and parents.

For the control day comfort conditions were desirable and the mean of the temperatures at which people feel most comfortable lies in the range from 22 to 24°C (Fanger, 1972). The lower limit for the exposure temperatures was given by the capacity of the air-conditioning plant; about 14°C. Several studies, such as Wyon (1969) and Wyon and Holmberg (1972), have found a drop in performance in moderately hot conditions of about 27°C. Hotter conditions lead to improved performance of some tasks. One condition in the present study was therefore to be moderately hot and a further one significantly hotter. The highest air temperature found in field studies by Schiefer et al. (1985) was 30.2°C, but more extreme conditions could be expected to show the effects of heat stress on performance more clearly. It was therefore decided to aim at a maximum exposure temperature in the range of 32 to 35°C.

Based on these considerations a range of equally spaced exposure temperatures was selected for the present study: a temperature of 24°C for the control days with cold exposures at 14 and 19°C and heat exposures at 29 and 34°C. As

acclimatisation to seasonal temperature changes occurs (Wyndham, 1965) it was decided to perform, where possible, the cold tests during winter and the heat tests during summer.

2.1.2.5 TIME-OF-DAY EFFECTS

Performance of mental tasks is subject to diurnal variation (Rutenfranz and Colquhoun, 1979), which must be taken into account in performance testing. Two ways to handle diurnal variation were discussed:

- A) use the same sequence of tests for each experiment, ensuring that each test is performed at approximately the same time; and
- B) use several different sequences, each with a different order of tests. Each exposure to a stress temperature is performed with the same schedule as the matching exposure at the control temperature.

Alternative A is a simpler and easier approach, but it is insensitive to the combined effects of circadian rhythm, fatigue and temperature. A test regularly performed in the early morning of the experimental day might not show the sensitivity to temperature that it might have shown when performed at noon. Therefore alternative B was chosen, involving three different sequences for the tests.

2.1.2.6 EFFECTS OF AGE

It may be expected that the effect of temperature on performance varies with the age of the child involved. As young children have a larger surface-to-volume ratio than older children or adults, they are also affected by temperature in a different way (Löfstedt, 1966; Araki et al. 1982). It was therefore decided to conduct tests with children of different age groups.

The ability to read and write was crucial for the performance tests envisaged. The lower age limit was therefore set to the second year of schooling; about eight years of age. In South African schools this educational level is Grade 2. Extensive studies have been performed on the effect of temperature on adults, and this study was especially focused on school children. The upper age limit for this study was therefore around puberty, at an age of about fourteen. This corresponds to the educational level of Standard 6.

To limit the size of the study, a maximum of three age levels was indicated. The intermediate step between the two extremes mentioned above is the age of 11, corresponding to the educational level of Standard 3. Therefore the performance of children in the following three educational levels was assessed:

Grade 2 (8 years of age);
Standard 3 (11 years of age); and
Standard 6 (14 years of age).

2.1.3 DETAILS OF THE EXPERIMENTAL DESIGN SELECTED

The sequence of events for an experiment is shown in Figure 2.1-1. Two school classes were split in half by a random procedure. One half of each class was assigned to the control group, the other to the stress group. It was decided by a random process whether the control group or the stress group would be exposed on the first day. In Figure 2.1-1 the stress group has been exposed first.

Experiments took place in a classroom of the children's own school, which had been furnished with the necessary equipment. The air temperature (dry bulb) was either 14°C or 19°C for the cold exposure, and either 29°C or 34°C for the heat exposure. The air temperature on control days was always 24°C. While one group was exposed, the other one received normal instruction in another classroom. On the following school day the roles of the groups were reversed.

Each experimental day consisted of two phases: an acclimation phase which lasted about 1.5 hours and a performance phase which lasted about 4.5 hours. During the acclimation phase weight and height of the children were measured, and the children completed the Personal Questionnaire. During the performance phase the children completed a battery of eight performance tests. The performance tests were presented in the same sequence on the stress and the control day of one experiment.

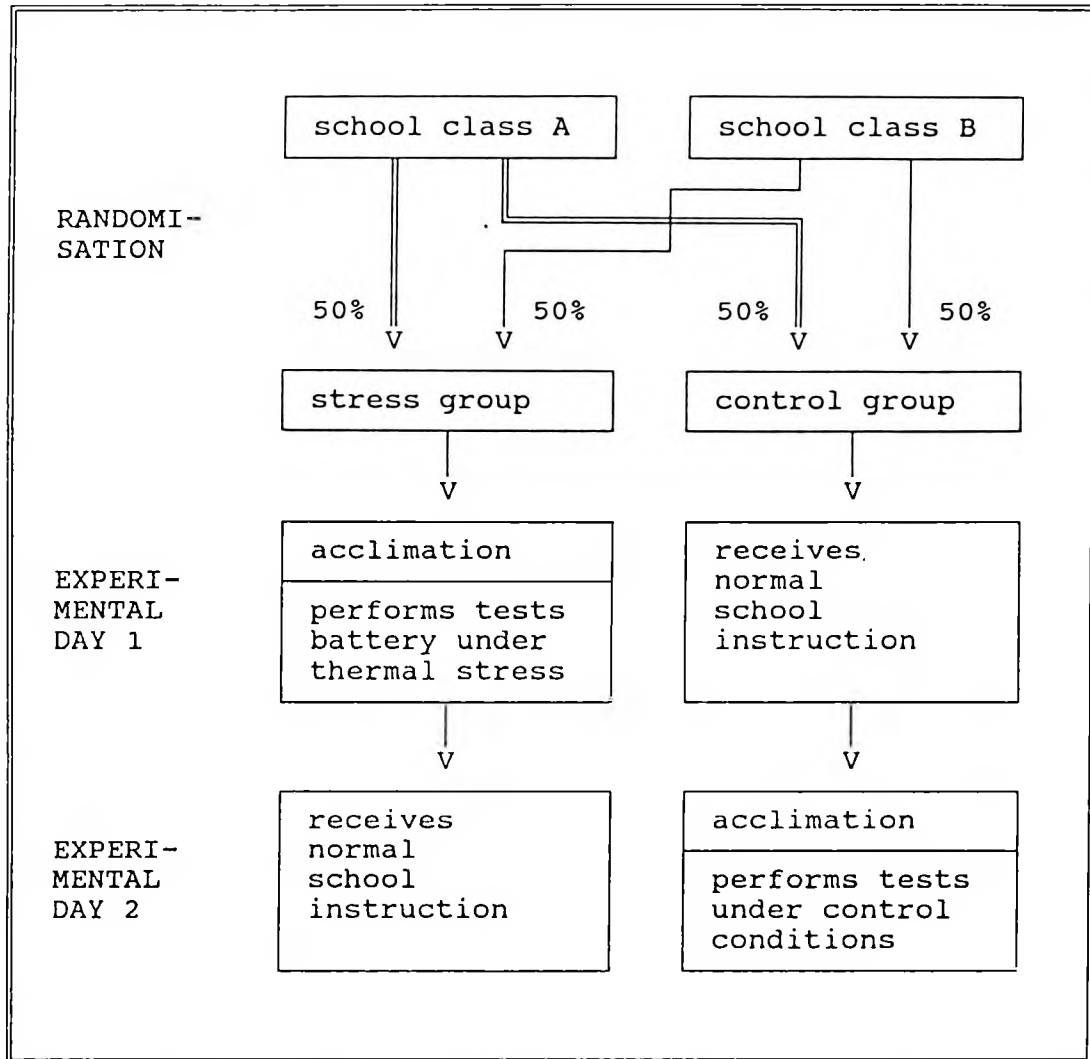


Figure 2.1-1: Sequence of events in an experiment.

To ensure that for each performance test results were available from different times of the day, three different sequences were used. Details are given under 2.6. Reaction time tests as well as the measurements of oral and finger temperature were repeated three times daily. The aim was to collect at least one set of data for each of the three sequences for each temperature condition. This would require:

- 2 experimental days per experiment (stress and control);
- 3 experiments per temperature condition (one for each sequence of performance tests);
- 4 temperature conditions per educational level (14°C, 19°C, 29°C, and 34°C); and
- 3 educational levels (grade 2, standard 3, and standard 6).

With approximately 35 children per school class, these 72 experimental days would provide a database of about 2500 children.

Each temperature condition at each educational level can be seen as a separate experimental series, to be analysed as a factorial design (Kirk, 1968; John and Quenouille, 1977). Two factors were essential in every analysis: the experiment, identified by a label, and the treatment, being either stress or control. Further factors such as sex, weight, height and their interaction with the treatment variable temperature were to be investigated for their relevance in further analysis. With such a large set of results it seemed acceptable to omit some of the experiments if they clashed with certain vital requirements of the schools such as examination periods, as long as at least one experiment was done for each educational standard and each temperature condition. It was intended to monitor the experimental routine and the results very carefully during pilot studies to allow for restructuring of the experiment in case of any unforeseen shortcomings.

2.1.4 PILOT STUDIES AND IMPROVEMENTS

Pilot studies following the experimental design described above were conducted at the J J de Jong lower primary school in Atteridgeville, Pretoria and at the Meyerspark primary school in Meyerspark, Pretoria.

The children of a class were split into randomly selected halves by taking every second entry on the class list and were identified during the experiment by number tags hung around their necks (Figure 2.2-1). In some cases it was also possible to use three classes for one experiment. Headmasters and teachers were willing to co-operate and the teachers coped with the requirement to provide lessons for a group consisting of two half classes. The exposure temperatures were considered acceptable by the educational authorities and most teachers, parents and children. The procedures to obtain consent from the relevant organisations and individuals are described in 2.6.3.1.

2.2 DATA COLLECTION SYSTEM

2.2.1 REQUIREMENTS FOR A DATA COLLECTION SYSTEM

The urgent need for automated data collection became evident after an estimation of the amount of data to be collected. It was planned to test about 2500 children, each for one school-day (5-6 hours), administering about eight tests with approximately 50 questions per test. Each child would answer about 400 multiple-choice question, therefore 2500 children would produce approximately one million answers.

If these answers were given on paper and pencil tests, the data would have to be coded on coding sheets, punched on punch cards and then read into a computer. At least two people would have to be employed to transfer these data. Apart from the cost of personnel, the reliability of the data would be problematic.

A further problem with the use of paper and pencil tests is the way of marking correct answers. The most reliable way is to let the test person mark the right answer directly into the test booklet, where each question is followed by a set of possible answers. A further disadvantage of this method, besides the data processing difficulties already mentioned, is an extremely high paper demand (for this study an estimated 250 000 pages). The use of test booklets in combination with additional answer sheets on which the correct answers have to be marked, allows for the repeated use of the test booklets, but leads to transfer mistakes. It is possible that a test subject can miss an answer and continue to mark in the wrong line or column.

The envisaged automated data collection system should register the answers of the test persons with a minimum of transfer errors and guarantee a reliable and easy transfer of the data to a mainframe computer for final evaluation. Electronic registration of the answers could also allow for the collection of additional information, such as the time between answers for each individual.

Automated data collection will in some cases lead to slightly different results from a paper and pencil test. Some children might be more motivated by the new and unusual situation (Roethlisberger and Dickson, 1939) whilst some might work less carefully because they only press a key and cannot see the answer "really" written down. These effects do not reduce the validity of the experiment as long as the scheme of automated data collection is kept constant throughout the experiment.

To select the system most suitable in performance and cost it was decided to:

- define a list of the essential and the desirable performance requirements of the system;
- conduct a pilot study to prove that automated data collection is suitable for use with children; and
- compare existing data collection systems and the possibilities of systems tailor-made by electronic companies and workshops with that list.

Discussions with psychologists at several universities and research institutions confirmed that most of the performance

tests available and suitable for this study were of the multiple-choice type, and that it would be acceptable to restrict the data collection system to multiple-choice-type input. This restriction would allow the use of more simple and less costly systems, that could still be used as flexible testing tools for a multitude of psychological applications in various languages. After consultation with electronic experts about technical possibilities and costs, the following performance requirements for the data collection system were defined:

- it must be possible to record the test results of a whole school class (about 40 children) at the same time, with each child working at its own pace. All answers of all children must be accessible one by one at a later stage of data analysis;
- to enter answers with a minimum of transfer mistakes, each child must be informed continuously about the number of the question to be answered;
- central control of the individual work stations was necessary, for example to reset the work stations after a test and to determine their mode of reaction to a test person's input via a central processor;
- the control software of the system should be written in a common high-level programming language such as BASIC, PASCAL or C, the source code should be supplied with the system, and the vendor should guarantee that no copyright problems would arise from any modification of the original software.
- the system must work reliably in thermal environments between 10 and 40 degrees Celsius. It should be easy for the person conducting the experiment to diagnose

and repair simple and common faults in the system. All components and spare parts as well as qualified service should be locally available;

- it would be desirable if the system could record the time intervals between key presses for each child. It would be valuable to determine whether response time (which includes such aspects of behaviour as response delay) is temperature sensitive. A knowledge of response times during the development of the test battery was also expected to help the refinement of the test material, for example unusually long answer times could indicate that the question has not been understood clearly or that it is not appropriate for a certain education level;
- the system should give an immediate indication of the behaviour of the children to the person conducting the experiment, e.g if a child answers no questions at all for a long time. This would indicate whether the children understand the test, the special way of answering and whether they are willing to answer;
- the part of the system visible to the children should be as small as possible. They should not be confused by too much visible technical equipment such as electronic control boards, lights or cable-trees; and
- it would be a desirable additional feature of the system if it were able to monitor the temperature at each workstation.

2.2.2 INVESTIGATION OF ALTERNATIVE DATA COLLECTION SYSTEMS

2.2.2.1 FEASIBILITY STUDY

To prove that the concept of automated collection of performance data can be applied to children, a test system consisting of two boxes was constructed. One box was similar to the final answer box shown in Figure 2.2-2, with five answer keys and a digital counter which increased by one whenever a key was pressed. The second box was connected to the first via a cable and had five light-emitting diodes (LED's) mounted in its casing. When an answer key was pressed, the corresponding LED lit up on the second box, so that an observer, removed from the respondent, could see which key was pressed. The test system was battery-driven and had no data storage capabilities.

Eight black Grade 2 children at the J J de Jong lower primary school in Atteridgeville performed a small test battery of 4 tests:

- Mathematics;
- Comparison of images;
- Spatial Perception; and
- Logical Reasoning.

Each test consisted of ten items. None of the children had any problem in understanding the explanation of the data collection system, and it took only a few seconds until they could use the answer box. The responses of the children were timed by the observer with a stop watch.



Figure 2.2-1: Children working with answer boxes of the ADCS.

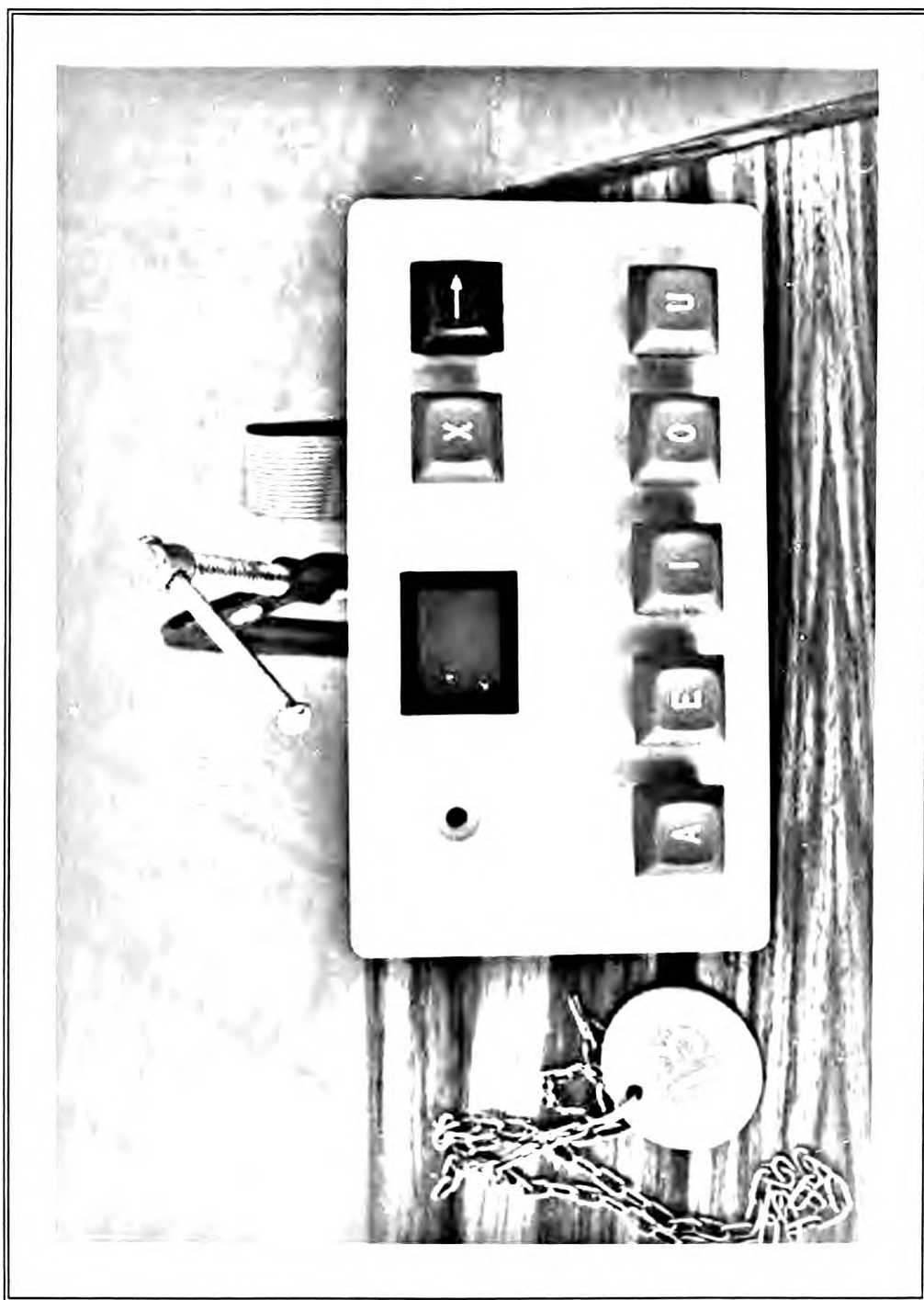


Figure 2.2-2: Answer box of the ADCS clamped onto a desk and an ID-disk.

Direct observation also gave clues for the construction of the final system. Several children held their forefinger in a waiting position over the answer box while searching for the right key. As the labels identifying the keys had been positioned below the corresponding keys, the children tended to obscure their view with their own fingers. It therefore became clear that the labels had to be etched onto the answer keys.

Black teachers pointed out that the Zulu language does not use the letter "C", and our labels "A","B","C","D", and "E" for the answer keys could therefore cause problems for some children. We were assured that the use of the vowels would be acceptable.

It was observed that the children answered the questions one by one, paying little attention to the digital counter of the answer box. Although none of them got out of step by answering a question twice or by omitting one, this indicated a potential problem. Over all, the feasibility study provided strong encouragement to continue the search for an automated data collection system.

2.2.2.2 COMPARISON OF PRODUCTS AVAILABLE

After searches through the relevant literature, attendance at trade fairs for educational equipment and discussions with electronic manufacturers, two viable solutions were identified.

A) The HÜTTINGER Responder System

The system is produced by HÜTTINGER Training Systems, Nürnberg, West Germany. It has been designed for multiple-choice testing. The vendor claimed at an educational exhibition in Johannesburg that the system had been used successfully by a number of leading companies in West Germany.

The system included 20 answer boxes that allow the input of multiple-choice questions with four alternatives. Before answering any question, the identification code of this question has to be keyed in by the test person on a numeric keypad. All test persons can work independently at their individual speed.

The electronic signals of the answer boxes are decoded in a communication interface. Evaluation of the answers is possible on an Apple II computer, which is part of the system. Results are stored on 5 1/4-inch magnetic diskettes.

The advantage of the system was the fact that it was a tried and proven product. The disadvantages were:

- its price (R 96 000);
- the vendor did not want to provide the source code of the software and adaptations would have to be done via Germany;
- because it would have been the first system of its kind in South Africa, service and maintenance could have been a problem;

- times between answers could not be measured;
- extension of the system to 40 answer boxes would have required costly modification;
- entering the question code before each question might have been confusing for the smaller children; and
- no extensions for temperature measurements would have been possible.

B) The NEERI system

The outline of this system was developed in co-operation with Mr. P. Kühn of the National Electrical Engineering Research Institute (NEERI) of the CSIR.

The advantage of this solution was the fact that it would be designed according to our demands and would therefore fulfill all our specifications. The price of R 30 000 was very competitive with alternative A.

Its disadvantage was the fact that it existed only in the form of a draft. Its real performance characteristics and its reliability would only become apparent long after the decision to buy had been made. The disadvantage was reduced by the fact that NEERI had a good reputation for its work and that a six months warranty was offered.

After careful consideration alternative B was chosen.

2.2.3 DESCRIPTION OF THE AUTOMATED DATA COLLECTION SYSTEM (ADCS)

2.2.3.1 OVERALL SYSTEM CONFIGURATION

Figure 2.2-1 shows children in typical interaction with the ADCS. The digital counters on their boxes tell them which question to answer. They study this question in their test booklet, select one of the multiple-choice answers and press the corresponding key.

The system has 40 answer boxes (Figure 2.2-2), thus allowing 40 children to work independently at their own pace. Their key responses and the time elapsed between two responses is registered. The boxes can measure unprepared response time (the time elapsed between a visual signal shown at the digital counter and the first key press) and both dry bulb and finger temperature.

The boxes are connected to the communication interface via a network of 16 core flat band cables. The cables are long enough to allow the boxes to be distributed throughout a large-sized classroom. The communication interface mediates the data transfer from the answer boxes to a SHARP MZ-80B microcomputer. The data-collection process is controlled via software within the MZ-80B. The software is written in compiled BASIC. Test results are stored on 5 1/4-inch magnetic disks, from where they can later be transferred to a mainframe computer for the final evaluation. A schematic drawing shows the arrangement in Figure 2.2-3.

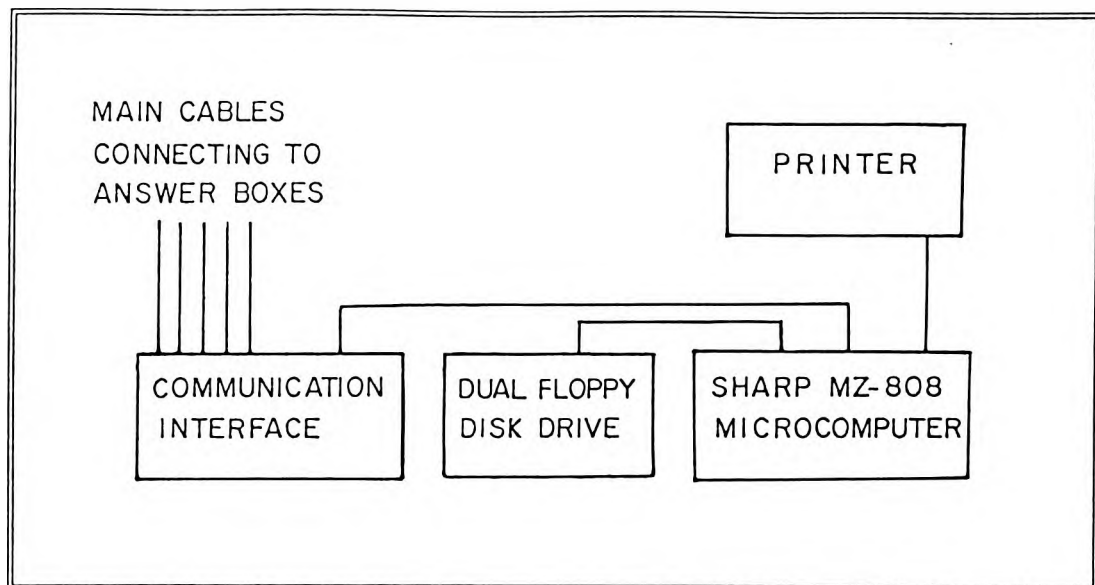


Figure 2.2-3: Schematic drawing of the ADCS system

2.2.3.2 ANSWER BOXES

The answer boxes, as shown in Figure 2.2-2, are mounted in 154mm x 84mm x 38mm plastic containers with a white top and grey bottom. Each box has a two-digit liquid crystal display (LCD). This is used to show the test person which question has to be answered next. Five red keys, labelled A, E, I, O and U, make provision for entering the answer to a multiple-choice question. Two special function keys are placed to the right of the LCD display. The black key with the arrow to the right allows for the omission of a question. The red key with the "X" serves as a control to avoid children getting out of step. This function is described under 2.2.4.1.

The indentation in the box cover on the left of the digital counter contains a temperature sensor (type National LM 335), which can measure either the air temperature at the work place of the test person, or his finger temperature, when he is instructed to press a finger onto the recess.

A 1.5 m long 16-core flat cable links the box to the main cable. Details of the cable system are discussed under 2.2.4.2. To communicate with a box, the computer sends an address over the communication interface to all boxes. Just after that, when the signal is steady, it sends an address latch pulse. Each box then compares whether the address sent is equal to the address set within each box on an 8 bit DIP switch. In the box where this is the case, a dual RS latch is set, which puts the box into the "addressed" mode. All other boxes are set to the "unaddressed" mode. When a read pulse is sent by the computer, the addressed box will make the content of its internal buffer available on the electronic bus, to be read by the computer. In addition, the analog signal of the temperature sensor is made available to the A/D card in the communication interface. When a write pulse is sent by the computer, the two LCD display drivers (for the two-digit display) will be latched, so that the data sent by the computer after the write pulse will update the display of the box.

The temperature sensor has an output of $10 \text{ mV} \cdot ^\circ\text{C}^{-1}$. Each box has an amplifier to transform this voltage to an output signal between 0 and +5 V. This signal is then sent via the cable system to the communication interface. Two potentiometers in each box are used for calibration of temperature readings. A range of temperatures between 5 and 46°C can be measured.

2.2.3.3 COMMUNICATION INTERFACE

The communication interface is housed in a 420 x 298 x 130 mm aluminium casing. It has input connectors for ten main cables and communicates with the MZ-80B via two 16-bit parallel ports. The communication interface contains the following units:

- a buffer card. The card buffers signals from the answer boxes to the microcomputer (one buffer) and signals from the microcomputer to the answer boxes (2 high-speed CMOS buffers). Pull-up resistors help with the interfacing between TTL and CMOS circuits;

- a 4-channel, 8-bit fast counter card.

Counters: 3*8 bit with 10 ms resolution
 1*8 bit with 10 ms resolution
Clock: crystal oscillator, 1 MHz
Power requirements: 12 ± 2.4 V at 10 mA
 (on board power supply +5 V);

- a 16-channel A/D card.

Type: Intersil DAS 952-R
Resolution: 8 bits
Conversion time: 64 microseconds
Full scale input: 0 to +5 V
Power requirements: 12 ± 2.4 V at 20 mA
 (on board power supply: +5 V);

- a power supply

Input: 230 ± 23 V, 50 Hz
Output: 12 V (for the electronic cards)
 5 V (for the answer boxes)

2.2.3.4 SHARP MZ-80B MICROCOMPUTER SYSTEM

The microcomputer system controls the function of the answer boxes and stores the results. The system consists of:

- an MZ-80B microcomputer including a Z80A processor with 4 MHz clock frequency, 64 kByte memory, a keyboard and an 8-inch screen;
- a dual magnetic disk drive with 329 kByte storage capacity per disk;
- a dot matrix printer used for the output of preliminary results on site;
- two universal 16-bit input/output cards used to connect the MZ-80B with the communication interface; and
- an RS-232 interface used to connect the MZ-80B with the telecontrol unit.

2.2.3.5 TELECONTROL UNIT

To allow for control of the experiment in case the electronic equipment has to be located outside the classroom, a SHARP PC-1500 acts as an intelligent remote terminal. It is connected to the MZ-80B via an RS-232 cable link. The PC-1500 together with the attached RS-232 interface measures 350 x 90 x 20 mm and is therefore easily carried. The PC-1500 has an 8-bit CPU (CMOS), 16 kByte ROM, 4

ROM, 4 kByte non-volatile RAM, an RS-232 and a printer interface, and a 35-digit mini-display.

2.2.3.6 INITIAL NEERI SOFTWARE

It was not possible to determine the optimal way of operation for the ADCS in the planning stage of the project. Only field experience could show how to improve on the initial concept. Therefore it was decided that NEERI should develop an initial software package that made all the hardware functions of the system available and allowed the researchers to start practical work. For all software the source code was supplied, so that the researchers could make changes and adaptations to new demands. This concept worked well and can be recommended for similar projects. The initial NEERI package performed the following basic functions:

- it scanned all boxes for answers and recorded answers and response times;
- it measured simple unprepared response times by addressing the boxes one by one to allow a higher time resolution for the measurement;
- it measured the temperatures of all box sensors; and
- it saved results from computer memory onto magnetic disks.

2.2.4 PILOT STUDIES, MODIFICATIONS AND ADDITIONAL DEVELOPMENTS

2.2.4.1 PRELIMINARY TESTS OF THE NEW SYSTEM

After completion of the system, tests were performed with children of colleagues at the NBRI. This revealed a fault in the electronic design of the system. When a message was sent from the control unit to a box, the control unit first sent the address of the box and then the data containing the message. The delay between address and data was too short, so that an addressed box sometimes read its own address as data. This fault was repaired by the NEERI.

2.2.4.2 CHILDREN GETTING OUT OF STEP

Pilot studies at the J J de Jong lower primary school and the Meyerspark primary school showed that children sometimes pressed an answer key twice for one answer. In other cases they forgot to answer a question and continued with the next question. Many children tended to pay little attention to the digital counter on their boxes that indicated the number of the question to be answered. Often they simply continued to key in answers without noticing that the answer for question N was registered as the answer to question N-1 or N+1. This invalidated the remainder of the child's answers to a test.

Double key presses

Observation showed that some children pressed the answer key a second time, when they had the impression that they did not press it hard enough the first time. They just wanted to "make sure". This second key-press usually occurred shortly after the first one. The control software was changed in such a way as to ignore any signals from a box for 0.3 seconds after a valid key press. This measure eliminated most errors caused by this particular behaviour, but children who answered a question for the second time after a few seconds (e.g. due to lack of concentration) or who omitted a question still got out of step.

X-key versus splitting tests into blocks

To improve the reliability of the results, two solutions were discussed:

- A) the questions of a test are grouped into blocks of about ten questions, resulting in about four to eight blocks per test. The question numbers for each block start with number one. The children work through the test block by block. When one block has been completed by all children, or when sufficient time for its completion has elapsed, the counters on the answer boxes are reset and work on the next block begins. The effects of getting out of step are thus restricted to the block in which the mistake was made;

B) at the end of each page of a test a dummy question is inserted, in which the children are requested to press a special key on the answer box, marked with the letter "X". As the question numbers of the X-questions can be supplied to the control software, it is possible to detect whether a child is out of step, i.e. if he enters a real answer to an X-question or vice versa.

Solution A did not require any changes on the answer boxes, but it was suspected that the continued interruption of the children's work would prolong the experiment and possibly distort the results. The scores might depend to a large extent on the ability to cope with continuous interruption.

Solution B promised less interference with the test procedure. It was therefore chosen, but it required a small hardware modification.

Implementation of the X-key

In addition to five red answer keys, the boxes originally had two black keys in the upper right-hand corner: one labelled with an arrow pointing towards the right, allowing the children to omit a question, and another labelled with an arrow pointing towards the left. The second key allowed the children to return to the previous question and re-enter that answer. It was hardly ever used by the children in the pilot studies and could therefore be changed to the X-key without losing an important function of the answer box. The key was painted red, the colour of the other answer keys,

and marked with an "X". Figure 2.2-2 shows one of the modified boxes. A schematic drawing is given in Figure 2.2-4.

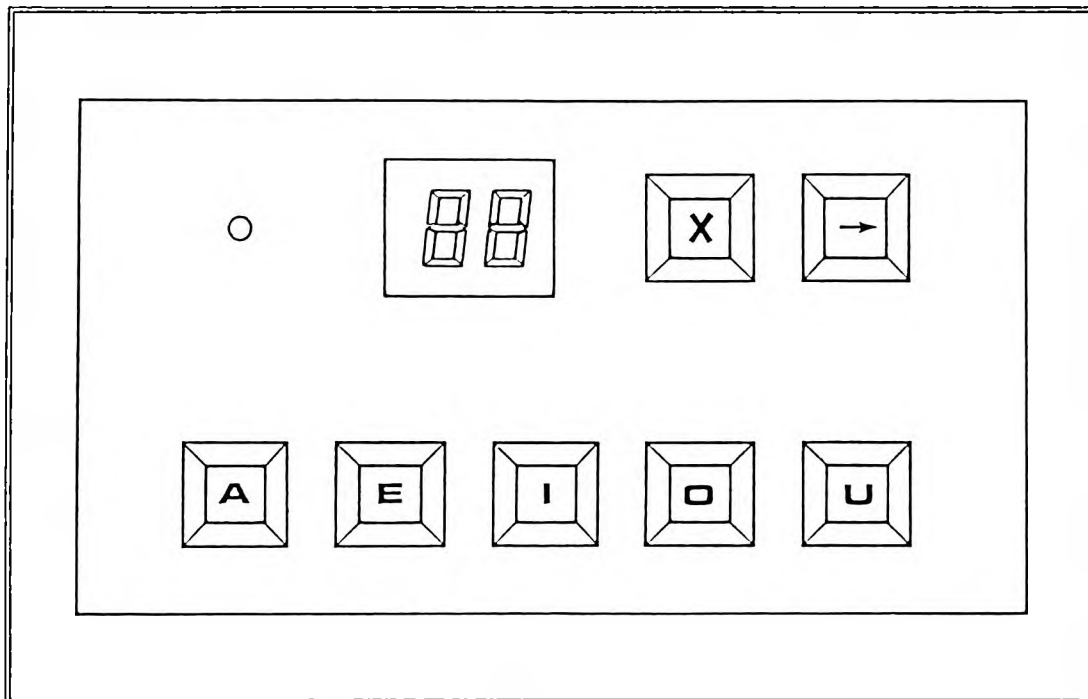


Figure 2.2-4: Drawing of the front panel of an ADCS answer box.

On the program disk a control data file was installed for each educational level. This contained the positions of all the X-questions for all tests. The control software was modified to prompt the experimenter to enter the educational standard when starting up the program, and to read the appropriate control data file. Before a test could be executed, the program asked for the name of the test to be performed. The data contained in the control data file determined the function of the boxes. This is described in detail in 2.2.4.6. An example of a control data file is given in Appendix B. When a child was detected as out of

step, the system blocked the box of the child and signalled a warning to the experimenter.

Feedback to experimenters via microcomputer screen

It was decided to keep the control system inside the classroom, and to use the screen of the microcomputer to provide information about children who were out of step. In earlier pilot studies the electronic equipment was placed on the teacher's desk at the front of the classroom. As the children were used to paying attention to things happening around the teacher's desk, and as they were curious about the computer, they often stopped working to observe the experimenter working with the equipment. Because of this, a hand-held telecontrol unit was developed, permitting the control equipment to be left in the mobile climate chamber and the experiment to be conducted from within the classroom. Later studies showed that the children hardly took any notice of the equipment when it was placed at the back of the classroom. The telecontrol unit was then abandoned, and the system kept in the classroom in order to take advantage of the microcomputer screen, which could provide much more detailed information about the state of the experiment than the small 40-digit display of the telecontrol unit. Figure 2.2-5 shows an example of the microcomputer screen, indicating that the children with boxes number 28 and 30 were out of step and that the children with boxes number 11 and 36 had not responded for more than 90 seconds.

SCHOOL PROJECT *** MODE =					P R A C T I C E				
TEST: MEMORY		WORKING: 33		ROOM TEMP: 17.9		RUNTIME = 1.7			

	11						28		30
					36				

.....

F1 = KILL Q F2 = MAIN Q F3 = INTER Q F5 = ROOM TEMP F7 = STORE Q

Figure 2.2-5: Drawing of ADCS microcomputer screen (questionnaire mode).

Additional feedback via flashing counters

During the training stage of a test, the experimenters spent most of their time in the aisles between the children's desks, giving explanations or watching out for children who needed help. Although the control computer screen proved very useful in gaining an overview of the situation and in locating children who needed help, returning to it at short intervals to get new information proved tiresome. Furthermore, as children often neglected the counter on their box (the initial cause of getting out of step) they often overlooked the fact that their box was blocked.

Both problems were overcome when the control software was altered to make the counters of blocked answer boxes flash at a rate of about 1 Hz, providing a sufficiently strong signal to be detected by the children as well as the experimenters. The boxes functioned completely independently of each other, and any number of counters could be flashing at the same time.

Description of the resulting procedure

If a child pressed the X-key when a normal answer (A to U) was expected by the system (this happened when he missed a question and continued working), the answer box stopped functioning, the counter of this box started flashing with a frequency of about 1 Hertz, and a warning flag was set on the screen of the control computer. A drawing of a screen displaying some warnings is shown in Figure 2.2-5. The system reacted in a similar way if a child pressed a normal answer key when the X-key was expected (this happened if a child answered a question twice and continued working).

The experimenter could easily detect a child who was out of step by looking at the control computer, by observing the answer boxes (the flashing signal was very prominent), or by waiting until a child indicated via a hand signal that there was a problem.

If a child was detected as out of step, the experimenter explained the importance of watching the digital counter and of answering each question only once. The answer box was

then unlocked by pressing a sequence of keys known only to the experimenter, and the child could continue working. The event was noted automatically on the result file and could later be taken into account when the results were evaluated.

Modification of test booklets and explanatory films

All test booklets were reprinted. The items were rearranged and renumbered, so that the last item on each page was a request to press the X-key (see 2.4). The explanatory films had to be re-produced, incorporating the X-keys. Special emphasis was given to explaining the X-key concept in the film about the Personal Questionnaire, the first to be shown on an experimental day.

Further improvements

After pilot tests, the following improvements were added:

- modified reaction of the control software after resetting. Initially the counter of an answer box returned to the number of the first question on the page on which the mistake had occurred and the child had to answer the whole page again. This proved to be a source of frustration for the children. The control software was changed so that the counter did not decrease after resetting. The child could continue

after re-entering the answer that had led to the blocking of the box;

- key delay deactivated for X-keys. Some children pressed the X-key immediately after the key for the last answer on the page. The X-key was then ignored because of the minimum delay of 0.3 seconds introduced to counteract double key presses. This led to confusion. The problem was overcome by making the delay conditional, so that it did not occur when an X-key was pressed after a non-X-key; and
- different handling of children resetting their blocked box themselves. A blocked answer box could be reset by entering the key-sequence: X-key, forward-key, forward-key, X-key, while leaving not less than 0.3 seconds and not more than 1 second between the key-presses. Intelligent children did not take long to find this out by watching the experimenters. During the first pilot studies an effort was made to discourage the children from doing so, but it was found that children intelligent enough to reset their boxes usually understood why they had been blocked in the first place and did not need any instructions. This behaviour was then tolerated.

The measures introduced to counteract the problem of children getting out of step proved to be successful.

2.2.4.3 RELIABILITY PROBLEMS WITH THE CABLE SYSTEM

During the pilot tests and the first full experiments an increasing number of reliability problems occurred, when all answer boxes stopped reacting to any input. Sometimes it was possible to counteract the problem by restarting the system, sometimes by bending the cables that connected the answer boxes with the control unit. This suggested a fault either in the cables or the connectors.

Two simple arrangements of cables and connectors were devised to test the reliability of a cable with one measurement. The first consisted of two connectors which had to be joined to appropriate connectors on a cable. One of the connectors provided a cable link to a digital voltmeter. The pins on the test-connectors were joined in such a way that all cores of the flat band cable were linked in series. It was thus possible to detect with one measurement if any core was broken or did not make proper contact with a connector. The second arrangement consisted of a single connector which linked all odd and all even cores, so that if any of the neighbouring cores were short-circuited they could be detected with a single measurement.

No short-circuits in the cables were detected, but 25% to 30% of the connectors made improper contact with the cable when the cable was bent or twisted. Dissection of some cables showed that the outermost cores of the flat band cables were often damaged by mechanical strain. Staff from NEERI confirmed that such improper contact could cause the processor in the control unit to cease functioning. The solution was obviously a redesign of the cable system. Possible improvements were:

- A) a total rebuilding of the cable system using round cables that could handle mechanical strain much better than flat band cables. More rugged connectors with bayonet mount were also discussed; and
- B) rebuilding the existing flat band cable system to achieve maximal reliability.

Alternative A guaranteed success, but terminating round cable with proper strain relief on the circuit boards inside the answer boxes was very labour intensive. For that reason flat band cables had been chosen in the first place. In addition, the cost to fit the ADCS with significantly more reliable and rugged connectors (Military Standard) exceeded the budget constraints. Therefore alternative B was chosen.

Figure 2.2-6 shows the initial cable system. It caused problems because:

- the functioning of the whole system depended on a single main cable, which connected the control unit to the branch cables;
- the cables lay exposed on the floor. Reminding the children not to step on the cables proved fruitless. The main cable was especially exposed; and
- when the children moved their feet while sitting, they sometimes caught one of the tangling box cables and overextended it.

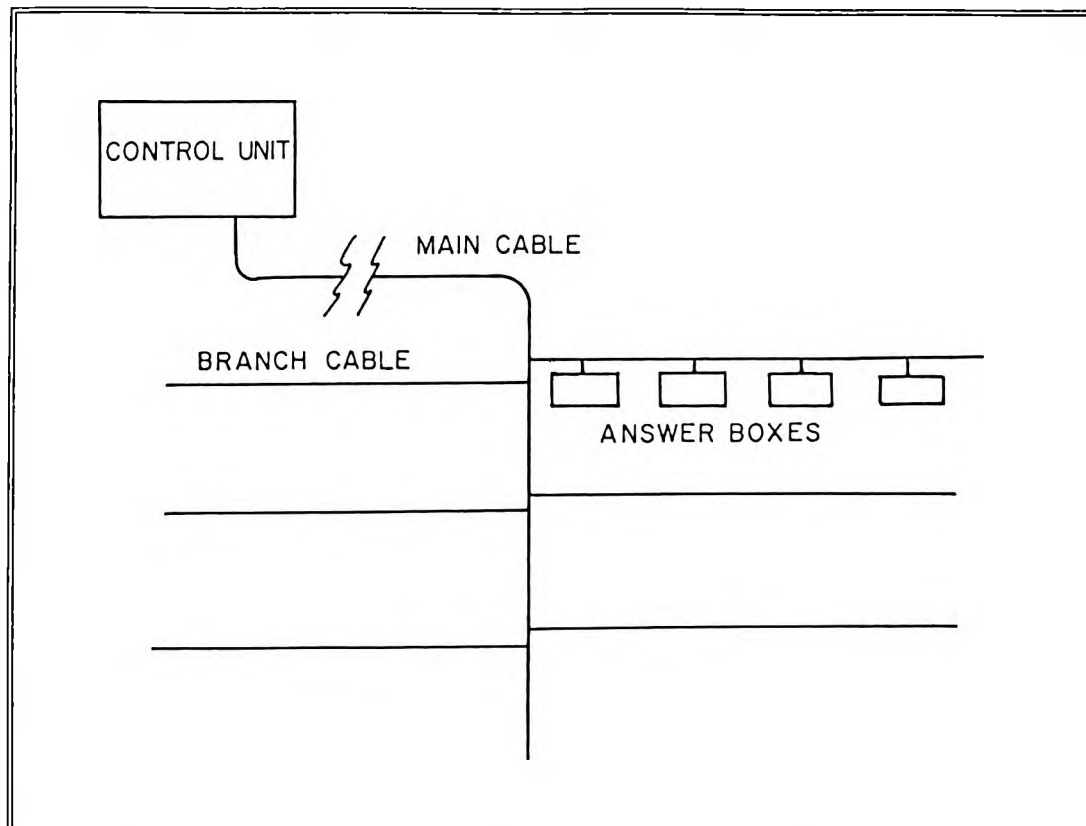


Figure 2.2-6: Initial cable system of the ADCS.

Part of the solution was a new arrangement for the cables, which is shown in Figure 2.2-7. A modification of the control unit allowed up to ten main cables to be connected. The answer boxes connected directly to one of the new main cables. This arrangement reduced the number of connections between a box and the control unit from three to two. The new main cables were interchangeable so that sufficient backup was available if one should break. Furthermore it was easy to identify the source of an error by disconnecting and reconnecting the main cables in a systematic manner.

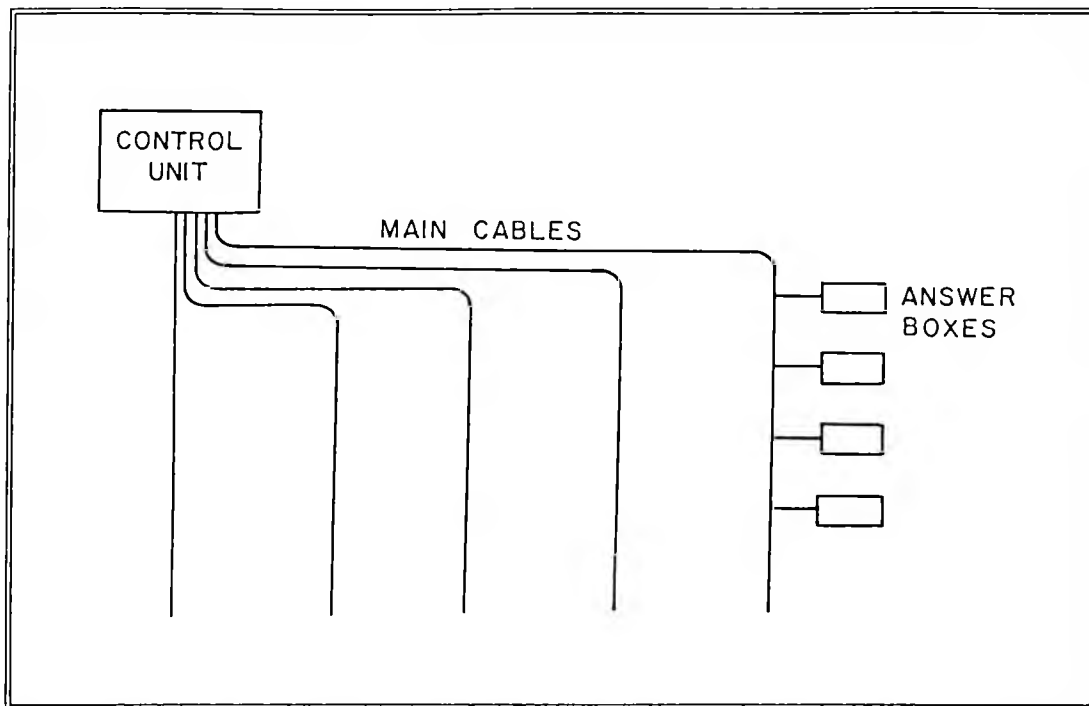


Figure 2.2-7: Improved cable system of the ADCS.

To protect cables and connectors, plastic cable ducts 42mm x 42mm square and 1.5 meter long were laid between the rows of desks in the classroom. Metal tongues were mounted on the ducts to facilitate a stable connection (see Figure 2.2-8). The ducts were covered with lids.

The new main cables were made of two parts: the first eight meter from the control unit consisted of rugged round cable that was resistant to mechanical strain; and the rest of the cable, also eight meters long, consisted of flat band cable with a crimp-on connector every 0.7 m. The cables from the rear of the answer boxes were tied to the legs of the children's desks, using rubber bands held by small metal hooks ("C"-shaped, approximately 15 mm long).

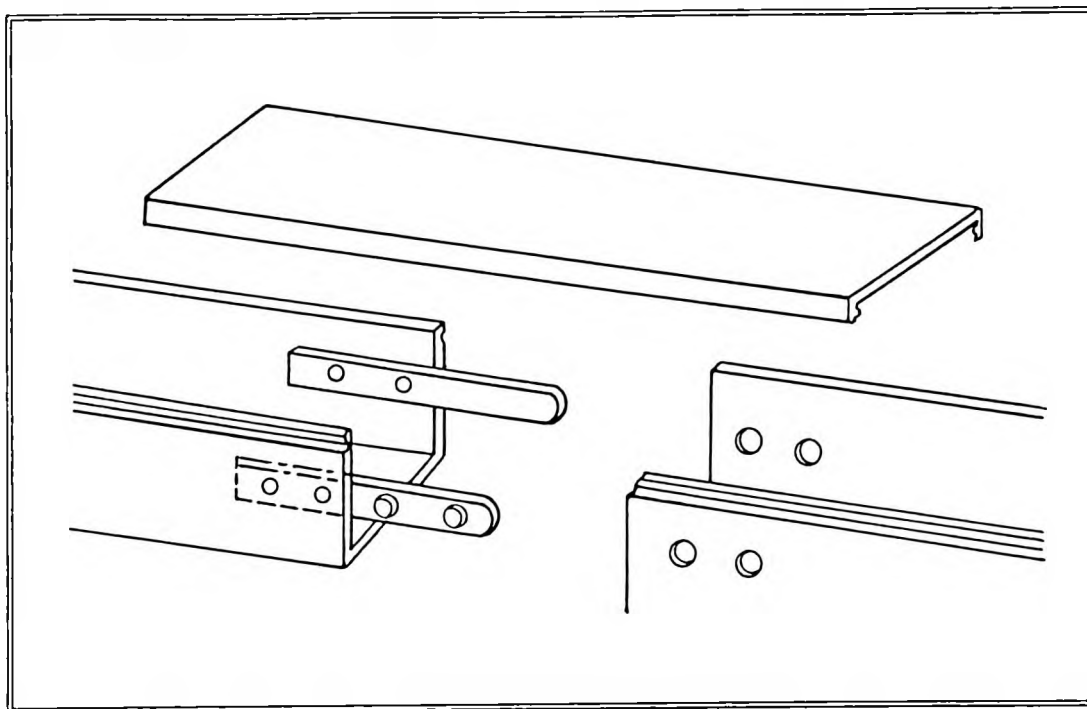


Figure 2.2-8: Connection between cable ducts of the ADCS.

Figure 2.2-9 shows an installation of the system in a classroom.

2.2.4.4 READABILITY OF THE COUNTER

Unsuitable viewing angle

The Liquid Crystal Displays (LCD's) in the answer boxes were easily read when viewed at a right angle to the display's surface, but when viewed at an oblique angle, the clarity of the digits decreased.



Figure 2.2-9: ADCS answer boxes installed in a classroom.

If the children placed their answer box close by, they could read the counter well, but the position of the box conflicted with that of the answer booklet. If they put their answer box at the edge of their desk they could hardly read the counter. Sometimes the box was accidentally pushed over the edge of the desk and fell on the floor - with detrimental effects on the electronics.

These problems were overcome by mounting the answer boxes on wedge-shaped wooden blocks. At an incline of about 30 degrees the digital counters could be read clearly when a box was positioned at the end of a child's desk. The wooden wedges were rubber-coated underneath to prevent the box from slipping. In addition, a recess in the vertical side of the wedge allowed the box to be fixed to the desk with a metal screw-on clamp. This kept the boxes in a standard position. Figure 2.2-9 shows the wooden wedges, the metal clamp can be seen in Figure 2.2-2.

2.2.4.5 TRANSPORT AND OVERHEATING PROBLEMS

Transport container

The elements of the control system, for example communication interface, printer and disk drive, had to be connected at every test site. This was time consuming and also detrimental to the electronic equipment.

An aluminium container, approximately 1.5m x 0.8m x 0.4m in size, was made to accommodate the control system. The container was equipped with metal brackets to hold the elements, which could then remain connected in the appropriate way. Figure 2.2-10 shows the control system mounted in the aluminium container; only the printer, disk drive and microcomputer are visible. The communication interface is located under the printer. To set up the control system in a classroom required only the connection of the main cables and the power cables. This is illustrated in Figure 2.2-11.

Cooling system

During failures of the ADCS, temperatures greater than 60°C were measured in the microcomputer. Although this may not have been the only cause of breakdown a cooling system was developed.

The cooling system is based on a central fan which blows air into four plastic ducts (diameter approximately 20 mm) and distributes the air to the electronic units. The units in danger of overheating are fitted with air-inlet flanges and additional holes in the casings to serve as exits for the hot air. The cooling system was fitted into the aluminium container as a permanent fixture.



Figure 2.2-10: Control system of the ADCS mounted in an aluminium container.



Figure 2.2-11: ADCS control system and cable connections in a classroom.

2.2.4.6 CONTROL SOFTWARE

The control software delivered with the hardware of the ADCS by NEERI was only intended as a basis for further development. Besides the changes described under 2.2.4.1 to 2.2.4.5, further additions were made to the control software to improve the functionality and reliability of the system. The user interface was menu driven and Figure 2.2-12 gives an overview of the options from the main menu. Figure 2.2-13 shows a flow diagram for working with "questionnaires", a name which is in this context used for the Personal Questionnaire as well as for all multiple-choice-type tests. Details about the operation of the program which are not evident from the flow diagrams in Figures 2.2-12 and 2.2-13 are given below under the following headings:

- initialisation of the ADCS;
- options from the main menu;
- questionnaire;
- reaction time tests; and
- data storage.

Initialisation of the ADCS

At the beginning of each experimental day the ADCS was switched on and the control program had to be initialised to function appropriately for the experiment. Figure 2.2-14 shows the messages on the computer screen during an initialisation dialogue with the following steps:

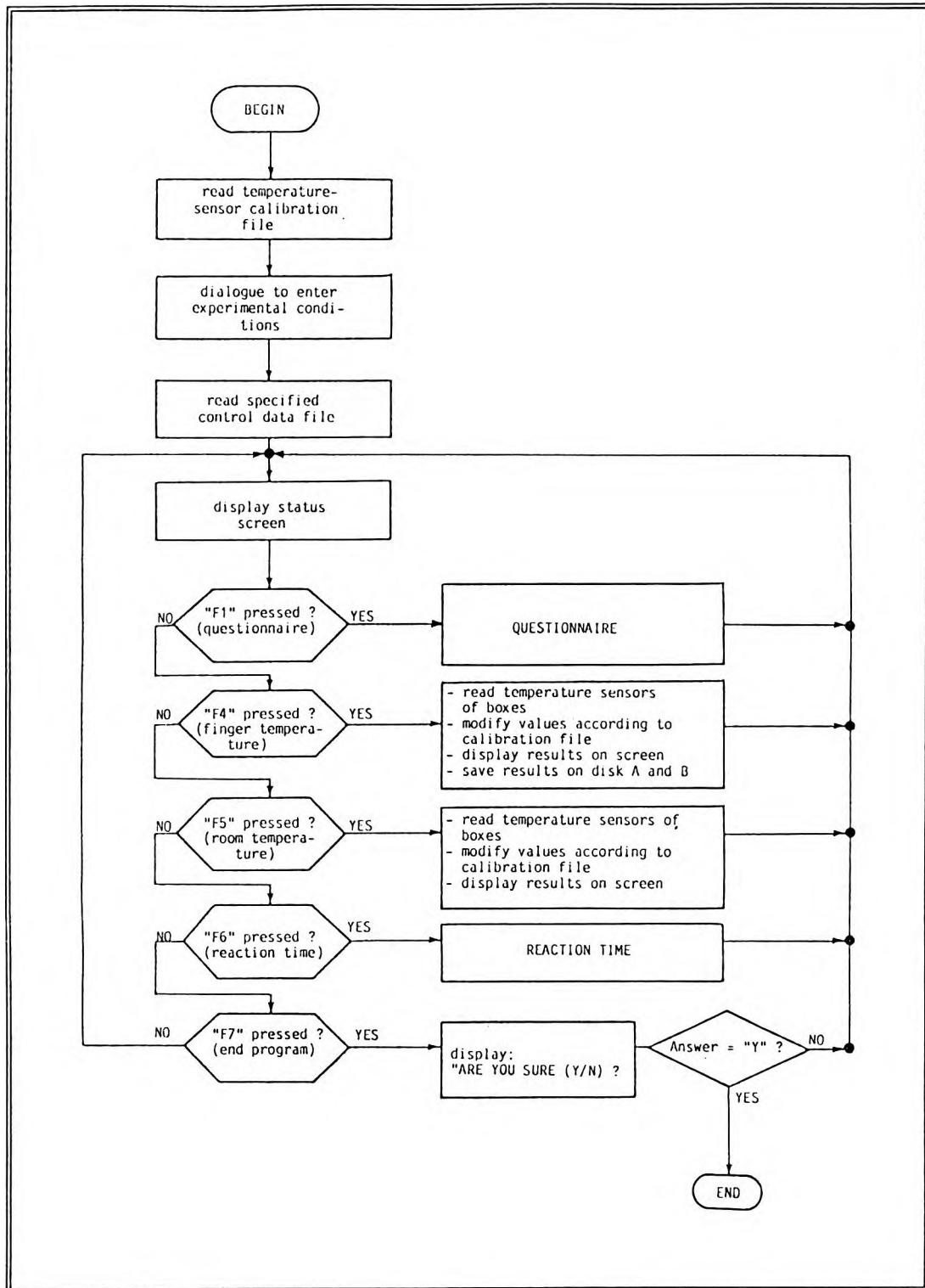


Figure 2.2-12: Flow diagram of operations from the ADCS main menu.

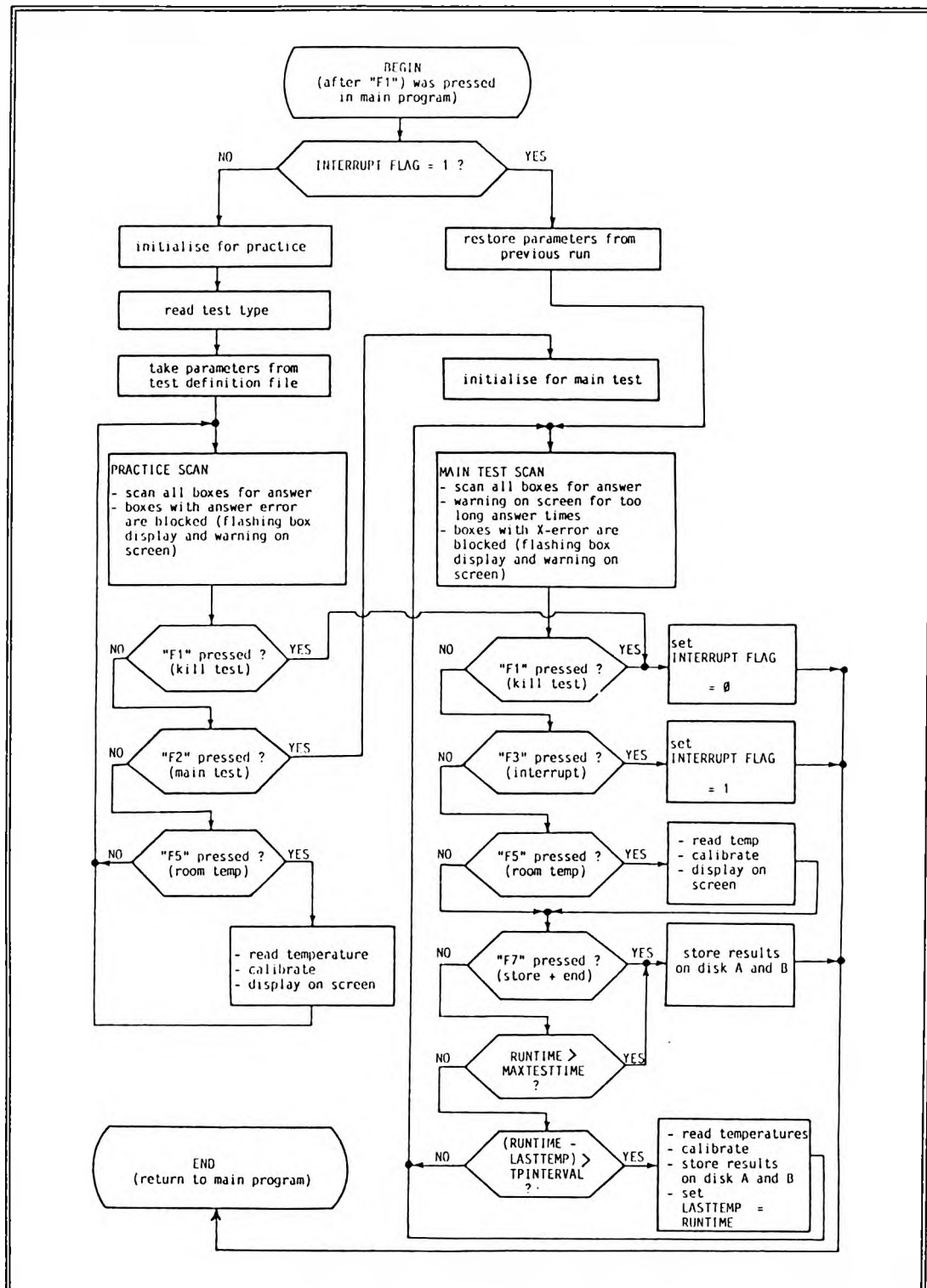


Figure 2.2-13: Flow diagram of operations from the ADCS "questionnaire" menu.

- the control program with the name SCHOOL is called;
- the experimenter can choose to add data to an already existing data set, or if data collection should start anew, to create a new result file;
- school name, experimental code and date are entered to label the test data;
- the number of children tested varies in the experiments and faulty boxes are not connected to the system. To allow the system to report the number of children who have not yet completed their test, the identity numbers of all boxes in operation have to be defined. All answer boxes have identity numbers between 1 and 40. The highest identity number of all connected boxes has to be entered. Then all boxes with identity numbers smaller than the given highest number have to be identified;
- the behaviour of the control program is largely defined by control data files that are resident on the diskette containing the control program. By choosing an education level, the experimenter selects one of the three control data files used in the main part of this experimental series. The control data files allow one to define:
 - the number of questionnaires (maximum of 15);
 - the names of the questionnaires;
 - the number of questions in the practice part of each questionnaire (maximum of eight);
 - the correct answers to practice questions (optional);
 - the number of questions in the main part of each questionnaire (maximum 99);

- the position of all X-questions in each questionnaire;
- a timespan in seconds for each questionnaire. If a child should take longer then this timespan to answer a question, a warning occurs on the display of the control computer;

SCHOOL ↵

NEW DATA DISC (NEW) OR ADD TO OLD ONE (ADD) ? NEW ↵

SCHOOLNAME: GLEN HIGH ↵

EXCODE (eg W6-34T-105): W3-14C-137 ↵

DATE (eg 05/12/83): 16/02/85 ↵

TIME (eg 10:55): 8:15 ↵

HIGHEST BOXNUMBER: 40 ↵

MISSING BOXES ? (GIVE ONE AT A TIME: 0=NO(MORE): 6 ↵

MISSING BOXES ? (GIVE ONE AT A TIME: 0=NO(MORE): 15 ↵

MISSING BOXES ? (GIVE ONE AT A TIME: 0=NO(MORE): 0 ↵

EDUCATION LEVEL (GRD2W, STD3W, STD6W): STD 6W ↵

Figure 2.2-14: ADCS initialisation dialogue.

Control data files can be edited with any word processor that can read or write standard ASCII code. An example of a control data file is shown in Appendix B.

Options from the main menu

After initialisation the main menu appears on the screen, as shown in Figure 2.2-5. It displays the following information, continuously updated, about the status of the experiment:

- MODE: if a questionnaire is selected, the mode is either "practice" or "main". In all other states of operation this field is left blank;
- TEST: shows the type of questionnaire selected (if any);
- WORKING: the number of children still working on a questionnaire. This proved especially useful for developing new tests, as it was easy to see when most children had completed their work;
- ROOM TEMP: average of the measurements of the temperature sensors of all active boxes, updated every 10 minutes; and
- RUNTIME: length of time the present test has been running (either in "practice" or in "main" mode).

The 4 x 10 fields in the middle of the screen give feedback about the actions of the individual children:

- blank field: no message;
- number in normal field: time warning - the child did not enter an answer for longer than a timespan defined in the control data file; and

- number in a highlighted field: box is blocked because the child got out of step.

When room temperatures or finger temperatures are measured, the values are displayed in these fields. Results of the reaction time test are also displayed here. The bottom line displays the options available. They can be selected by pressing function keys labelled from F1 to F10. Figure 2.2-12 shows these options in a flow-diagram. These options are:

F1: QUESTIONNAIRE: discussed in detail below;

F4: FINGER TEMPERATURE: the temperature of all box-sensors is read, displayed on the screen and stored on disk;

F5: ROOM TEMPERATURE: same as finger temperature, but the data are labelled differently in the data set. When a questionnaire is performed, the temperature is read and stored automatically every ten minutes;

F6: REACTION TIME: discussed in detail below; and

F7: END PROGRAM

Questionnaire

Once "questionnaire" has been selected, the answer boxes are reset and the experimenter is prompted to enter the name of the questionnaire. Thereafter the appropriate control data file is read from disk.

The possible operations for questionnaires are shown in a flow diagram in Figure 2.2-13. The system starts the practice session automatically. If correct answers were specified in the control data file, boxes of children giving wrong answers will block and flash. This allows the experimenter to see if the instructions on how to answer the questions have been understood. In practice mode the system allows the following options:

F1: KILL: the questionnaire session is cancelled;

F2: MAIN TEST: when all children have completed their practice, the experimenter informs them that the main test is beginning, and he starts it by pressing F2; and

F5: ROOM TEMPERATURE: same function as in main menu;

Once the main test is started, the options change to:

F1: KILL: the questionnaire session is cancelled;

F3: INTERRUPT: all answers and answer times obtained until now are kept in the computer's memory. The runtime count for the questionnaire is halted, and the main menu is displayed. This option enables the experimenter to deal with unforeseen interruptions, for example long and loud announcements via the schools loudspeaker system. One can also perform operations from the main menu, for example a reaction time test or an additional temperature measurement. When questionnaire is selected again, the system continues from the point where it was interrupted. This option was only used on rare occasions, on which it proved to be very useful;

F5: ROOM TEMPERATURE: as in main menu; and

F7: STORE+END: the questionnaire data are stored automatically, either when all children have completed all the questions, or when the maximum time, defined in the control data file, is reached. In case the automatic procedure has to be overruled, for example if a box breaks and the child cannot complete the work, F7 provides a manual override.

Reaction time tests

For tests of unprepared reaction time the children were instructed to watch the counter of their answer box carefully, and to press a certain key on their box as quickly as possible, when the counter changed. Different types of reaction time tests were investigated, and two types of reaction time tests were selected for the experimental series. The tests are described in detail under 2.5.

In the questionnaire mode all answer boxes were scanned continuously, and to scan all boxes once took 150 milliseconds. This time resolution was not sufficient for the reaction time tests. To improve the time resolution, the way in which the answer boxes were addressed by the control software was changed for the reaction time tests. During such a test an answer box was selected randomly, and the stimulus (a change of the number shown on the box display) was applied to this box only. The system then scanned this box only, until the child had reacted or until a timespan of two seconds had elapsed after the stimulus. The scan rate per box was much faster for a single box than for 40 boxes, allowing for a time resolution of approximately four milliseconds. Thereafter another box was selected randomly and the process was repeated until all boxes had been addressed. One test for a whole class of children usually took less than one minute.

Data storage

Results of a questionnaire were stored automatically when the allowed maximum time (defined in the control data file) had elapsed, when all children had answered all their questions or when the special key F7 was pressed on the control computer's keyboard. Reaction times and temperature measurement were stored immediately after they have been taken.

The data are stored in a compressed format to save disk space, for example the number 1234 would indicate that key 1 (equivalent to button A) has been pressed, and that $2.3 \times 10^{**4}$ milliseconds (equal to 23 seconds) had elapsed since the previous key press. All response times and reaction times were stored in this compressed scientific format with a mantissa of two digits. An "8" in the first position of a compressed format indicates that the child had been out of step, and that the box had been reset at this position. The answer entered previously at this position would have no value and was overwritten.

A dual disk drive was used for the control system computer. All results were saved on both disk drives to ensure data integrity in case of a faulty disk. The source code of the control software is given in Appendix A.

2.2.4.7 CALIBRATION OF TEMPERATURE SENSORS

The temperature sensors had been calibrated by NEERI technicians with a hand-held electronic thermometer. This method was repeated to assess its accuracy.

Hardware calibration

The hardware calibration was performed by adjusting two trim potentiometers in each box. The boxes were open while connected to the control system. According to the technical specifications for the system the offset voltage of the temperature measuring circuit was set by tuning the first potentiometer until the voltage between two defined measuring points on the circuit board of the box was 2.7815 Volt. A Hewlett-Packard digital voltmeter with 4 $\frac{1}{2}$ digits resolution was used for these measurements. Then the temperature of the temperature sensor was measured with another independent temperature measuring system. A THERMOPHIL 4451-3 (Ultraküst Gerätebau GmbH, Ruhmannsfelden, West Germany) was used for all calibrations. The THERMOPHIL was equipped with a sensor to measure surface temperatures. The second potentiometer was adjusted until the temperature displayed on the screen of the control computer was equal to the reading on the THERMOPHIL.

This procedure, even when carefully executed, produced only a relatively low accuracy (± 0.3 C) because heat radiated by the hands affected the temperature of the sensors. As the trim potentiometers had to be adjusted with a screwdriver

moving the hands close to the temperature sensor was unavoidable. Therefore a second calibration step was added to compensate for this shortcoming.

Software calibration

The boxes were put in a controlled thermal environment (NBRI mobile climate chamber) for several hours to ensure thermal equilibrium. The THERMOPHIL contact sensor was connected to a tripod, which was positioned appropriately, so that the contact sensor touched the sensor of an answer box. This ensured that the measurements were not effected by thermal radiation from the experimenter. The difference between the readings of the ADCS and the THERMOPHIL were established for each answer box. The measurements were performed at two temperature conditions: 14 and 34°C.

From the deviations of each box at these temperatures two calibration terms were calculated for each box: one to adjust the zero setting and one to adjust the gain. The calibration terms of all boxes were incorporated in a calibration file which was read by the control program during initialisation. The calibration terms were automatically applied to each temperature reading. The THERMOPHIL has an accuracy of $\pm 0.1^{\circ}\text{C}$. The ADCS uses an 8-bit analog to digital conversion card, and the temperature range for measurements was set between 6 and 42°C . The resolution of the system was therefore:

$$(42-6)/(2^{**}8) = 34/256 = 0.13^{\circ}\text{C}$$

In a follow up test in the climate chamber the readings from the answer boxes differed only by $\pm 0.1^{\circ}\text{C}$ from the readings of the THERMOPHIL. The temperature readings of the ADCS can therefore be treated as accurate to within $\pm 0.2^{\circ}\text{C}$.

Duration of finger temperature readings

When the children were instructed to put the index finger of their preferred hand onto the temperature sensor, the fingers had to be kept in this position until thermal equilibrium was reached. Figure 2.2-15 shows a typical warming-up curve during a finger temperature measurement. Based on such measurements a stabilisation time of one minute was determined to be sufficient.

Accuracy of room temperature readings

Measurement of finger temperatures had been the main reason for building temperature sensors into the answer boxes, but the sensors were also suited to measure temperatures in classrooms. Measurements from all 40 boxes were taken every ten minutes during an experimental day. To convert these measurements into room temperatures the effect of the children's hands had to be taken into account. During each experimental day three finger temperature measurements were performed which heated the sensors above room temperature. After such a measurement the sensor temperature fell within about fifteen minutes to the environmental temperature

level. During most of an experimental day the children interacted with their answer boxes, thereby heating the temperature sensor by radiation from their hands. As was found during the sensor calibrations, this would have increased the temperature of the sensors by up to 0.3°C.

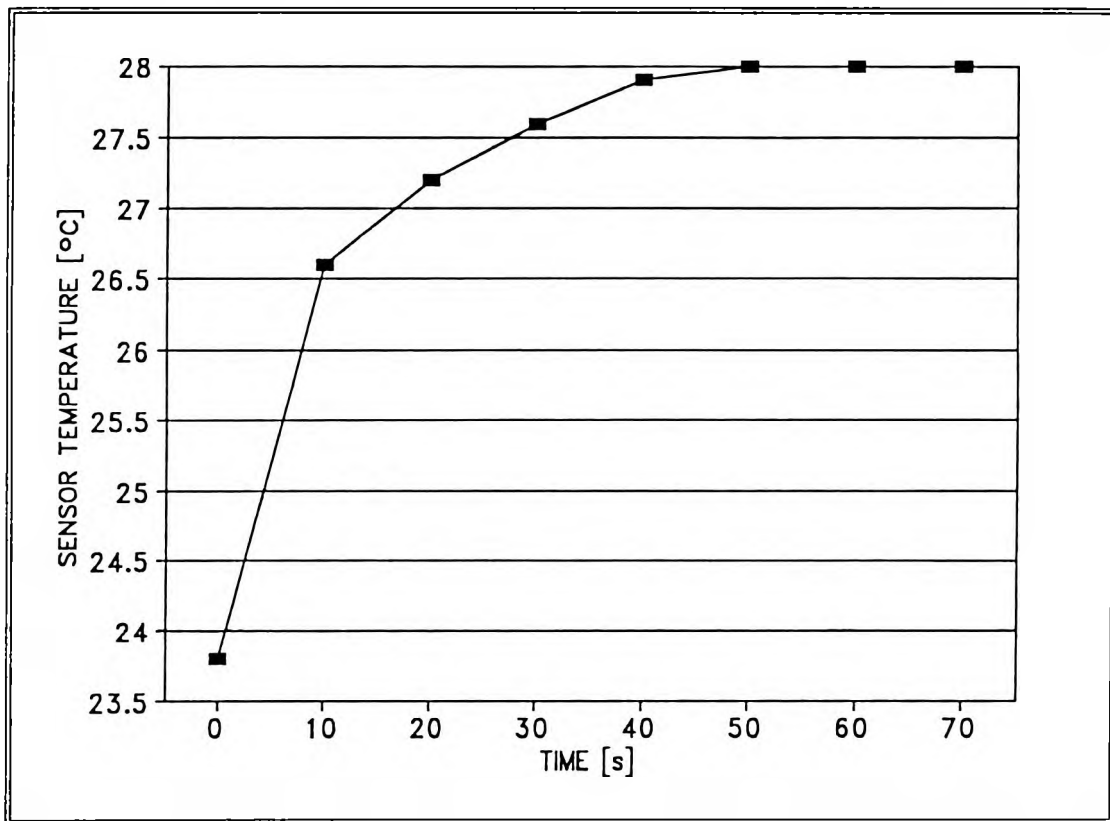


Figure 2.2-15: Warming curve of a temperature sensor in contact with a fingertip.

To increase the accuracy of temperature measurements at the work places, the box measurements were only used to calculate the differences in average environmental temperatures over an experimental day between work places. These differences were used to adjust the interpolated readings from a mercury-in-glass thermometer, which was positioned freestanding in the middle of the classroom, and

which was read at intervals of less than half an hour by the experimenters. The accuracy of the compensated work place temperature therefore depends on:

- the accuracy of the mercury-in-glass thermometer (within $\pm 0.1^{\circ}\text{C}$);
- the linearity of the temperature change between two readings of the mercury-in-glass thermometer. The difference between two readings was usually smaller than 0.5°C , and the maximum error is therefore also in this range;
- the degree to which the children affect the temperature sensor equally, when averaged over an experimental day. As the effect of finger temperature measurements is only very short and very similar for all children, and as the effects encountered during calibration was in the range of 0.3°C , the overall error on the daily average can be neglected; and
- the accuracy of the box sensors ($\pm 0.2^{\circ}\text{C}$).

The calculated workplace temperature can therefore be treated as accurate within less than $\pm 1.0^{\circ}\text{C}$.

2.3 THE MOBILE AIR-CONDITIONING UNIT

2.3.1 REQUIREMENTS FOR A CONTROLLED THERMAL ENVIRONMENT

The objective of this project was to determine the effect of temperature on performance. It was therefore necessary to test a large number of children in a thermally controlled environment at temperatures between 14 and 34°C. The system providing this environment had to comply with the following requirements:

- maintain the dry bulb temperature at a minimum of 14°C during the cooler half of the year, and at a maximum of 34°C during the hotter part of the year, while up to 40 children, two experimenters and equipment radiating about 1 kW of heat are present. None, or only a small percentage of workplaces should at any time deviate from the given target temperature by more than $\pm 2^{\circ}\text{C}$;
- avoid a temperature gradient within the climate chamber of more than $\pm 2^{\circ}\text{C}$ from the set point;
- avoid temperature fluctuation over time of more than $\pm 2^{\circ}\text{C}$;
- air movement should be of similar speed throughout the room and should be kept low at seating height;
- keep the humidity at the normal levels of the fairly dry "Highveld" area around Pretoria. Around noon on hot summer days the RH is approximately between 30 to 40% and on winter mornings between 09:00 and 11:00 RH is approximately between 40 and 60% (Wentzel et al. 1985).

It was not intended to study the effects of different levels of humidity in this experiment;

- not introduce any surfaces with high thermal radiation, for instance heaters, within the experimental chamber;
- generate less than 75 dB(A) noise at any work place by air flow through louvres and plant noise;
- look unobtrusive and familiar to the children (as far as possible); and
- allow quick and easy installation and dismantling when necessary.

2.3.2 COMPARISON OF DIFFERENT OPTIONS

2.3.2.1 THE NBRI MOBILE CLIMATE LABORATORY

At the time when this project was started, the National Building Research Institute of the CSIR already owned a mobile climate laboratory. It consisted of two large caravans, one containing an air-conditioning plant and a room for the experimenters and data collection equipment, the other containing a climate chamber, 2.7m x 6.5m in size and a toilet.

The mobile air conditioning plant had three compressor units, two with 5 kW and one with 3 kW power. The heating capacity of the plant was 12 kW and the fan used to blow the

heated or cooled air into the classroom could deliver 620 liter per minute of air.

The climate laboratory was capable of delivering the thermal environment required in the school experiment, and it was available. Because of the cost of such facilities any realistic proposal had to be based on using the existing climate laboratory. Before selecting an alternative it had to be established which solutions were feasible.

2.3.2.2 FEASIBILITY STUDY: EXTENDED CLIMATE CHAMBER

It had to be established whether the air-conditioning unit of the mobile climate chamber could be used to provide a controlled thermal environment in a room the size of a school classroom.

The dimensions of a sample of classrooms, including floor area, height of the room, window area and thickness of walls, were measured in the J J de Jong lower primary school and the Meyerspark primary school. Experts in the thermal behaviour of buildings (Dr J Wentzel and Mr J Basson at the National Building Research Institute) and in air-conditioning systems (Dr A Johannsen at the National Mechanical Engineering Institute) at the CSIR were consulted. Their calculations indicated that the capacity of the air-conditioning unit was just large enough to control a smallish classroom. An upgrade of the unit seemed possible within the constraints of the budget. It was recommended to use one or two air distribution boxes with louvres to allow for air flow direction. The boxes should be mounted high in

the room, with the openings for the return of the air to the plant below them. The airflow in the room should consist of two layers: an upper layer in which the air flows radially from the distribution box into the room, and a lower layer, in which, after sinking down near the walls of the room, the air flows concentrically back towards the return opening.

An air distribution box with louvres and the appropriate ducting was made, and the air-conditioning unit was connected to an unused room of the NBRI building. It was 7.0m x 4.5m in area and 3.5 meters high with a row of five windows on the long wall. One window was opened and the frame was filled with an aluminium plate that allowed passage of the air ducts and sealed the rest of the opening.

The air conditioning plant controlled the temperature in the room within the specified limits and with the necessary accuracy. Air flow patterns were traced with smoke. The flow followed the expected patterns, and at the height of a workplace the air movement did not exceed the specified limit. The noise level seemed fairly high (around 85 dB(A) 1 meter from the air distribution box), but it was expected to drop once the short, uninsulated aluminium ducts were replaced by longer plastic ducts insulated with glass fibre.

2.3.2.3 FEASIBILITY STUDY: POWER SUPPLY AT SCHOOLS

It had to be established whether primary and secondary schools had a sufficient power supply to operate the air-

conditioning unit. It required a 3-phase power connection with a minimum current of 60 Ampere.

A list of schools in Pretoria was obtained from the Human Sciences Research Council and it was found that several schools did have a sufficient power supply, and that it was possible in many cases to get sufficient power by tapping the main circuit breaker on the street directly. Only electricians of the City Council are allowed to do such work, but the City Council was willing to help if notice was given in due time and a fee was paid.

2.3.2.4 FEASIBILITY STUDY: ACCESS AT SCHOOLS

It had to be established if the school grounds at a sufficient number of schools would allow the caravan containing the air-conditioning unit to be parked:

- outside a classroom;
- at a wall that had windows;
- parallel to that wall; and
- not more than 5 meters away from the classroom windows.

It was further necessary to get permission from the headmasters to drive trailer-horses and heavy caravans over their school lawns. After inspection of several sites and interviews with headmasters it was found that access to schools was possible.

2.3.2.5 ALTERNATIVE USES OF THE CLIMATE CHAMBER

After the feasibility studies, one of the following alternatives had to be selected:

- A) use the climate laboratory in its original form, permanently set up at the CSIR premises and transport the children to the laboratory and back. This would allow the experiments to start immediately, without any feasibility studies or new developments;
- B) use the air-conditioning part of the climate laboratory to provide a thermally controlled environment in a fairly large room at the CSIR premises and transport the children to the laboratory and back. This way more children could be tested at a time;
- C) use the climate laboratory in its original form, but transport it to the school where the tests were to be performed. The children could stay at school and experiments could have started immediately;
- D) use the air-conditioning part of the climate laboratory to provide a thermally controlled environment in a classroom of the school where the tests were to be performed. The children could stay at their school, but a feasibility study and some development would be necessary to establish this option.

Alternatives A and B involved severe ethical and insurance problems (risk of accident during transport), acceptance problems (consent of parents) and organisational problems (provision of toilet facilities, food, etc). The organisational problems in transporting the equipment were

smaller and the research team had experience from previous work. Considerable time would also be lost in transporting the children to the CSIR and back. As the feasibility studies showed that testing at the schools was possible, A and B were ruled out.

Alternative C involved less preparation work at the schools and less additional equipment such as air ducts but had two drawbacks:

- a climate chamber would be a very unfamiliar working environment for children; and
- it would only allow a small number of children to be tested at a time.

Therefore alternative D was chosen.

2.3.3 DESCRIPTION OF THE AIR-CONDITIONING SOLUTION

Figure 2.3-1 shows the caravan containing the air conditioning unit connected via air ducts to the windows of a classroom. The air-conditioning unit consists of two compressors, one with 4 kW and one with 5 kW capacity and a fan (Fischbach) that allows variable control of the air output. The maximum output is $525 \text{ litres} \cdot \text{s}^{-1}$ of air at 0°C at the outlet of the caravan (calculated from an array of 10×9 data points, measured with an ALNOR 8500 thermo-anemometer). This is equal to 31.5 m^3 per minute.

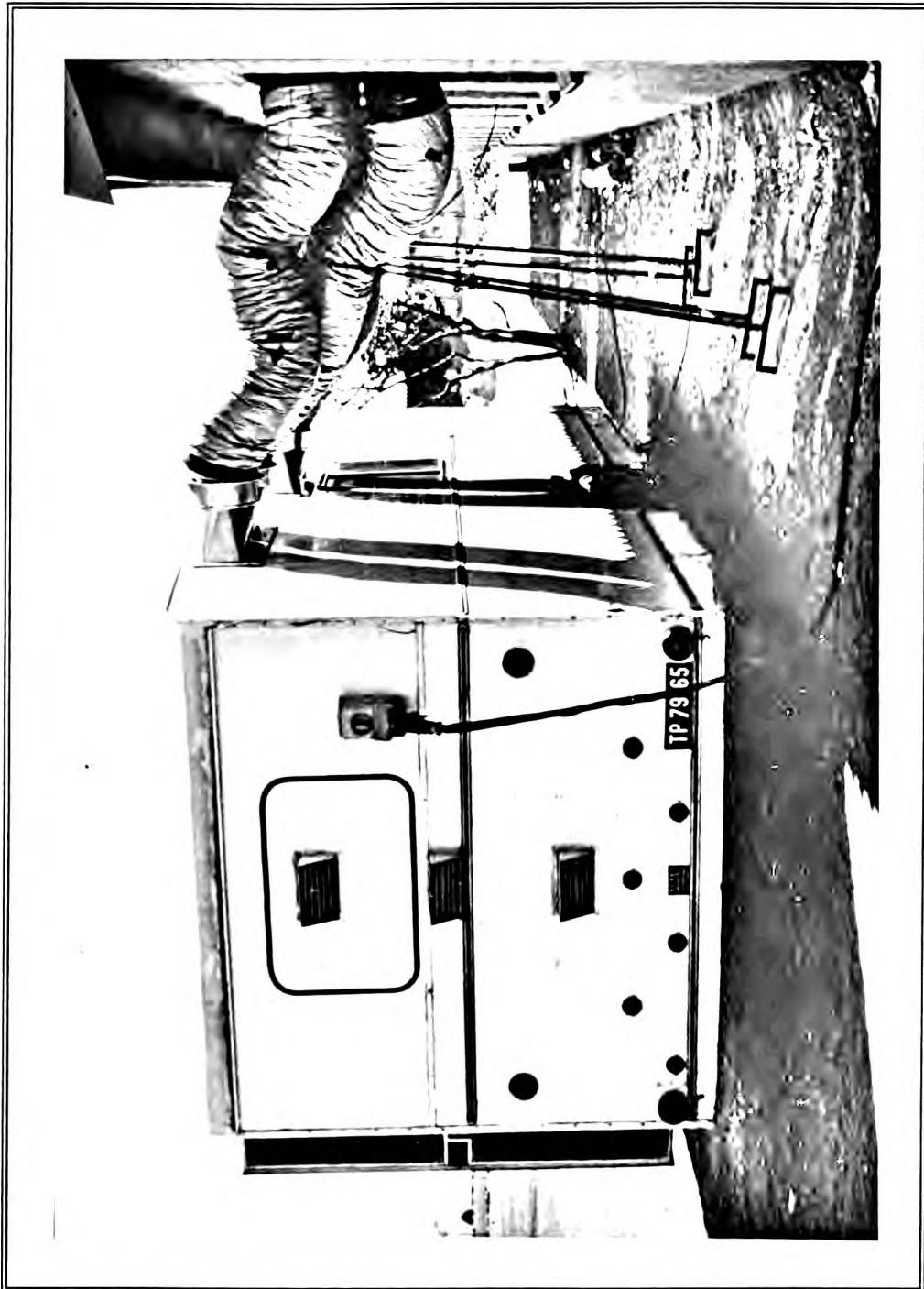


Figure 2.3-1: Caravan containing the air-conditioning unit connected to a classroom.

Wire-reinforced plastic ducts of 360 mm internal diameter were used as air ducts. They were insulated with 50 mm thick glass fibre sheets and covered with PVC foil to protect them from rain. Adjustable stands supported the air ducts and two pairs of air ducts connected the caravan to two air distribution boxes. An aluminium plate was made that sealed the window and connected the air ducts to the air distribution boxes inside the class room. Figure 2.3-2 is a schematic drawing of the system. An air distribution box with an opening for the returning air is shown in Figure 2.3-3. The box was made of aluminium and had three louvres to direct the air flow. The louvres were turned slightly upward to ensure that the outgoing and the returning airflow did not interfere with one another.

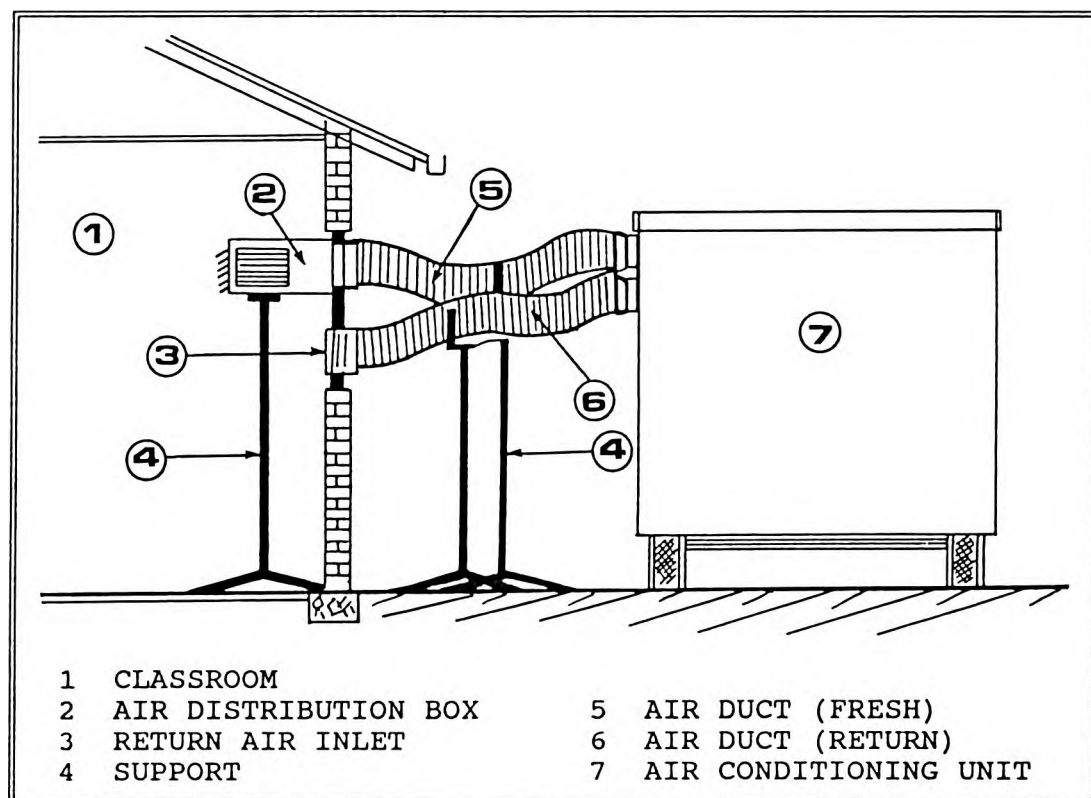


Figure 2.3-2: Schematic drawing of the link between air-conditioning unit and classroom.



Figure 2.3-3: Air distribution box for temperature control in classroom.

Figure 2.3-4 shows a classroom with pupils working and two air distribution boxes. The boxes are mounted apart from each other to minimise the temperature gradient within the classroom.

2.3.4 FIELD EXPERIENCE AND IMPROVEMENTS

2.3.4.1 MODIFICATIONS OF THE AIR-CONDITIONING PLANT

In the first field tests the cooling coils of the heat exchanger tended to ice up during the cold tests. On advice of air conditioning experts the cooling medium was changed from Freon 24 to Freon 12. The power of the cooling system was sufficient to keep the temperature at 14°C on cool days, but it took several hours to reach this temperature. It was therefore necessary to switch the plant on at about 05:00 in the morning to ensure that 14°C were reached at the beginning of the school day.

2.3.4.2 EXTENDED DUCTING

For some schools the 3 metre ducting was too short, and an extension was required. Figure 2.3-5 shows the caravan connected with extended ducting. The additional flow resistance and the temperature change of the air in the additional part of the ducting did not prove problematic (except in experiments at 14°C on sunny days, which were rare).

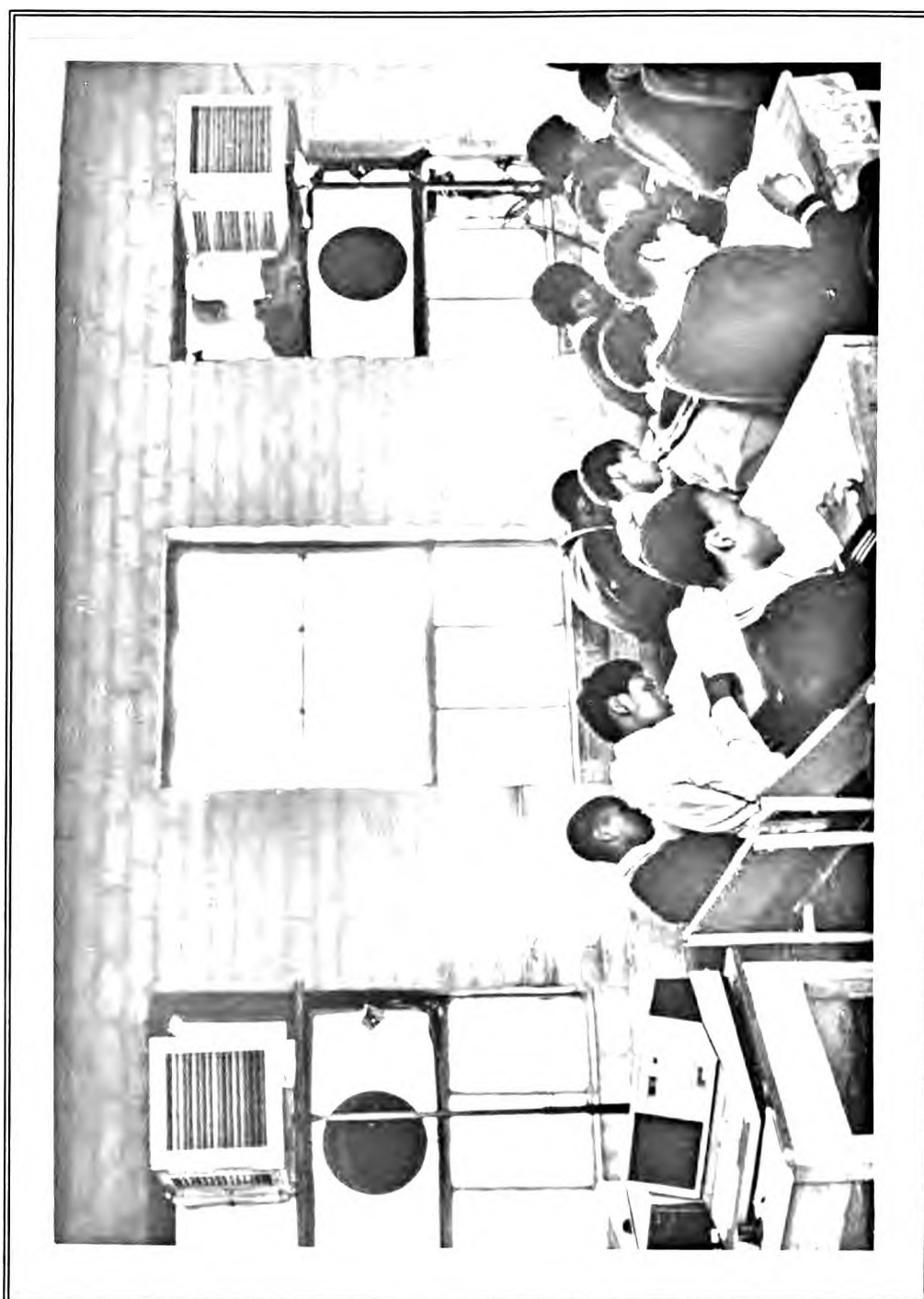


Figure 2.3-4: Air distribution boxes installed in classroom.



Figure 2.3-5: Caravan containing air-conditioning unit connected to classroom with extended ducts.

2.3.4.3 QUALITY OF TEMPERATURE CONTROL

During the first field trials the temperatures measured at workplaces at the window were several degrees higher than the mean temperature on all work places. This was due to direct sunlight. To reduce the radiant temperature the relevant parts of the windows were covered with white paper sheets. The same white paper was also used to cover the bottom part of the windows and prevent curious pupils, who had gathered at the windows during breaks, from disturbing the children performing the tests.

The quality of temperature control can be appreciated from Table 2.3-1, which shows means and standard deviations of the temperatures measured under different experimental conditions at all workplaces during all performance tests.

planned T [°C]	No. of measure- ments	measured mean T [°C]	standard deviati- on [°C]	% within ±2 °C of mean
14	1506	14.6	1.6	80
19	1180	19.2	0.9	98
24	5504	24.1	1.0	96
29	1263	29.1	0.8	98
34	1699	34.1	1.4	86

Table 2.3-1: Means and standard deviations of temperature measurements at different planned temperatures and % of values within ±2 °C.

As expected, the control of temperature worked best close to the environmental temperatures. At the extreme temperatures a higher fluctuation was found. It can also be seen from

Table 2.3-1 that the temperature control worked least efficiently at 14°C, as the mean of all temperatures measured was 0.6°C higher than the target temperature and only 80% of all measurements were within 14.6±2°C.

Figure 2.3-6 shows the distribution of all measured room temperatures at a target temperature of 14°C during the performance of one specific test (Classification). In the present study experiments are identified by their target temperature, for example 14°C, but the limitations of temperature control have to be kept in mind when interpreting the results.

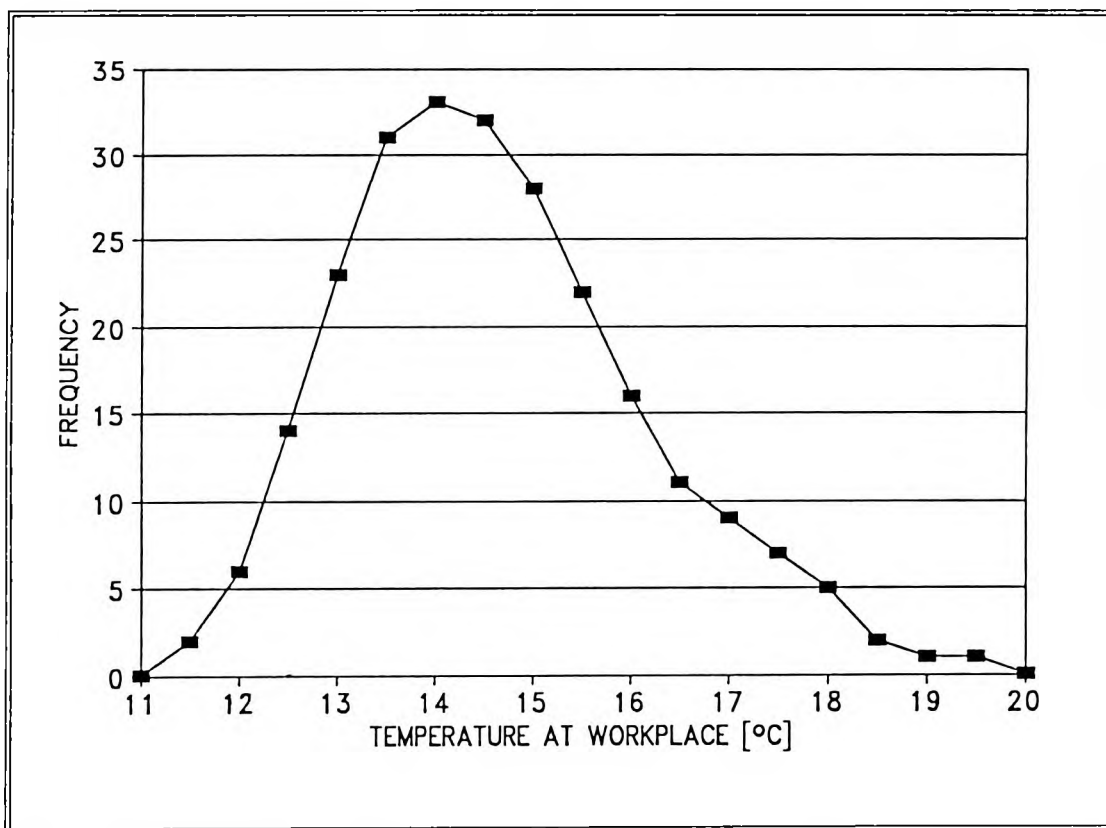


Figure 2.3-6: Frequency distribution of all room temperature measurements at a target temperature of 14°C during the performance of the Classification Test.

2.4 PERFORMANCE TESTS

2.4.1 REQUIREMENTS FOR PERFORMANCE TESTS AND CO-OPERATION WITH THE HSRC

Groups of children in different thermal environments were to be given a battery of tests. The effect of temperature was to be assessed by comparing the results achieved under different conditions. The tests had to be sound and suitable from the psychological point of view. They had to be selected to ensure that an effect of temperature found on the performance of a certain test would allow conclusions about the effect of temperature on certain types of school work. As I did not have sufficient training or experience in psychological testing, this part of the project could only be undertaken in cooperation with researchers who had such skills.

The main purpose of the project was to inform educational authorities, headmasters and teachers whether the effect of temperature on the performance of children is strong enough to require intervention and if so, to make specific recommendations. To maximise the chance of such recommendations being implemented, the tests had to be approved by the psychologists who are usually consulted in educational affairs. In South Africa these are mainly the researchers of the Human Sciences Research Council (HSRC). For these reasons the HSRC was approached for cooperation. The researchers of the Institute for Psychological and Edumetric Research agreed to:

- select the performance tests;
- provide the test items;
- cooperate in adapting the tests to our specific needs as far as necessary;
- take part in the experimental design; and
- help in obtaining approval from the Department of Education and Training.

It remained the responsibility of the CSIR research team to:

- modify the items to suit the ADCS if necessary (item numbers, labels etc);
- conduct pilot studies and analyse the results;
- identify items that were too easy , too difficult or ambiguous, by analysing the pattern of response (what percentage of children chose which answer) and by calculating response times;
- see if each test contained enough items to keep most children busy for the time of the test, and request more items if needed; and
- observe the children's behaviour for any other problems.

2.4.2 DESCRIPTION OF THE PERFORMANCE TESTS

2.4.2.1 CLASSIFICATION

Figure 2.4-1 shows an example from the Grade 2 test. Five drawings were given for each item. The objects in four of them had a "topic" in common, for example they all showed birds, whereas the object shown in the fifth drawing did not fit the common topic of the others; it showed an insect. The object that did not fit into the group had to be identified.

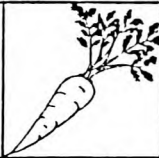
01					
	A	E	I	O	U
02					
	A	E	I	O	U
03					
	A	E	I	O	U
04	PRESS BUTTON DRUK KNOPPIE X				

Figure 2.4-1: First page of Classification Test for Grade 2.

The ability to determine the relation between given objects and, on the basis of this relation, establish which object is not common to the others, was regarded as a valid indication of a facet of a children's non-verbal reasoning ability (Taljaard, 1989).

2.4.2.2 COMPARISON

Figure 2.4-2 shows an example from the Grade 2 test. Six drawings were given for each item: one in a thicker frame, slightly offset to the left, and five others, labelled with vowels. Only one of the five was identical to the drawing on the left (in Figure 2.4-2 the correct answer was "U"). The Comparison Tests for Standard 3 and Standard 6 were based on the same principle, but instead of drawings, names and letters were used. The ability to perceive names, figures and letters quickly and accurately and to compare them with one another, was regarded as a valid indication of perceptual speed and accuracy (Owen, 1977).

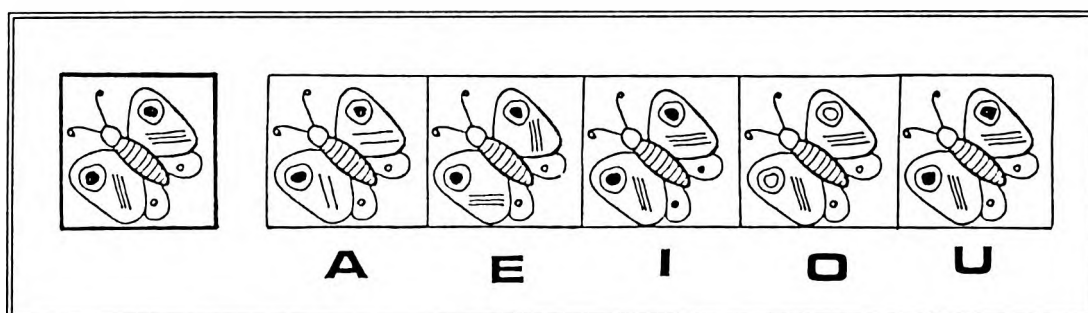


Figure 2.4-2: Item from the Comparison Test for Grade 2.

2.4.2.3 MATHEMATICS

Figure 2.4-3 shows an example from the Grade 2 test. For this test the children were issued with pencils and a sheet of paper so that they could work out their answers in writing before they pressed an answer key, i.e. it was not a mental arithmetic test. The test for Grade 2 entailed simple addition and subtraction of numbers, the test for Standard 3 was based on addition, subtraction, division and multiplication problems and combinations thereof, and the test for Standard 6 included ordinary and decimal fractions in some items.

$3+3+4=$	12	11	13	10	9
	A	E	I	O	U

Figure 2.4-3: Item from the Mathematics Test for Grade 2.

It was assumed that the ability of the children to do calculations quickly and accurately can be regarded as a valid indication of a facet of their numerical ability (Owen, 1977).

2.4.2.4 MEMORY

For Standard 6 and Standard 3 the Memory Test consisted of a short story that the children had to read carefully within 5 minutes. Afterwards they had to answer questions concerning the story. The test for Standard 6 had a story about students going for a picnic. An example of the questions was:

Just before the group went home, they ...
A. had a rest.
E. went fishing.
I. went for a swim.
O. went mountain-climbing.
U. went to look for plants.

For the Grade 2 children this approach was not feasible, as their reading ability was not developed enough to cope with a short story. They were given a list of 20 words to learn. Thereafter, they were presented with items that each contained five words (see Figure 2.4-4).

light	sun	cloud	home	indian
A	E	I	O	U

Figure 2.4-4: Item from the Memory Test for Grade 2.

Only one of the words in one item had been on the previously presented list. This word had to be identified. The two memory tests are of different nature and do not necessarily involve the same basic abilities.

The composition of these tests was based on the assumption that a child's ability to memorise the contents of a paragraph (short story) or of a list of words in a given time is a valid criterion for short term memory (de Villiers, 1977).

2.4.2.5 NUMBER SERIES

In every item a series of numbers is presented. One number, represented by a question mark, is missing. Five numbers are offered as possible answers. Examples from the Standard 6 test are shown in Figure 2.4-5.

number series:	4	5	6	?	8	9	
possible answers:	7	5	8	4	9		(correct: 7)
number series:	12	10	12	?	12	10	
possible answers:	11	10	9	12	22		(correct: 10)
number series:	54	48	41	33	24	?	
possible answers:	12	18	14	16	10		(correct: 14)

Figure 2.4-5: Examples from the Number Series Test for Standard 6.

This test was only applied to Standard 6 and Standard 3 children.

This test is based on the assumption that the ability to determine the relation between the numbers in a number series, to deduce the rule and to apply it to complete the number series, provides a good indication of an aspect of non-verbal reasoning ability (Claassen, 1987).

2.4.2.6 PATTERN COMPLETION

Each item consisted of a square, subdivided into nine (3x3) fields of equal size (Figure 2.4-6). The field at the bottom right was empty. The other eight fields contained symbols which changed systematically from field to field according to a prescribed pattern. The pattern has to be analysed and used to identify one of five presented fields as the one that should be put in the empty place.

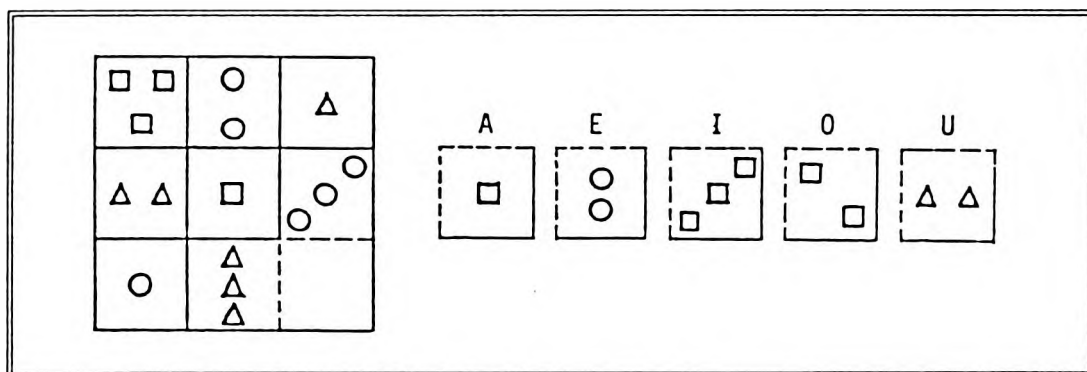


Figure 2.4-6: Item from the Pattern Completion Test for Standard 6.

An example is shown in Figure 2.4-6. Each complete row contains a set of squares, a set of circles and a set of triangles. The same is true for the columns. To fit this pattern the empty field had to be filled with a set of squares. Further, each complete row contains a field with three, a field with two and a field with one object. The same is true for the columns. To fit this pattern the empty field had to contain two objects. The correct answer for the item in Figure 2.4-6 was therefore "0": two squares. The patterns were different for each item. This test was only applied to Standard 6 and Standard 3 children.

It was assumed that the ability to observe figures accurately, to determine the relation between the figures and to apply the rules thus deduced to complete the pattern, provides a good indication of an aspect of non-verbal reasoning ability (Claassen, 1987).

2.4.2.7 O'CONNOR PEG TEST

The test used was a modification of the O'Connor Peg Test described by Parker and Fleishman (1960). It is a finger dexterity test. The children were given the following instruction:

Work with the hand you write with. Take three pegs out of the tray. Make sure you have exactly three pegs in your hand. Put them one by one into one of the holes. Each hole will take three pegs before it is full. Then take another three pegs and put them one by one into the next hole. Work as fast as you can, and go on until all holes are filled. When you are finished press button "A" on your answer box.

Figure 2.4-7 shows two O'Connor Peg Test units. The board has 10 x 5 holes. A metal lid (shown on the right) covers all holes but a row of five. These five holes are used for instruction, while the metal lid keeps over-eager and playful children from starting too early or filling the wrong holes. Only when the main test was started were the children allowed to open the metal lid.

The test has been extensively used to investigate the effect of temperature on the performance of light manual tasks by factory workers (Meese et al. 1981). This test was only applied to Standard 6 and Standard 3 children.

2.4.2.8 WRITING SPEED

Figure 2.4-8 shows an example of the Writing Speed Test. The test was identical for Grade 2, Standard 3 and Standard 6. The children were instructed to copy the characters at the top of the page into a line, to press key "A" of their answer box when they finished, and to continue immediately with the next line.



Figure 2.4-7: Pegboard for O'Connor Peg Test.

	3	a	b	5	4	h	4	7	m	k	6	8	
01													Press Button
02													Press Button
03													Press Button
04													Press Button

Figure 2.4-8: Top of page one from the Writing Speed Test.

Writing is an essential component in many school tasks and it was also assumed that it provides a good indication of finger dexterity.

2.4.2.9 SIMPLE REACTION TIME TEST

The children received the following instruction:

Put the index finger of the hand you write with on button "I" of your answer box. Keep it there. Watch the counter of your box. It shows "00". When your counter jumps to "99", press button "A" as fast as possible.

The time between the changing of the counter and the pressing of the key was stored by the computer. As it takes the system about 150 ms to scan all boxes once, and reaction times are in the range of about 300 to 600 ms, the normal mode of extracting information from the boxes would have led to inaccurate results. Therefore the computer selected a box randomly and addressed only this box until the child had responded or a time of 2 sec has passed. Thereafter the next box was randomly chosen. This mode allowed a time resolution of less than 10 ms. To test the children of a whole school class in this sequential manner took less than one minute.

During the pilot study it was observed that children assumed different hand positions while waiting for their counter to change. Some put their index finger already on key "A" while others kept their hands on the desk. The instruction to put the index finger on key "I" ensured that their hands were in a standardised position. This test was only applied to Standard 6 and Standard 3 children.

2.4.2.10 CHOICE REACTION TIME TEST

Whereas the Simple Reaction Time Test required the child only to press a predefined key as fast as possible, the Choice Reaction Time Test included a decision making process. When the number on the counter changed the children first had to determine the correct key. Then they had to press it as fast as possible. A choice between four options corresponds to an information content of two bits (Jensen and Munro, 1979). This test was only applied to Standard 6 and Standard 3 children.

The children received the following instruction:

Put the index finger of the hand you write with on button "I" of your answer box. Keep it there. Look at the counter of your box. It is blank. When it changes to "00" it is your turn to watch the counter very carefully. When it jumps to another number, you must press the right button as fast as you can.

If it jumps to 11 press button "A",
if it jumps to 22 press button "E",
if it jumps to 44 press button "O", and
if it jumps to 55 press button "U".

2.4.2.11 FIGURE ANALOGIES

Figure 2.4-9 shows an example from the Figure Analogies Test for Standard 6. The top left frame showed two objects, implying a relationship between them. The top right frame showed an object and a question mark. The aim was to find the object that would imply the same relationship in the top right frame as in the top left frame. Five possible objects were shown in the bottom frame. In Figure 2.4-9 "lion to antelope" implies the same relationship as "rabbit to carrot" because rabbits eat carrots and lions eat antelopes.

This test was based on the assumption that the ability to observe the relation between figures and to use this relation in order to identify a suitable missing figure by analogy, provides a good indication of an aspect of non-verbal reasoning ability (Claassen, 1987).

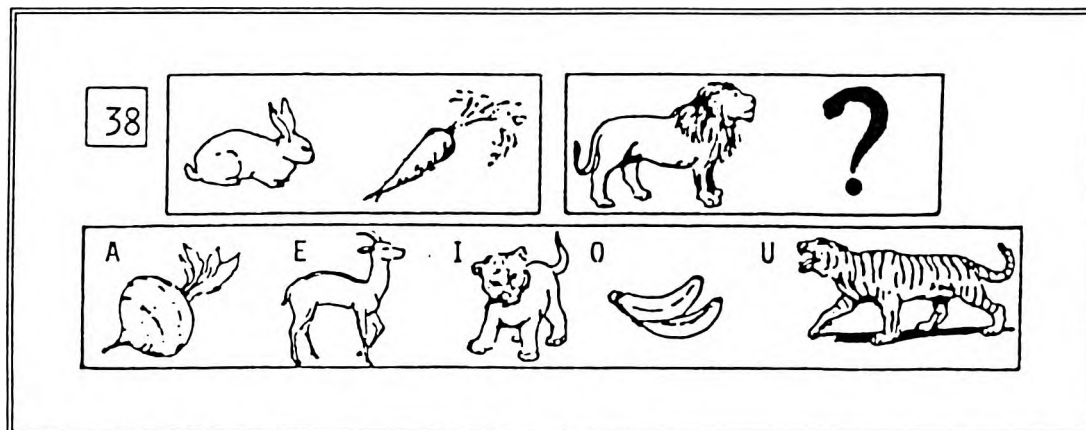


Figure 2.4-9: Item from the Figure Analogies Test for Standard 6.

2.4.2.12 PERSONAL QUESTIONNAIRE

The Personal Questionnaire was included:

- to find concomitant variables to which a part of the variation in the data could be ascribed; and
- to train the children how to use the answer box by giving them a task with which they could immediately cope.

The Personal Questionnaire was always presented during the acclimation phase before the performance tests and it addressed the following issues:

nutrition, e.g.: Did you bring something to eat or drink to school today?
Do you often feel hungry at school?

way to school,e.g.: What time did you get out of bed today?
Did you walk all the way to school
today?

home life, e.g.: Do you have a quiet place at home where
you can do your homework?

temperature, e.g.: How do you feel in the classroom today?
(too cold / too hot / just right)

socioeconomic,e.g.: Do you have a television in your home?

A full list of the questions is given in Appendix C.

2.4.3 PRESENTATION OF THE TESTS

2.4.3.1 TEST BOOKLETS

All tests, except the O'Connor Peg Test and the reaction time tests, were presented in form of A4 sized booklets, covered in coloured cardboard. On the first page, 3 to 5 items were given for instruction purposes. The second page contained only the words:

STOP Do not turn over !

The main test started on page three, with the layout identical to that on the first page and the items were numbered beginning with one. The item numbers were printed in square frames to resemble the square digital counter on the answer box. Figure 2.4-1 shows the first page of the Classification Test for Grade 2.

The children were told that they had to answer the question with the number that was shown on the square digital counter of their answer box. The possible answers were labeled with vowels, and the children were told that they could give an answer by pressing the key with the matching vowel on their answer box. The last "item" on each page (except for page number two) was the instruction:

PRESS BUTTON X

For the children the test items were named "questions", and the keys on their answer boxes were named "buttons".

2.4.3.2 TEST INSTRUCTIONS

The test instructions were presented on a video film (see 2.5). In the film two or three items were first discussed in detail. For example, in the explanation of the first item of Figure 2.4-1, the monitor displayed the appropriate page of the test booklet. The drawings mentioned in the sound track

were pointed out on the monitor by a moving finger or a pen.
The soundtrack was:

Open your books. In this test every question shows the pictures of five things. You have to find the odd one out. In question one (point to "01") you see five animals. Four of them are birds (point to each of the four birds). One is an insect (point to the insect). This is the odd one out, so the answer for question one is "A". Please press the "A" button NOW.

After the second item was explained in a similar way the children were asked to answer the next question on their own, and to press button "X" afterwards. If wrong answers were given when the children worked on their own, the ADCS refused the answer and alerted the experimenters so that further explanation could be given.

2.4.4 FIELD EXPERIENCES AND IMPROVEMENTS

2.4.4.1 ELIMINATION OF THE FIGURE ANALOGIES TEST

The analysis of the results from pilot studies indicated problems with the Figure Analogies Test. The desired response pattern for a question was that about 65% of the respondents select the correct option, with the rest of the responses fairly evenly distributed over the wrong options. In the Figure Analogies Test various items showed a different response pattern, for example two options each getting 40% of the responses.

Discussions with children after the test showed that the intentions of the test authors were often not understood. Figure 2.4-9 gives a good example. "Rabbit to carrot" is supposed to be equivalent to "lion to antelope", as rabbits eat carrots and lions eat antelopes. Do rabbits eat carrots? Hardly in their natural habitat, but frequently in European picture books. Children who did not have sufficient exposure to such books were puzzled by that item.

It would have been labour intensive to identify all items that were regularly misunderstood, to replace them with supposedly better ones, and to test the quality of the new items in further pilot studies. Leaving the misunderstood items in place would have reduced the validity of the results. It was therefore decided to drop the Figure Analogies Test from the test battery.

2.4.4.2 ELIMINATION OF UNSUITABLE TEST ITEMS

The percentage of correct answers, the mean response time and the pattern of responses were calculated and printed for each item and each test. Items that showed any deviation from the normal pattern were discussed with HSRC psychologists. These items were then either improved (for example better graphics) or eliminated.

2.4.4.3 DURATION OF TESTS AND NUMBER OF QUESTIONS

Pilot studies were performed with all tests, the time taken per item was recorded for each child. The number of items that would on average be completed for each test in the time planned as well as the standard deviation of this measure were calculated. The desired number of questions for a test for a given Standard was defined as the mean plus two standard deviations to ensure that most children would be kept busy until the end of the test time.

Most tests had to be extended by about 20%. The additional items were produced by the HSRC. Table 2.4-1 shows the test time and the number of test items for the tests used in the three educational standards.

	Grade 2		Standard 3		Standard 6	
performance test	items	time	items	time	items	time
Classification	33	15	60	8	67	8
Comparison	33	10	60	10	50	10
Mathematics	51	15	40	15	40	15
Memory	20	-	29	5	25	5
Number Series	-	-	55	10	66	15
Pattern Completion	-	-	35	10	71	15
O'Connor Peg Test	-	10	-	10	-	10
Writing Speed	57	10	99	10	99	10
Personal Questions	21	-	47	30	47	30

Table 2.4-1: Number of test items without X-questions and maximum work time in minutes for different tests. For the Personal Questionnaire and the Memory Test in Grade 2 no time limit was set.

In addition to these items each test contained a dummy item at the end of each page, requesting the child to press button "X". These dummy items were introduced to keep the children from getting out of step (see 2.2.4.2). The tests had on average five test items and one dummy item on one page. The total number of items was therefore about 20% higher than the number of test items.

2.4.4.4 IMPROVING THE RESULTS FOR THE O'CONNOR PEG TEST

During the pilot studies it was not uncommon for the children to play with their answer boxes while instructions were given. When the boxes were activated for the O'Connor Peg Test, some keys were pressed while still playing and some due to misunderstanding the instruction, before the children started working. This made the analysis of the results difficult.

The control program for the ADCS was therefore modified in a way that made the answer boxes inactive during the first two minutes of the O'Connor Peg Test. As no response time on this test was ever shorter than two minutes, this measure eliminated most erroneous results.

2.4.4.5 SPECIAL PROBLEMS WITH GRADE 2 CHILDREN

As expected, the Grade 2 children showed a much shorter attention span than the Standard 3 children. They were also used to a shorter school day of about four hours. Therefore the duration of the performance test was reduced (see Table 2.4-1) and the number of tests was cut from eight to five. Number Series, Pattern Completion and the O'Connor Peg Test as well as the reaction time tests were omitted. The Personal Questionnaire was reduced from 57 to 27 questions.

Grade 2 children had a limited reading ability compared with children of the higher grades. Therefore the text in their test booklets was presented to them in big letters. This was accomplished by printing fewer test items on one page (three items instead of five) and by using the page of the test booklets sideways (A4 pages bound at the small side) to provide more space for each item.

The Memory Test, which for the elder children was based on reading a short story, was changed to a different test, where the children had to learn 20 words by heart (see 2.4.3.4). This required less reading ability and comprehension of written text.

2.5 VIDEO SYSTEM FOR TEST INSTRUCTION

2.5.1 REQUIREMENTS FOR TEST INSTRUCTIONS

Before the children could perform any tests they required instructions on how to work with their answer boxes and on how to interpret text and graphics in their test booklet. This explanation had to be:

- clear and concise;
- with a minimum of variation due to the presenter;
- free from any systematic effect of temperature; and
- delivered in English, Afrikaans and possibly some African languages.

2.5.2 COMPARISON OF DIFFERENT WAYS OF EXPLANATION

2.5.2.1 FEASIBILITY STUDY: INSTRUCTION VIA VIDEO FILM

The presentation of the test instructions via video film was seen as an option that could satisfy the criteria mentioned above, but before it could be compared with other solutions cost feasibility had to be established.

The first part of this investigation was discouraging. Representatives of commercial video film companies, as well as disinterested experts in this field, projected very high costs, arguing that a team of specialists for camera, sound

and lighting, as well as costly professional equipment, were required for a film of acceptable quality.

Mr W Smith from the STAR SCHOOL in Johannesburg claimed that anybody could learn how to make video films of a quality sufficient for educational purposes, and that this could be done in a studio built from home market equipment. He headed an organisation that produced educational films and hired video studios at low cost to people who wanted to make their own films. A visit to STAR SCHOOL assured us that video films were a viable option at acceptable cost.

..5.2.2 ALTERNATIVE WAYS OF PRESENTING STANDARDISED TEST INSTRUCTIONS

Possible methods of instruction presentation discussed were:

- A) an experimenter gives the instructions. The wording is kept the same in every presentation by reading from a text sheet;
- B) all instructions are presented in written form; and
- C) video films are produced for instruction purposes.

It was not possible to ensure that all instructions would always be given by one person. The persons involved in the field work had different home languages and had different degrees of proficiency in English and Afrikaans. None of them was fluent in an African language. In addition the

experimenter would have to be exposed to the same temperature conditions as the children and his style of presentation could be temperature dependent.

Alternative B could have been used for Standard 6, possibly for Standard 3, but the children in Grade 2 did not have sufficient reading skills. Therefore alternative C, instruction via video film, was chosen.

2.5.3 DESCRIPTION OF THE VIDEO SYSTEM FOR TEST INSTRUCTIONS

2.5.3.1 VIDEO STUDIO

The following equipment was purchased:

- Sony T9 Betamax video cassette recorder;
- Hitachi GP61 colour camera with zoom;
- Sony CKV 2760 colour monitor with 67 cm screen and sound; and
- a clip-on microphone.

A small air-conditioned room at the NBRI was converted into a studio (Figure 2.5-1). The windows were covered to eliminate daylight. A suspended ceiling with panels of compressed wood fiber improved the acoustic properties. A steel frame was constructed to hold the camera in a vertical position.

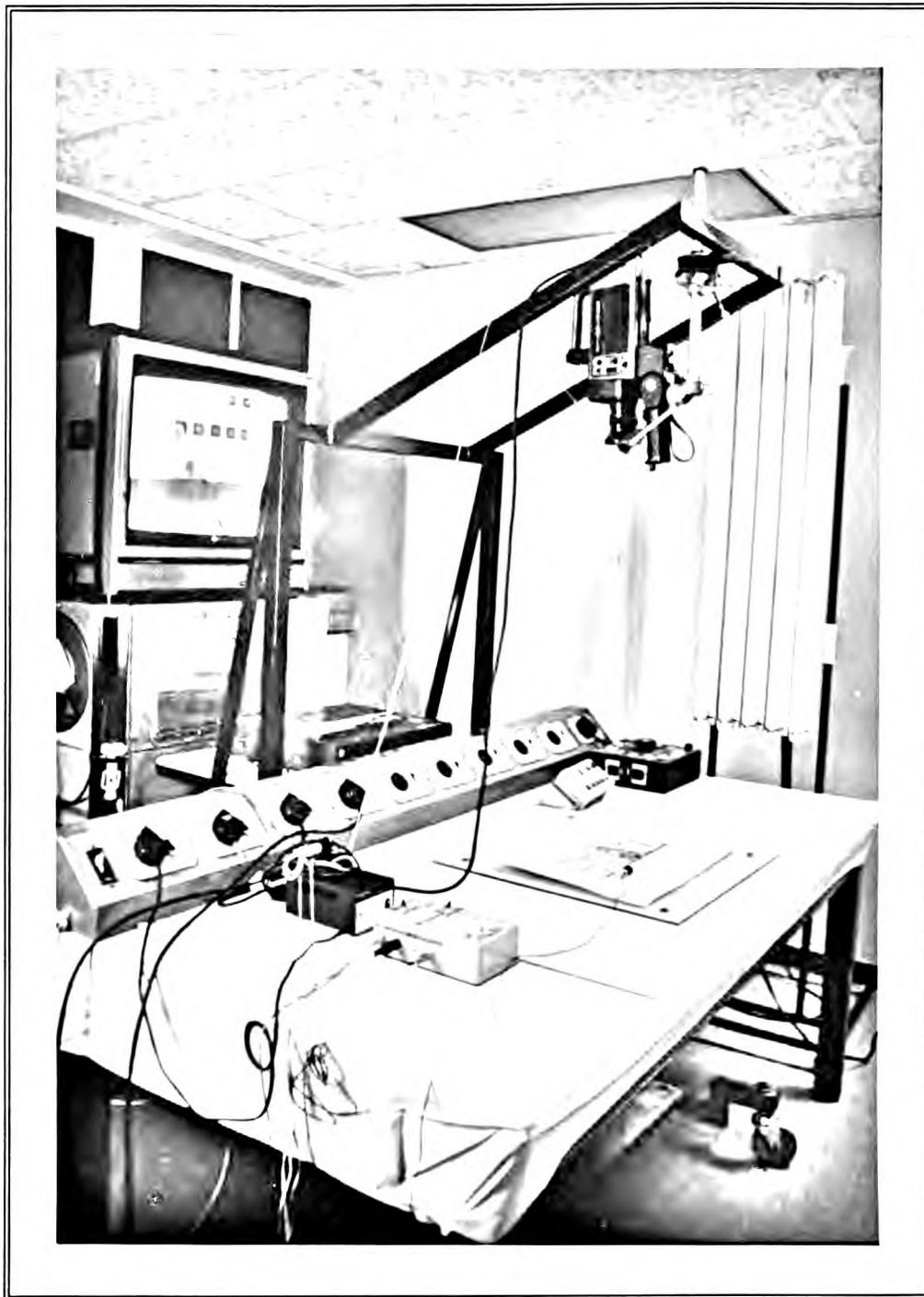


Figure 2.5-1: View of the video studio.

The height of the camera was adjustable. Connections were made to the electronic control of the camera to allow operation of the zoom from the work desk. A similar connection was made to the loudspeaker of the monitor so that the operator could avoid acoustic feedback via the microphone. The work desk was covered with a glass plate. A second, smaller glass plate of rectangular shape was equipped with a coin-sized piece of plastic at each corner, and put onto the larger glass plate. Objects on the small glass plate could then be introduced into the field of vision of the camera with a smooth sliding action. Two batteries of five fluorescent tubes (40 Watt, 1.2 m long) were built to ensure sufficient, even lighting at the work desk.

Preliminary tests showed that it was difficult for the operator to keep a constant distance from a microphone standing on the table, and variation of the distance produced variation in the intensity of the sound. A clip-on microphone was used in all recordings to overcome this problem.

2.5.3.2 PRESENTATION UNIT WITH TELECONTROL

Figure 2.5-2 shows the presentation unit in a classroom. The monitor rests on a steel-reinforced, aluminium container that contained the video cassette recorder (VCR). The bigger steel-reinforced aluminium container below it is used to protect the monitor during transport. The unit can be moved on wheels.



Figure 2.5-2: Presentation unit in a classroom.

After the unit had been transported to a classroom, the VCR container was removed, and the monitor lifted out of its container by a pulley attached to the steel frame around the monitor. The pulley was operated by the crank handle visible on the right of the unit. Thereafter the VCR container was put back in place and the monitor lowered onto it. After establishing the required connections the unit was ready for use.

2.5.3.3 TRANSPORT EQUIPMENT

The presentation unit was far too heavy to be lifted safely by two people. The truck in which the unit was transported was therefore equipped with a special lifting facility. After the back door of the truck had been opened, a steel frame on hinges was folded out (see Figure 2.5-3) and a hook was lowered on a pulley. The VCR container of the presentation unit was detached, and the heavy monitor container with the monitor was lifted with the pulley and brought into the truck by folding back the steel frame. Guard rails inside the truck kept the container in place.



Figure 2.5-3: Loading of the presentation unit into a truck.

2.5.4 PILOT STUDIES AND MODIFICATIONS

2.5.4.1 PRODUCTION OF THE FILMS

Instructions on how to perform tests consisted of two parts: the first, in which several examples of test items (usually three) were discussed in detail, and the second, where the children were instructed to work on some items on their own (usually two); these items were also discussed in detail afterwards.

The instruction films were tested in a pilot study, their shortcomings were analysed and an improved version was produced. Testing and re-filming was repeated until all faults were corrected, and the children understood the message without getting bored. On average the third version of an instruction film was satisfactory. For instruction purposes only original recordings could be used. The quality of copies produced on normal video equipment was unacceptable.

2.5.4.2 USE IN THE CLASSROOM

The children in our experiments did not show any problems with receiving instruction from a monitor. They could usually remember what they had been told, and they performed appropriately. What the monitor could not do, was to prompt them into action. The words: "Please open your books and begin" coming from the monitor usually achieved nothing. A

person, preferably standing in front of the classroom had to order: "Please open your books. Start NOW!".

The films were produced in such a way that small graphic detail was not necessary for understanding the content, so that children sitting in the back of a classroom had no problems with the graphics on the monitor. Glare on the monitor was avoided by covering part of the windows with white packing paper, and by shielding the sides of the monitor with cloth where necessary.

2.5.4.3 SECONDARY USES OF THE PRESENTATION UNIT

In the beginning of each experiment as well as after each break the children had to be acclimated. Besides measuring heights and weights and performing the Personal Questionnaire, all activities had to be performed in an acclimated state. This meant that there was nothing useful to do during most of the acclimation. To avoid boredom, the children were entertained by showing hired films from a video shop (cartoons, music films, etc.). This proved to be very successful, and motivated the children to return from their breaks in time, even when there was no teacher present.

2.6 DETAILS OF THE EXPERIMENTAL PROCEDURE

2.6.1 ADDITIONAL MEASUREMENTS

2.6.1.1 NOISE LEVEL MEASUREMENT

Noise levels were measured with a Bruel & Kjaer noise level analyser type 4426. The values were measured using the "A" weighting network. The analyser performs statistical level analysis, which allows the determination of levels exceeded for a defined percentage of the measuring period. The following parameters were measured:

- L1: noise level exceeded 1% of the measurement time;
- L10: noise level exceeded 10% of the measurement time;
- L50: noise level exceeded 50% of the measurement time;
- L90: noise level exceeded 90% of the measurement time;
- Leq: equivalent continuous noise level based on the equal energy principle.

The results measured were accurate to within 1 dB. Readings were taken at intervals of less than one hour. The whole time between readings was used as measurement time.

2.6.1.2 HEIGHT MEASUREMENT

A simple height measuring device was constructed from a stand, an aluminium pipe and a sliding top. The child stood close to the vertical pipe and the top was moved downwards

until it touched the head of the child. The measuring device was accurate to within ± 0.5 mm, but readings depended on the posture of the child and the height measurements were probably within ± 5 mm of the child's real height.

2.6.1.3 WEIGHT MEASUREMENT

Two bathroom scales were used to measure the weight of the children. These scales were accurate within ± 1 kp when compared with the results of a highly accurate electronic scale (type "Toledo" from Trek Scale Corporation, Cleveland, Ohio, USA), but their readings varied slightly when the weight was unevenly distributed (for example when standing mainly on one leg or standing off-centre). The weight measurements can therefore only be assumed to be within ± 2 kp of the child's real weight.

2.6.2 CONTROL OF THE THERMAL ENVIRONMENT

2.6.2.1 STANDARDISATION OF CLOTHING

In cold experiments all children had to wear pullovers. On the day before the experiment the children were reminded to bring their school uniform pullover. Children who did not have a pullover were supplied with one by the experimenters. For this purpose about 15 cheap pullovers were purchased.

During the heat experiments no pullovers or jackets were worn.

Because of the requirement for a 60 Ampere, 3-phase power connection, most experiments were conducted in an urban environment where very few children came to school barefoot. Therefore no effort for the standardisation of footwear was required.

2.6.2.2 REDUCTION OF TEMPERATURE GRADIENTS

The windows in most classrooms were situated on the north side, to provide good light. In some schools there were no overhangs outside the windows to provide shade, so that one or two rows of desks were exposed to direct sunshine, increasing the temperature at these workplaces above the class average and exposing the children to directional radiation. Both effects had to be avoided, because equal thermal conditions were aspired to and investigating the effects of directional radiation was not part of this project. This was achieved by covering part of the windows with white sheets of paper.

2.6.2.3 ACCLIMATION

On each experimental day the children were exposed to an acclimation phase at the thermal condition under which the

performance tests were to take place. Shorter acclimation phases were given after the mid-morning break and after the lunch break, when the children had left the classroom to go to the toilet or to buy food.

In the morning the acclimation phase was used to measure heights, weights, oral temperatures, finger temperatures and reaction times. The answer boxes were explained, and the Personal Questionnaire was completed at this time as it was not considered temperature sensitive. The acclimation lasted at least 75 minutes. If all the above tasks were completed in a shorter time, an entertaining video film was shown to keep the children busy.

During the school breaks the children needed access to the toilet facilities and they wanted to buy food. It was therefore not possible to keep them in the classroom for the whole day, and a short acclimation phase was introduced after each break. This included:

- 10 minutes for a short break of 5 to 10 minutes (the explanation of a performance test took at least another 5 minutes, so that the shortest acclimation period was 15 minutes), and
- 20 minutes after a long break of 20 to 30 minutes.

During the acclimation phases video films were shown to relieve boredom.

2.6.3 ORGANISATION OF THE EXPERIMENTS

2.6.3.1 APPROVAL, ACCEPTANCE AND SITE SELECTION

Before each experimental series it had to be ensured that:

- the Transvaal Education Department (TED) had given formal permission (in writing) for the experiment;
- the headmaster of the school had been informed about the experiment in detail, agreed to it and had selected a suitable time;
- it was possible to move the caravan with the air-conditioning unit close enough to at least one classroom of the school, and that the headmaster agreed to using that classroom;
- a 60 Ampere, 3-phase power connection was available, either directly or after electricians of the City Council had installed it on request; and
- a circular letter had been distributed to the parents of all children who would be involved in the experiments, and that the objections of all parents or children were registered. Objections were rare.

2.6.3.2 PREPARATION OF THE TEST GROUPS

Randomisation: The children of two, sometimes three, classes assembled in the classroom which had been prepared for the experiment. On the first day of each experiment the children were divided randomly into two groups of equal size, by assigning every even entry on an alphabetically sorted class list to one group, every odd entry to the other.

Assigning of identity discs (ID-discs): Each child was issued with a small ID-disc on a thin chain (Figure 2.2-2). The children were instructed to hang the disk around their neck (Figure 2.2-1). The numbers on the disks were used to identify the children, for example to link their performance data with height measurements and the results of the Writing Speed Test. The answer boxes were also numbered, and the children were requested to take a seat at the answer box with the same number as their ID-disk.

Introductory speech: The children were asked to co-operate in an experiment that would help to build better schools. They were told that the purpose of the experiment was to study the effects of temperature, but they were not informed of the thermal condition in the class.

2.6.4 STRUCTURE OF AN EXPERIMENTAL DAY

Table 2.6-1 shows the sequence of events on an experimental day with schedule number 1 for a Standard 6 class.

NUMBER	ACTIVITY	DURATION (min)
1	Sort test groups	5
2	Issue ID-discs	5
3	Introductory speech	5
4	Height and weight	15
5	Oral temperature	6
6	Finger temperature	3
7	Reaction times	6
8	Acclimation	10
9	Explanation of answering box	10
10	Questionnaire	15
11	Classification	20
12	Break	10
13	Acclimation	10
14	Writing Speed	15
15	Mathematics	25
16	Comparison	20
17	Number Series	20
18	Oral temperature	6
19	Finger temperature	3
20	Reaction times	6
21	Break	30
22	Acclimation	20
23	Memory	20
24	Pattern completion	25
25	O'Connor	10
26	Oral temperature	6
27	Finger temperature	3
28	Reaction times	6
29	Thank children for cooperation	3
TOTAL TIME		338

Table 2.6-1: Schedule of an experimental day for a Standard 6 class.

A similar schedule was used for Standard 3 children. For Grade 2 children the Number Series, Pattern Completion and O'Connor Peg Test as well as the reaction time tests were omitted, and the duration of the remaining tests was reduced (see 2.4).

For schedules 2 and 3 the tests were presented in a different sequence. The sequence for all three schedules is shown in Table 2.6-2.

No.	SCHEDULE 1	SCHEDULE 2	SCHEDULE 3
1	Classification	Comparison	Memory
2	Writing Speed	Number Series	Pattern Complet.
3	Mathematics	Memory	Classification
4	Comparison	Pattern Complet.	Writing Speed
5	Number Series	Classification	Mathematics
6	Memory	Writing Speed	Comparison
7	Pattern Complet.	Mathematics	Number Series
8	O'Connor	O'Connor	O'Connor

Table 2.6-2: Sequence of tests in three different schedules for Standard 3 and Standard 6 children.

2.7 DATA HANDLING AND PREPARATION

2.7.1 DATA COLLECTION, TRANSFER AND CONVERSION

2.7.1.1 OVERVIEW

The flow of data is illustrated in Figure 2.7-1.

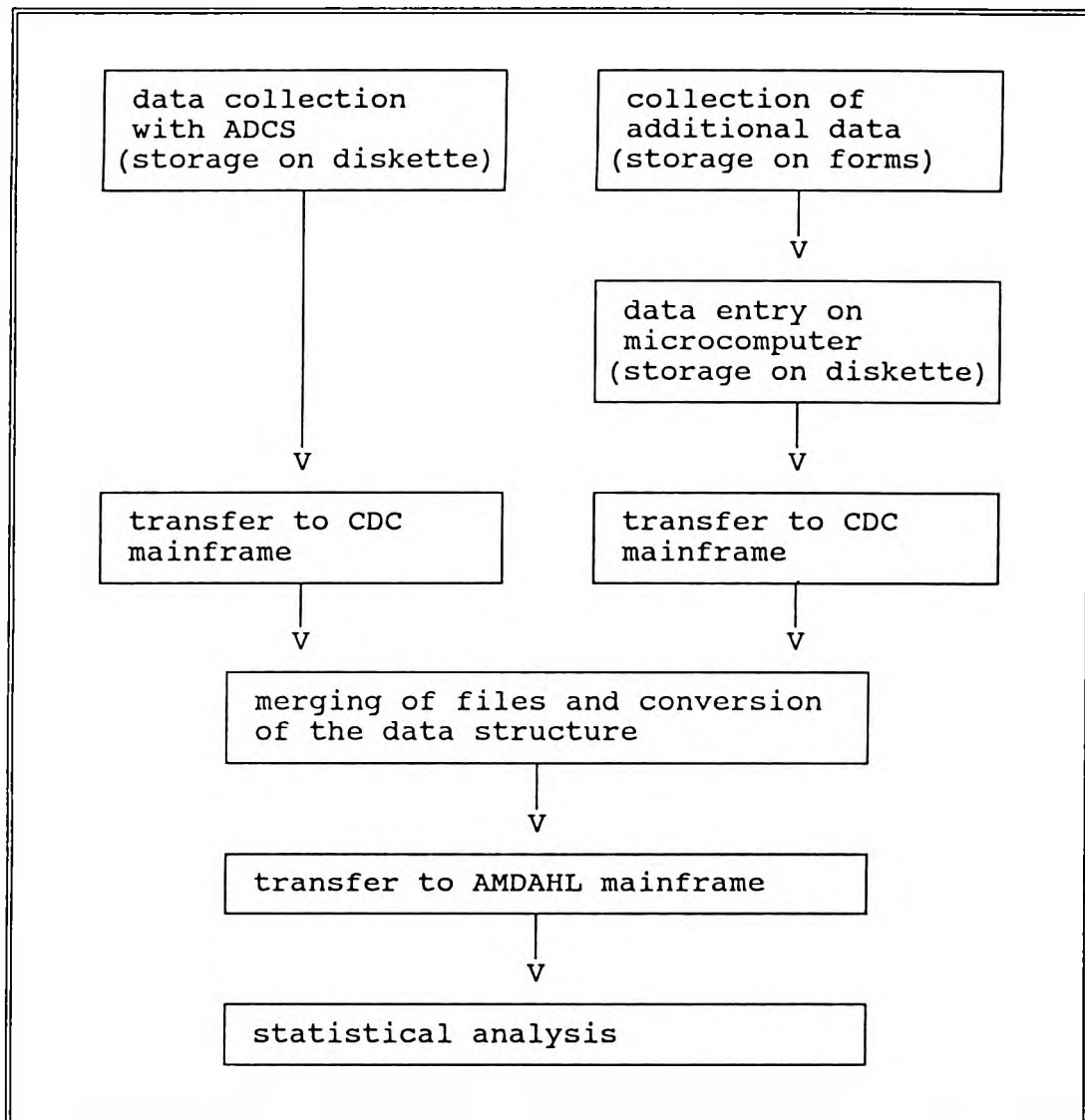


Figure 2.7.1: Collection and transfer of experimental data.

2.7.1.2 INPUT OF ADDITIONAL DATA

Most of the results of the experiments were contained on the data disks of the ADCS, but some types of data could not be integrated into the system. They were:

- heights and weights;
- oral temperatures and times when they were taken;
- air temperature measured with a mercury-in-glass thermometer and times of the measurements;
- noise levels and times of the measurements;
- dates of birth;
- preferred hand; and
- school class to which the children belong.

These data had to be converted into computer readable form. To reduce errors during this conversion a computer program was written (in BASIC on a SHARP MZ-80B) that allowed entry of these data while checking if all the values were within predetermined limits. The data were then stored on magnetic diskettes.

2.7.1.3 DATA TRANSFER

The data were analysed with the statistical package SAS (Statistical Analysis System, SAS Institute Inc., Box 8000, Cary, North Carolina 27511, USA), resident on an AMDAHL mainframe computer at the Centre for Computing Services at the CSIR. Therefore the data had to be transferred from the magnetic diskettes to the mainframe computer.

At the time when the experimental procedures were developed, there was no suitable communication software package available for the SHARP MZ-80B that allowed transmission of data from magnetic diskettes. Therefore an outside contractor with experience in communication protocols was found and contracted to develop such a package. The developed software package (XFER) could facilitate communication with the CDC (Control Data Corporation) mainframe computer of the CSIR, which had a simpler communications protocol. All experimental data on one disk could be transferred with a single command. The data were then transferred from the CDC to the AMDAHL mainframe computer via magnetic tape.

2.7.1.4 CONVERSION OF THE DATA STRUCTURE

Results of experiments were saved on disk in chronological order, as frequent saving of data freed the computers memory and reduced data loss in case of a power failure. The data were organised by test, i.e. the responses of all children on an experimental day to a certain test forming a block of data. For the statistical analysis the data had to be ordered by child. A software program was written to facilitate this conversion. The converted data were read with SAS, and converted into SAS data sets.

2.7.2 PREPARATION OF RESULTS OF THE MULTIPLE-CHOICE-TYPE TESTS

2.7.2.1 FILTERING OF INCORRECTLY ENTERED DATA

The result files of the ADCS contained a special marker in places where a child pressed an X-key instead of a normal answer-key or vice versa. This indicated that the child had got out of step between the last correct X-key press and the marker. Therefore all answers between the last correct X-key press and the marker were deleted. The average number of X-key mistakes by standard and by test is shown in Table 2.7-1.

TEST	GRADE 2	STANDARD 3	STANDARD 6
CLASSIFICATION	1.05	0.08	0.35
COMPARISON	1.03	0.28	0.42
MATHEMATICS	0.84	0.36	0.52
MEMORY	1.03	0.23	0.31
NUMBER SERIES	not used	0.44	0.98
PATTERN COMPLETION	not used	0.62	0.65
MEAN	0.99	0.34	0.54

Table 2.7-1: Means of the number of X-key mistakes per child during one test, by test and by standard.

The tests had on average 60 questions in total and about 4 to 5 questions on each page. The maximum number of X-key mistakes was therefore in the range of 15. At the end of each page was an instruction to press the X-key, therefore the maximum loss of results due to an X-key mistake were the answers derived from one page. With about 3-4 answers lost

per X-key mistake, the total loss of data is in the range <5% for Standard 3 and Standard 6. The Grade 2 children showed a higher occurrence of X-key mistakes, and up to about 10% of all data were lost.

The Personal Questionnaire was always presented to the children as their first task. Besides assessing details about the children's home life, their socioeconomic status and their eating habits, it had the purpose of acquainting the children with their answer boxes. X-key mistakes were therefore quite frequent in the results of the Personal Questionnaire. Observation of the children in the classroom showed that most of these mistakes occurred, when the children forgot to press the X-key at the end of a page without actually getting out of step on the questions. To preserve the bulk of the answers to the Personal Questionnaire, only questions directly identified by marker for X-key mistakes were deleted.

2.7.2.2 IDENTIFICATION OF UNSUITABLE TEST ITEMS

To identify environmental effects on performance the difficulty of the performance tests must be suited to the capabilities of the respondents. If the tests are too easy high scores can be achieved even under adverse conditions; if they are too difficult the score will be low even under ideal conditions. The tests were therefore selected to suit the age and the educational level of the children tested.

It was found during the pilot studies that several tests contained a few items that were much easier or much more difficult than the rest of the items in this test. Sometimes the low score on an item resulted from wording or graphics that led to misunderstandings. Items of this kind were considered unsuitable and were removed during the pilot studies.

The significance of an environmental effect on the performance of a test could be reduced by a few unsuitable items that are either always or never answered correctly. The opportunities to detect unsuitable items during the pilot studies were limited because of the limited sample. It was therefore decided to eliminate unsuitable items also after the data collection was completed. This could be done without introducing bias by:

- basing the elimination of items only on results collected at comfort temperature (as in the pilot studies); and
- eliminating all the results on items identified as unsuitable without exception.

The difficulty values of the items are defined as the percentage of correct answers on each item and the means and the standard deviations of these difficulty values were calculated by test and by educational standard. If the difficulty value of an item was more than two standard deviations from the mean, all results on this item (on stress and control days for all experiments in the respective standard) were deleted.

The ADCS had stored the response times for each answer and the item response times were calculated as the mean of all response times on each item. Means and the standard deviations of the item response times were calculated by test and educational standard. If an item response time was more than two standard deviations from the mean, all results on this item (on stress and control days for all experiments in the respective standard) were also deleted. In this process about 3 questions per test (5% of all questions) were eliminated. Table 2.7-2 shows the percentage of questions answered correctly and mean response times per question for control days (24°C) after the removal of unsuitable items.

T E S T	GRADE 2		STANDARD 3		STANDARD 6	
	%	IRT	%	IRT	%	IRT
CLASSIFICATION	73	12	85	7	82	7
COMPARISON	71	14	86	10	78	13
MATHEMATICS	79	12	57	25	56	26
MEMORY	75	10	68	10	58	9
NUMBER SERIES	not used		81	11	59	15
PATTERN COMPLETION	not used		57	15	54	15
MEAN	75	12	72	13	65	14

Table 2.7-2: Means of the item difficulty values (%) and item-response times (IRT in seconds) on control days.

2.7.2.3 CALCULATION OF STANDARDISED PERFORMANCE TEST SCORES

Measures of performance should not be affected by answers that were deleted in the filtering procedures described

above or because of an X-key error. For each child and each test the number of valid answers, i.e. the responses to items that were not marked invalid, was counted, and the sum of the response times to these items was calculated. The first answer in each test was ignored, because the electronic clocks measuring the answer times were started at the same time for all children, but not all children could be persuaded to start immediately. The working SPEED was calculated as:

$$\text{SPEED} = \frac{600}{(\text{sum of response times}) / (\text{total of all answers})}$$

The response times were expressed in seconds, and the denominator in the SPEED formula is the average time required to give an answer. SPEED is the number of answers the child will give on a certain test in 10 minutes (600 seconds).

The POWER score is the average number of correct questions a child will give in 10 minutes. It was calculated as:

$$\text{POWER} = \frac{600}{(\text{sum of response times}) / (\text{total of correct answers})}$$

The ACCURACY score, the percentage of correct answers of all answers given by a child in a certain test, was:

$$\text{ACCURACY} = \frac{(\text{total of correct answers})}{(\text{total of all answers})} * 100$$

2.7.2.4 IDENTIFICATION OF UNCOOPERATIVE CHILDREN

Most children that took part in this experiment were eager to co-operate. The experiment was seen as a welcome break in the school routine. A few children gave the impression that they keyed in their answers after a short guess, so that they could give a cooperative impression without working hard or admitting that they did not understand the test.

These children can be identified by a high working SPEED and a low ACCURACY. Figures 2.7-2 to 2.7-4 show the frequency distributions for POWER, SPEED and ACCURACY for the Standard 6 Classification Test. Frequency distributions for other tests and for children of other age groups were similar. The tail on the right (high) side of the SPEED graph was probably due to children who answered without due regard for accuracy. If they had been genuinely better performers the POWER graph would also show a tail on the high side. Instead the ACCURACY graph has a tail on the left (low) side, corroborating the suggestion that there were a number of children who stressed speed at the cost of accuracy. The arrows in Figures 2.7-2 to 2.7-4 indicate the range of two standard deviations from the mean.

Deleting all data outside the 2 standard deviation range might have removed individuals that were especially sensitive to temperature. Therefore means and standard deviations of the ACCURACY score were calculated for each experimental day and each test and the results of a test (POWER, SPEED and ACCURACY) were only deleted when the ACCURACY score was lower than the mean minus two standard deviations.

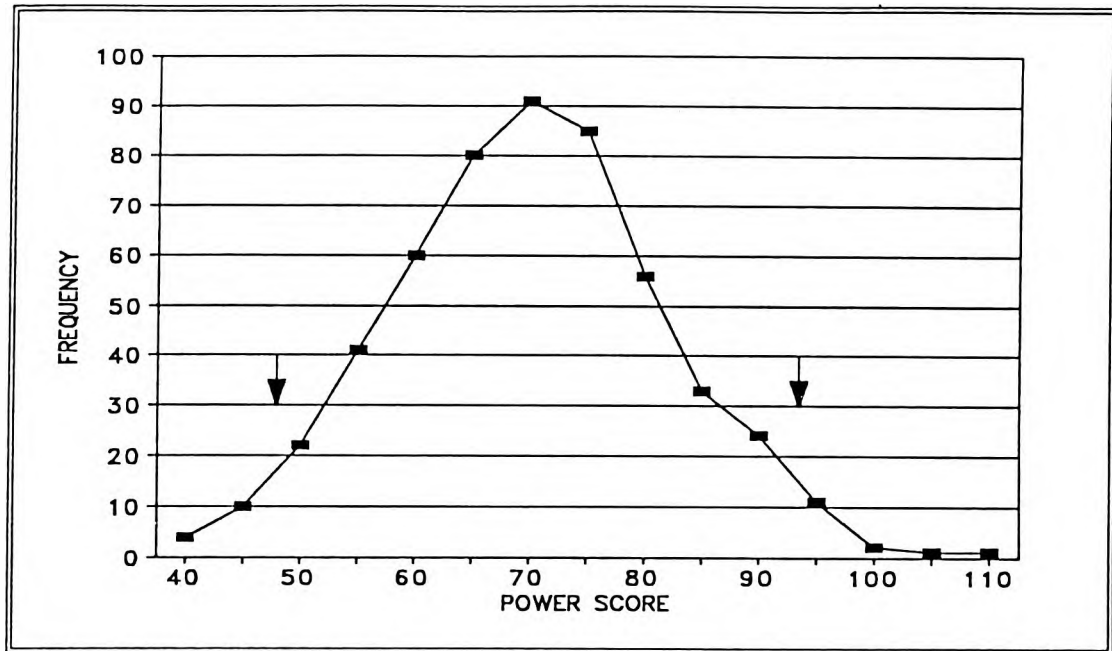


Figure 2.7-2: Frequency distribution for the POWER scores of the Classification Test for Standard 6 at 24°C.

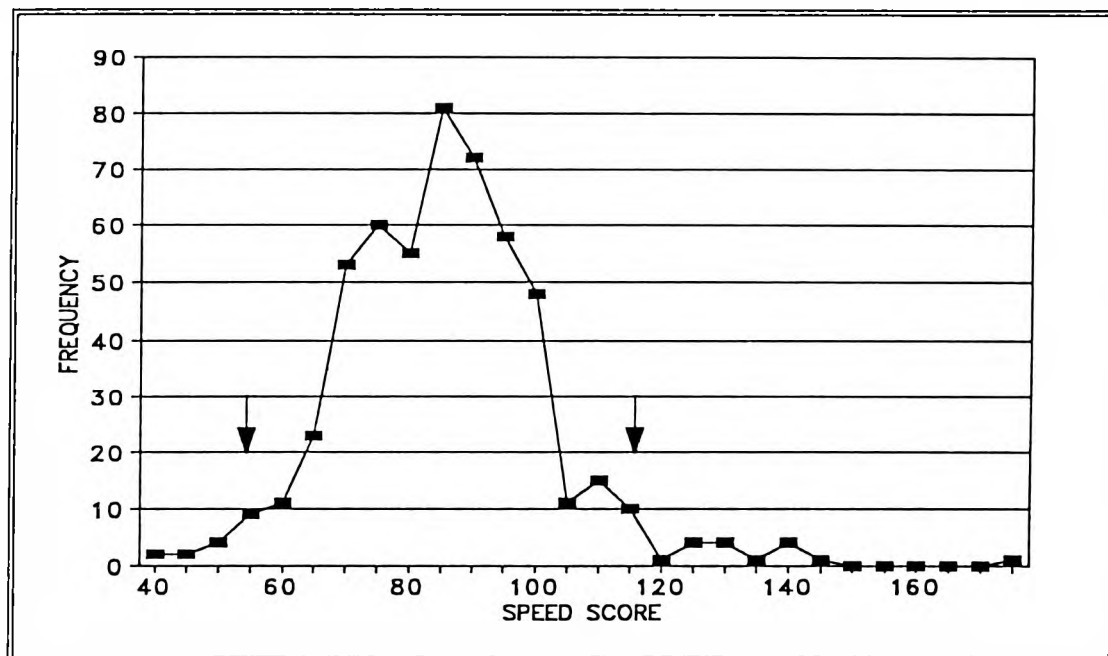


Figure 2.7-3: Frequency distribution for the SPEED scores of the Classification Test for Standard 6 at 24°C.

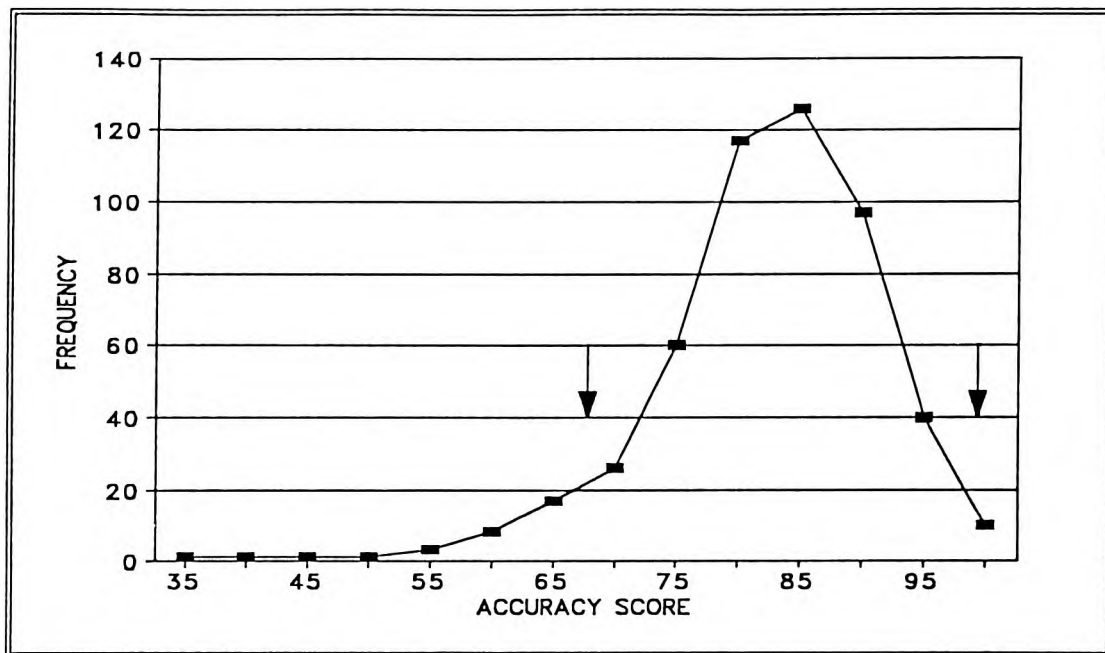


Figure 2.7-4: Frequency distribution for the ACCURACY scores of the Classification Test for Standard 6 at 24°C.

2.7.3 PREPARATION OF RESULTS OF THE O'CONNOR PEG AND THE WRITING SPEED TEST

2.7.3.1 O'CONNOR PEG TEST

After a short training session the children were instructed to insert 45 x 3 pegs into a pegboard and to press button "A" on their answer box after completion. Faulty results due to early key presses are unlikely because:

- the answer boxes were programmed not to respond to key presses for the first two minutes of this test, because no child ever finished the test in this time, but some

children tended to play with their boxes before they started working on the test;

- the children were never observed to play with their boxes once they had started the O'Connor Peg Test; and
- the experimenters observed the children carefully during the test.

Faulty results due to late key presses were unlikely because of the competitive spirit and supervision by the experimenters. The results of the O'Connor Peg Test were therefore used without data filtering. The results consisted of times recorded to fill 45 holes (with 3 pegs each), i.e. in this test the score value decreased with increasing performance. To bring the results in line with the other tests, the times were converted to the number of holes a child could fill in 10 minutes with its calculated working speed.

$$\text{score} = \frac{600}{(\text{seconds required to fill 45 holes}) / 45}$$

2.7.3.2 WRITING SPEED TEST

The results of the Writing Speed Test were verified by comparison between the score achieved on the ADCS and the number of lines filled on the test form. As the lines on the Writing Speed form were numbered, it was possible to determine the performance score of a child with a single inspection. The children were asked to write the number of

their ID-disk on the Writing Speed form. When the difference between the ADCS score and the number of lines filled on the form was greater than three it was assumed that the child had either marked the form with the wrong ID-disk number or that he had not pressed the answer keys appropriately. In this case the score was deleted. Visual inspection of the forms did not reveal cases where children had produced totally illegible characters, therefore no scores were deleted because of insufficient legibility.

2.7.4 PREPARATION OF RESULTS OF THE REACTION TIME TESTS

In all reaction time tests the children had to perceive the change on the display of their answer box, move their index finger to the response key and press it. Practical tests with the ADCS and analysis of the results indicated that this could not be accomplished in less than 0.1 seconds. Shorter reaction times were only produced when the children ignored their instructions, for example by keeping the response key pressed down. Therefore all response times shorter than 0.1 seconds were deleted.

Observation indicated that even slow responders took less than 1.5 seconds to perform the Choice Reaction Time Test (CRT). The response time for the Simple Reaction Time Test (SRT) was shorter. Therefore all reaction times longer than 1.5 seconds were deleted. To facilitate comparison of the impact of temperature on the performance of different tests, and for calculating the correlations between test scores, the performance on both reaction time tests was expressed as "reaction speed", which was calculated as the inverse value of the reaction time:

$$(\text{reaction speed}) = \frac{1}{(\text{reaction time})}$$

2.7.5 ORAL TEMPERATURE

Figure 2.7-3 shows a frequency distribution of oral temperatures for Standard 6 children at 24°C.

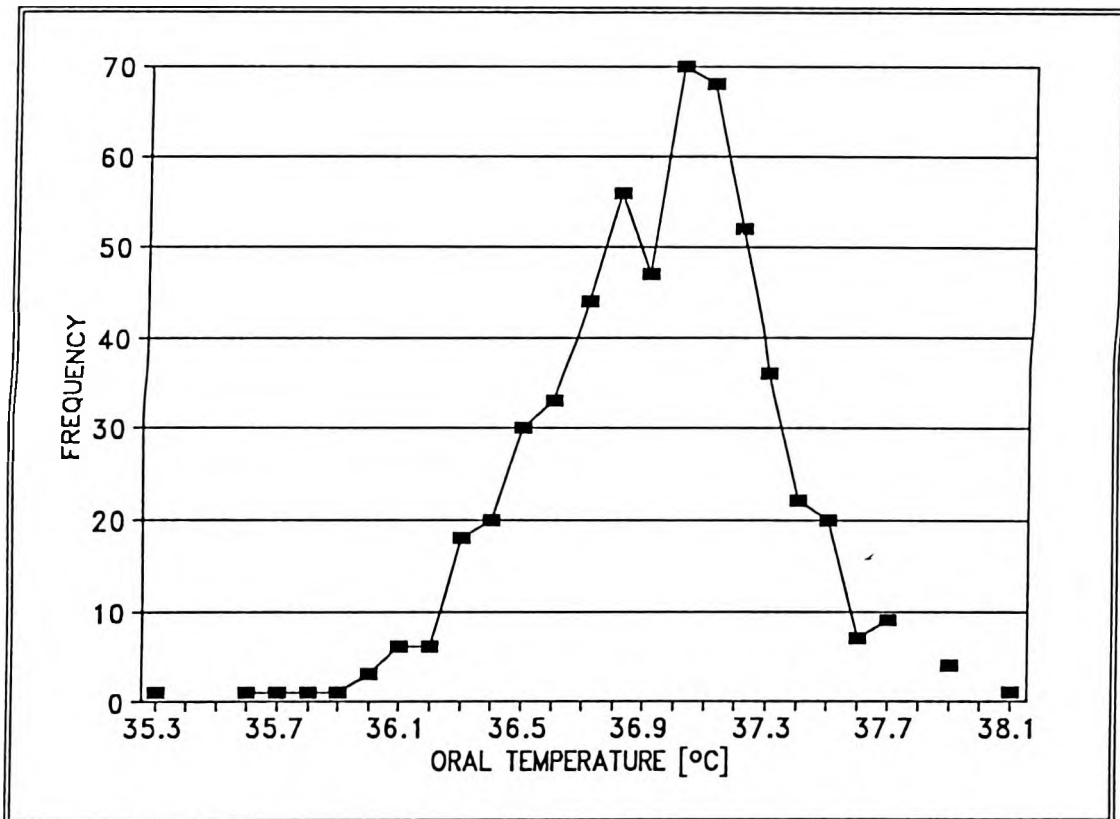


Figure 2.7-5: Frequency distribution of oral temperatures of Standard 6 children at 24°C measured during the late morning.

The measurements were taken during the late morning at approximately 11:00. The shape of the curve indicates a normal distribution with a tail at the high end (possibly due to fever) and a longish tail at the low end (possibly due to breathing through the mouth).

Table 2.7-3 indicates that different age groups have different distributions of oral temperature at a given room temperature. The proportion of oral temperature measurements above 37.4°C and above 37.6°C decreased with age.

	GRADE 2	STANDARD 3	STANDARD 6
No. of children	162	172	473
% above 37.4°C	24.4	14.2	7.3
% above 37.6°C	6.7	4.0	2.0
% above 37.8°C	1.0	1.3	0.4
% above 38.0°C	0.5	0.4	0.1

Table 2.7-3: Percentage of all oral temperatures measured at 24°C air temperature above a given level.

Means and standard deviations were calculated by educational standard, by temperature condition and by time-of-day (early morning, late morning and after lunch). Measurements that were more than two standard deviations from the mean of their category were deleted.

2.7.6 FINGER TEMPERATURE

Two sources of faulty finger temperature readings were:

- bad contact between finger and sensor resulting in a low reading; and
- sunshine on the sensor resulting in a too high reading.

Means and standard deviations were calculated by standard, by temperature condition and by time-of-day (early morning, late morning and after lunch). Measurements that were more than two standard deviations from the mean of their category were deleted.

2.7.7 PONDERAL INDEX

Obesity influences the response of the body to thermal stress (Haymes et al. 1975) and might therefore help to explain part of the inter-individual variation. The ponderal index (Broman et al. 1942) is a measure of body shape. The higher the weight of people with a given height, the higher is their ponderal index. It is calculated as:

$$(\text{ponderal index}) = \frac{\text{weight}^{** (1/3)}}{\text{height}}$$

where "**" is used as a symbol for exponentiation. The ponderal indices of all children were calculated and added to the data set.

2.8 STATISTICAL METHODS

2.8.1 GENERAL LINEAR MODEL (GLM)

This study is based on a factorial design which, by using every combination of a series of treatments and experimental conditions, allows the average effects and their interactions with one another to be estimated simultaneously (John and Quenouille, 1977).

In the analysis the total sum of squares (i.e. squared distances of the scores from the overall mean of the experiment) is divided into component parts. Each part should represent a source of variation the experimenter wants to control or to evaluate (Kirk, 1968).

The statistical significance of a factor is evaluated with the F- statistic. The F-value is derived as:

$$F = \frac{(\text{SS of factor } x) / (\text{df for } x)}{(\text{SS unexplained}) / (\text{df for unexplained})}$$

where "SS" stands for "sum of squares", and "df" for "degrees of freedom". An F-distribution is used to convert the F-value according to its size and the available degrees of freedom into a probability. "Unexplained" describes the sum of squares not allocated to any factor or interaction between factors. It depends obviously on the factors that have been introduced in the analysis before the significance of factor x is tested.

It should be noted that the introduction of an irrelevant factor for example the first letter of the surname, would naturally explain little variation but would, by reducing the degrees of freedom, also reduce the significance of the other effects tested in the same model. However, omitting an important factor which explains a large portion of the sum of squares would set the remaining factors against a larger unexplained sum of squares and so reduce their significance.

The procedure GLM (General Linear Model) of the statistical package SAS performs the calculation of the total sum of squares, its partitioning, the calculation of the F-value and its conversion into a probability value (Freund et al. 1986). The description of GLM analyses in the present study is illustrated by the following arbitrary example:

```
analysis:  GLM

model:     score = experiment, type

variables: score:
            Classification[power], Comparison[accuracy]

            experiment:
              {class variable; each class being a pair of
               a stress day and its control day})

            type:
              {class variable, discriminating between
               stress and control days}

data:      stress and control days
           [Std6, Std3, Grd2] x [14°C, 19°C, 29°C, 34°C]
```

"Model" states the dependent variable (score) and the independent predictor variables (experiment and type). An "*" between two variable names describes an interaction term (sex * age).

The different values of a variable for which a separate analysis was performed are described in the "variables" section. In the above example the variable "score" represents either the power score of Classification or the accuracy score of Comparison. Two lists in square brackets linked by an "x" stands for all possible pairs of elements from the two lists.

"Data" describes the part of the total data base with which the analysis was performed.

2.8.2 SIGN TEST

The sign test gets its name from the fact that it uses plus and minus signs rather than quantitative measures as its data. It is applicable to the case of two related samples, when the experimenter wishes to establish whether two conditions are different.

The only assumption underlying this test is that the variable under consideration has a continuous distribution. The test does not make any assumptions about the form of the distribution, nor does it assume that all subjects are drawn from the same population. The different pairs may be from different populations with respect to variables such as age

and sex; the only requirement is that within each pair the experimenter has achieved matching with respect to the extraneous variables.

The null hypothesis tested by the sign test is:

$$p (X_a > X_b) = p (X_b < X_a) = 1/2$$

where X_a is the score under one of the conditions and X_b is the score under the other condition. Another way of stating the null hypothesis is: the median difference is zero. The test may be either one-tailed or two-tailed. In a one-tailed test the advance prediction states which sign will occur more frequently. In the present study the two-tailed test was used as it could not be predicted in advance if the temperature would improve or reduce performance.

The power-efficiency of the sign test is about 95% for $N=6$ but declines as the size of the sample increases asymptotically to 63%. The power of a statistical test is the probability of rejecting the null hypothesis when it is false. The power-efficiency indicates how much power a test has at a given sample size as compared with the most powerful parametric test when used with data that meet its conditions (Siegel, 1956).

2.8.3 FACET ANALYSIS

Facet Analysis provides a set of tools for conceptualising complex problems and for organising and interpreting multi-variate data. A central technique is smallest-space analysis, a form of multidimensional scaling. The analysis provides a geometric representation of the different variables as points in a Euclidian space. The distance between pairs of points in the space corresponds to the correlations of the variables. Hence two points are closer if the correlation between the variables is higher (Brown, 1985).

In essence, the computing algorithm calculates the rank order of the correlations between all variables. It then generates a spatial representation of those variables, with points representing variables and distances between the points the rank-orders. An iterative procedure is used which compares the ranks of the correlations with the ranks of the distances, altering the configuration until the best fit is achieved between the two sets of ranks. A limitation is set by the researcher on the dimensionality of the space in which the configuration is generated. In the present study only two-dimensional Facet Diagrams were used.

Unlike in factor-analytic procedures, the axes of the configuration of Facet Diagrams are arbitrary. Because the Facet Diagram is developed from the relationships among variables, and not from their relationships to some nominal "dimension" or "factor", the pattern of the points (their regional distribution) can be examined directly (Canter, 1983).

The Guttman-Lingoes coefficient of alienation is a measure of the proportion of variation in the data that is expressed by the arrangement of data-points in a Facet Diagram (Brown, 1985). A coefficient of alienation of "0" indicates that all the variation is expressed. The closer the value is to "1" the less variation is expressed. The coefficient of alienation is given in the legend of all Facet Diagrams of the present study.

A facet is a classification of data into mutually exclusive groups. The facet "sex", for example, has the mutually exclusive elements "male" and "female". The value of a facet in explaining the structure of data is high when it is possible to group the data points in a smallest-space analysis diagram according to the elements of this facet with a minimum of overlap. The facet "sex" has a high explanatory value when the male scores form a region on one side of the diagram, and the female scores form a region on the other side.

The correlation between scores was calculated by using Spearman's rank order correlation (Siegel, 1956). Positioning of the data points in a two-dimensional space according to their correlation was achieved with the procedure MDS of the statistical package SYSTAT (produced by Systat Inc., Illinois 60201, USA) according to the method of Guttman and Lingoes (Guttman 1968; Lingoes, 1973). Part of the calculations were repeated with the procedure ALSCAL for Kruskal-Shephard "non-metric scaling" of the statistical package SAS (du Toit et al. 1984). The agreement between the two methods was satisfactory.

3.1 STRUCTURE OF THE RESULTS PRESENTATION

PART	HEADING AND CONTENT
3.2	<u>Description of sample sizes</u> Tables illustrate how many children in which categories were tested.
3.3	<u>Differences in performance on stress and control days</u> The differences were expressed as a percentage of the performance on the control day and were presented in tabular and graphical form.
3.4	<u>Effects of room temperature on test performance</u> The predictive value of room temperature for performance scores was determined with a General Linear Model (GLM). This included: - an investigation of concomitant variables; - an investigation of higher-order effects; - a table of significance values for all scores under all conditions; and - results and summary tables for the percentage of variation in performance attributable to room temperature.
3.5	<u>Predictive value of body temperatures and comfort vote</u> Correlations between performance and: oral temperature, finger temperature and comfort vote were calculated and the predictive value of these parameters and room temperature was compared.
3.6	<u>Inter-individual variation at different temperatures</u> Coefficients of variation for scores achieved at different temperatures were compared to investigate if some sub-groups were more strongly affected than the average
3.7	<u>Facet Analysis</u> Patterns in the data were analysed by interpretation of graphical output based on non-parametric correlations.
3.8	<u>Effects of room temperature on combined scores</u> Combined scores were calculated from the performance tests as suggested by the Facet Analysis. The effect of room temperature on these scores was investigated.

3.2 DESCRIPTION OF SAMPLE SIZES

The results of 1642 children were used in this analysis. The different educational standards were represented as follows:

- Standard 6: 956;
- Standard 3: 357; and
- Grade 2: 329 children.

The number of children participating in different tests at different experimental conditions are shown in Table 3.2-1. Conditions at which no experiments were performed were marked with a dot.

To assess patterns in performance in detail it was decided to increase the sample size significantly with one group of children. As access to Standard 6 children was most easily gained, this standard was chosen for the largest sample sizes. Because of organisational problems no valid sample could be obtained with Grade 2 children at 19°C.

Grade 2 children had a shorter attention span and more problems coping with written material than older children; in addition, their school days were much shorter. Therefore the test battery had to be reduced for Grade 2 children, and the following tests were omitted:

- Number Series;
- Pattern Completion;
- Peg Test;
- SRT (Simple Reaction Time); and
- CRT (Choice Reaction Time).

	Grade 2				Standard 3				Standard 6			
°C	14	19	29	34	14	19	29	34	14	19	29	34
CLASSIFIC.	143	.	76	95	104	48	134	58	216	241	134	299
COMPARISON	146	.	74	97	79	50	134	59	182	267	133	297
MATHEMATICS	86	.	77	94	105	50	136	59	218	275	118	311
MEMORY	141	.	53	92	103	49	136	58	218	271	121	309
NUMBER SERIES	.	.	.	.	79	.	96	57	219	214	134	307
PATTERN COMP.	.	.	.	.	105	50	101	59	220	246	137	281
PEG TEST	.	.	.	.	81	.	106	60	172	154	116	245
WRITING SPEED	81	.	32	98	103	49	135	58	215	196	114	259
SRT 1	.	.	.	.	64	32	81	40	138	170	76	187
2	.	.	.	.	60	33	82	39	135	160	81	190
3	.	.	.	.	69	.	64	36	81	118	63	180
CRT 1	.	.	.	.	50	26	51	25	114	135	69	141
2	.	.	.	.	51	25	72	29	118	153	68	162
3	.	.	.	.	52	.	56	31	76	110	61	168

Table 3.2-1: Number of children who took part in performance tests on stress and control days.

With 804 boys and 838 girls the representation of the sexes was sufficiently balanced. Table 3.2-2 gives a gender breakdown by standard and temperature condition.

	Grade 2				Standard 3				Standard 6			
°C	14	19	29	34	14	19	29	34	14	19	29	34
boys	80	.	43	53	55	32	69	30	90	130	63	159
girls	71	.	35	47	52	19	70	30	133	150	75	156
TOTAL	151	.	78	100	107	51	139	60	223	280	138	315

Table 3.2-2: Number of children who took part in experiments at different conditions.

The means of ages, weights and heights of the children are shown in Table 3.2-3.

		Grade 2		Standard 3		Standard 6	
		boys	girls	boys	girls	boys	girls
AGE [years]	mean	8.1	8.1	11.0	11.9	13.7	13.6
	SD	0.5	0.4	0.4	0.4	0.5	0.4
WEIGHT [kp]	mean	27.0	26.6	36.6	37.2	51.0	50.8
	SD	4.7	4.6	6.6	7.7	9.6	8.7
HEIGHT [cm]	mean	128.6	129.2	145.0	146.2	162.4	161.6
	SD	5.7	5.9	6.7	6.9	8.4	6.3

Table 3.2-3: Means of the ages, weights and heights of boys and girls in Grade 2, Standard 3 and Standard 6.

3.3 DIFFERENCES IN PERFORMANCE ON STRESS AND CONTROL DAYS

The level of performance between children drawn from different schools varied considerably. To allow comparison of results obtained with different groups of children, the differences in performance between stress days and control days of each experiment were expressed as a percentage of the performance on the control day. The results shown in Table 3.3-1 were derived through the following operations:

- A) for each score type (for example "power") for each test (for example Classification) the mean value for the stress day and the mean value for the control day were calculated; and
- B) the relative difference in performance (RDP) was calculated by test and score type as:

$$\text{RDP} = \frac{(\text{mean on stress day}) - (\text{mean on control day})}{(\text{mean on control day})} * 100$$

For the purpose of analysis the results of experiments performed at the same condition (for example with Standard 3 children at 19°C) were combined. As the number of subjects varied between the experiments, the combined RDPs were calculated as weighted means in the following manner:

- C) for each score type and each test the RDPs of all experiments were multiplied by the number of children who participated in the test (stress plus control day);

D) for each score type and each test the multiplied RDPs were added and the sum was divided by the total number of children in all experiments who participated in the test.

		Grade 2				Standard 3				Standard 6			
°C		14	19	29	34	14	19	29	34	14	19	29	34
CLA	power	-10	.	8	2	-4	-2	2	-1	0	8	-1	5
	speed	-13	.	18	14	-5	-1	4	-2	-1	8	-1	3
	accur.	3	.	-8	-10	2	-2	-1	2	1	-1	0	2
COM	power	-10	.	5	10	-11	-3	7	9	5	5	-1	7
	speed	-9	.	11	18	-14	-1	6	11	1	5	-5	4
	accur.	-1	.	-5	-5	3	-1	1	-1	4	0	5	3
MAT	power	-17	.	-8	-5	-3	18	-6	17	8	1	-10	10
	speed	-14	.	8	0	-6	23	-13	16	16	2	-18	-13
	accur.	-3	.	-10	-3	2	-5	7	1	-2	1	1	21
MEM	power	-2	.	-11	4	2	1	7	0	12	18	3	14
	speed	-1	.	15	1	2	3	8	1	2	11	-2	7
	accur.	-3	.	-19	3	1	-3	-1	-2	8	4	6	6
NUM	power	.	.	.	.	-10	.	2	-3	8	5	-10	7
	speed	.	.	.	.	-9	.	2	-2	5	8	-11	-1
	accur.	.	.	.	.	-1	.	-1	-1	4	-2	-1	7
PAT	power	.	.	.	.	0	3	1	-5	5	1	1	9
	speed	.	.	.	.	-9	14	14	-1	6	-4	0	-4
	accur.	.	.	.	.	12	-5	-6	-5	1	3	-1	12
PEG TEST		.	.	.	.	-10	.	14	0	-13	-17	3	-8
WRITING SPEED		-17	.	-1	-3	-3	2	7	4	1	0	-7	2
SRT	1	.	.	.	.	2	-8	3	9	0	6	1	10
	2	.	.	.	.	-11	-1	0	12	3	0	1	4
	3	.	.	.	.	-8	.	6	16	15	-10	-7	6
CRT	1	.	.	.	.	-3	-1	-12	5	-1	-1	-7	-10
	2	.	.	.	.	3	12	-2	-3	-13	-22	4	-2
	3	.	.	.	.	11	.	-6	16	3	-10	12	1

Table 3.3-1: Percentage increment or decrement of performance on stress days as compared with control days.

3.4 EFFECTS OF ROOM TEMPERATURE ON TEST PERFORMANCE

3.4 1 AIM OF THE ANALYSIS

The statistical significance of the relationship between room temperature and different scores on performance tests, as well as the percentage of variation of these scores attributable to temperature was to be determined.

It was further to be determined if sex of the child, the time-of-day when the test took place as well as any of the additional variables measured for each pupil, such as height, had any bearing on the temperature relationship.

The percentage of variation attributable to the difference between stress and control days at different experimental conditions is presented for all conditions and in summary tables.

3.4.2 SIGNIFICANCE OF THE TEMPERATURE EFFECT

To gain an overview of the effects of temperature on the performance of all children the significance of the difference in performance between stress and control days was investigated on all test scores at all temperatures as follows:

```

analysis:  GLM

model:      score = experiment, sex, type, type*sex

variables:  score:
            [Classification, Comparison, Mathematics,
             Memory, Number Series, Pattern Completion]
            x
            [power, speed, accuracy],

            Peg Test, Writing Speed,

            [SRT, CRT] x [first, second, third]

            experiment:
              {class variable; each class being a pair of
               a stress day and its control day}

            sex:
              {class variable with two classes}

            type:
              {class variable, discriminating between
               stress and control days}

data:       stress and control days
            [STD6, STD3, GRD2] x [14°C, 19°C, 29°C, 34°C]

```

Details on the GLM analysis and the format of description used above can be found in 2.8.1. The resulting significance levels for "type" after compensation for all other variables are given in Table 3.4-1. Table 3.4-1 does NOT allow the comparison of temperature sensitivity between standards because the average number of children involved in experiments at a certain temperature was different for each standard. This can be seen from Table 3.2-1.

		Grade 2				Standard 3				Standard 6			
°C		14	19	29	34	14	19	29	34	14	19	29	34
CLA	power	043	.	-	-	-	-	-	-	-	006	-	009
	speed	004	.	009	007	-	-	-	-	-	005	-	-
	accur.	-	.	-	003	-	-	-	-	-	-	-	-
COM	power	001	.	-	-	-	-	027	020	-	-	-	005
	speed	024	.	-	006	043	-	-	014	-	-	-	-
	accur.	-	.	-	-	-	-	-	-	-	-	029	-
MAT	power	-	.	-	-	-	-	-	049	-	-	-	010
	speed	-	.	-	-	-	-	-	036	004	-	026	000
	accur.	-	.	-	-	-	-	-	-	-	-	-	000
MEM	power	-	.	-	-	-	-	-	-	-	002	-	002
	speed	-	.	-	-	-	-	-	-	-	001	-	006
	accur.	-	.	-	-	-	-	-	-	019	-	-	-
NUM	power	.	.	.	.	-	.	-	-	032	-	018	005
	speed	.	.	.	.	-	.	-	-	-	-	020	-
	accur.	.	.	.	.	-	.	-	-	-	-	-	017
PAT	power	.	.	.	.	-	-	-	-	-	-	-	036
	speed	.	.	.	.	-	-	-	-	-	-	-	-
	accur.	.	.	.	.	-	-	-	-	-	-	-	041
PEG TEST		.	.	.	.	-	.	018	-	001	013	-	001
WRITING SPEED		007	.	-	-	-	-	012	-	-	-	033	-
SRT	1	.	.	.	.	-	-	-	-	-	018	-	001
	2	.	.	.	.	028	-	-	-	-	-	-	-
	3	.	.	.	.	-	.	-	032	-	-	-	035
CRT	1	.	.	.	.	-	-	-	-	-	-	-	-
	2	.	.	.	.	-	-	-	-	007	000	-	-
	3	.	.	.	.	-	.	-	-	-	-	-	-

Table 3.4-1: Significance levels of performance differences between stress and control days in abbreviated format: "043" stands for " $p < 0.043$ ". For $p < 0.01$ the levels were printed bold and for $p \geq 0.05$ they were replaced by a hyphen. A dot indicates that no experiments were performed.

A significance level of 5% or $p < 0.05$ indicates that the probability of the difference in performance between stress and control day being achieved by chance is smaller than 5%. The smaller the difference between the mean performances on the stress and the control day, the larger a sample is required to prove that this difference is statistically significant on a given level (Kirk, 1968). The larger sample size used with Standard 6 children is therefore one of the reasons why most of the significant temperature effects were found in this group. Therefore the number of subjects participating in the experiment should always be considered in conjunction with the significance of the findings when results for different conditions are compared.

3.4.3 EFFECTS OF OTHER VARIABLES ON PERFORMANCE

3.4.3.1 NOISE LEVELS

To establish if the difference in noise level between stress and control days was negligible, the noise levels were measured during most experiments. (Noise measurements during some experiments with Grade 2 and Standard 6 children could not be performed, as the noise level meter had been stolen.) The mean noise levels measured in experiments at different temperatures, including the noise produced by the instruction films and the children, are given in Table 3.4-2.

	n	Leq	L1	L10	L50	L90
		mean SD	mean SD	mean SD	mean SD	mean SD
14°C stress control	3	75 4	84 3	79 3	67 5	57 2
	3	69 5	79 4	73 5	61 6	54 4
19°C stress control	5	73 3	83 4	76 5	62 5	57 4
	5	73 2	84 2	78 2	63 5	55 4
29°C stress control	5	70 2	81 2	73 3	60 3	54 2
	4	71 3	81 3	75 4	63 3	56 3
34°C stress control	6	70 3	81 3	73 3	60 2	54 1
	6	70 1	81 1	73 2	60 2	54 2

Table 3.4-2: Means and standard deviations of five noise level measurements on stress and control days at four temperature conditions. The results are given in dB(A) and "n" is the number of experimental days on which noise measurements were performed.

The noise level measurements are described in 2.6.1. Only at 14°C were the stress days found to be slightly more noisy than the control days. At this temperature the cooling compressors worked at their limits and were active most of the time. The most appropriate measure seems therefore the noise level that was exceeded for 50% of the time: L50. At this measure the stress days were on average 6dB(A) more noisy than the control days. The literature discussed in 1.7.2 indicated that such small differences in the level of meaningless noise do not have measurable effects on performance. It was therefore assumed that the effect of noise on performance as measured in this experiment could be safely disregarded.

3.4.3.2 SEX DIFFERENCES

It was to be investigated whether the effect of temperature on the results of boys and girls was similar enough to justify analysing their results together, and make general statements about the effect of temperature on children, or whether a significant interaction between the effect of temperature and sex would require separate analysis. An investigation of the differences in test performance between boys and girls apart from their interaction with the effect of temperature was not part of the present study, but the possibility of different reactions of boys and girls to mild thermal stress was of particular interest.

The analysis described in 3.4.2 included the variable "sex" as well as a term for the interaction between temperature and sex. The interaction between temperature and sex was significant at the 1% level for 5 out of 256 relationships at the following conditions:

- Grade 2, 34°C, Comparison, accuracy;
- Standard 3, 14°C, Mathematics, accuracy;
- Standard 6, 19°C, Memory, power;
- Standard 6, 19°C, Memory, speed; and
- Standard 6, 34°C, SRT, second measurement.

For this number of relationships and at this significance level about three values can be expected to occur as significant by chance. The results indicated therefore that the influence of the variable "sex" on the relationship between temperature and performance was negligible.

To establish how the variation attributed to the variable "sex" influenced the significance of the relationship between temperature and performance, a further GLM analysis was performed similar to that described in 3.4.2 but without the variable "sex" or its interaction with "type".

In the analysis including "sex" 24 relationships were found to be significant at the 1% level (see Table 3.4-1). In the analysis excluding "sex" the same relationships were found to be significant at the 1% level with only two exceptions:

- Standard 3, 29°C, Writing Speed
(sex included: $p < 0.012$,
sex excluded: $p < 0.006$); and
- Standard 6, 14°C, Memory, accuracy
(sex included: $p < 0.019$,
sex excluded: $p < 0.007$).

Because of these findings it was decided to combine the results of boys and girls and to analyse the effect of temperature on children without further reference to their gender.

3.4.3.3 TIME-OF-DAY

All experiments, consisting of a stress day and its control day, were conducted according to one of three schedules. The schedules defined the order in which the tests were administered. The purpose of the schedules was to

investigate any possible connection between the time-of-day when a test was conducted and the way this test was influenced by temperature. The O'Connor Peg Test was excluded from this analysis, as it was not always part of the schedules; it was presented always at the end of each experimental day (see Table 2.6-2).

The variable "schedule" was not used on its own as each experiment was conducted according to one schedule only. After compensating for the variation explainable by "experiment", no variation would be left to be attributed to "schedule". The variable "schedule" is therefore only used in the interaction term. The following analysis was used:

```
analysis:  GLM
model:     score = experiment, type, type * schedule
variables: score:
            [Classification, Comparison, Mathematics,
            Memory, Number Series, Pattern Completion]
            x
            [power],
            Writing Speed
            experiment:
            {class variable; each class being a pair of
            a stress day and its control day}
            type:
            {class variable, discriminating between
            stress and control days}
            schedule:
            {class variable; one class for each of the
            three schedules}
data:      stress and control days
            [STD6, STD3, GRD2] x [14°C, 19°C, 29°C, 34°C]
```

No interaction was significant at the 1% level and possible interaction effects were therefore not considered any further.

3.4.3.4 PUPIL DATA

From each pupil the following data were collected:

- weight (in kp);
- height (in cm);
- ponderal index (calculated from weight and height, as described in 2.7.8);
- preferred hand (right or left); and
- age (in months calculated from the birth date).

It was to be investigated whether sufficient variation in the performance data could be attributed to any of the variables among the pupil data to have an effect on the analysis of a potential temperature effect.

To select the variables playing a major role the following preliminary analysis was performed on a subset of the results:

```
analysis:  GLM
model:     score = pupil variable
variables: score:
            Classification[power], Mathematics[power]

            pupil variable:
            weight, height, ponderal index, age
            {co-variates},
            preferred hand
            {class variables}

data:      control days only
            STD6, STD3, GRD2
```

None of these variables was significant at the 1% level in any of the analyses. As the variables had no predictive value while using all data of the control days only, their use for reducing variation in less homogeneous and smaller data sets, made up of results from stress and control days, seemed very limited. For the same reason they were not used in an investigation of mixed effects.

3.4.3.5 PERSONAL QUESTIONNAIRE

To investigate the relevance of all items of the Personal Questionnaire for all scores at all experimental conditions would have required too much computer time. Items with a high predictive value for performance were therefore preselected by the following analysis:

```

analysis:  GLM
model:     score = item
variables: score:
            Classification[power], Mathematics[power]
            item:
            {responses to item 1 to 57 of the Personal
              Questionnaire except the X-items
              (see Appendix C); Grade 2 children were
              presented with a sub-set of these items;
              class variable}
data:      control days only
            STD6, STD3, GRD2

```

The items found to be significant at the 1% level in at least two analyses were number 8, 17, 22, 32, 39 and 41. Item 39 deals with the thermal comfort of the children and was therefore excluded as a concomitant variable. It is analysed separately in 3.5.4. The relevance of the remaining items on the effect of temperature was investigated as follows:

```

analysis:  GLM
model:     score = experiment, item, type * item
variables: score:
            [Classification, Mathematics]
            x
            [power, speed, accuracy]
            experiment:
            {class variable; each class being a pair of
              a stress day and its control day}
            item
            {responses to item 8, 17, 22, 32 and 41 of
              the Personal Questionnaire
              (see Appendix C); class variable}

```


	type:	{class variable, discriminating between stress and control days}
data:	stress and control days	[STD6, STD3, GRD2] x [14°C, 19°C, 29°C, 34°C]

None of the interactions was significant at the 1% level and possible interaction effects were therefore not considered any further.

3.4.4 PERCENTAGE OF VARIATION ATTRIBUTED TO ROOM TEMPERATURE

3.4.4.1 ATTRIBUTING VARIATION TO VARIABLES

In a General Linear Model the variation in the results, expressed as the sum of the squared distances of the data points from their mean, is split into the variation that can be attributed to model variables and the remaining, unexplained variation. For a model variable "x" the percentage of variation V(x) attributed to this variable is calculated as:

$$V(x) = \frac{(\text{variation attributed to } x)}{(\text{total variation})} * 100$$

The percentages of variation attributable to temperature are shown in Table 3.4-3.

3.4.4.2 RESULTS

		Grade 2				Standard 3				Standard 5			
°C		14	19	29	34	14	19	29	34	14	19	29	34
CLA	power	2.4	.	1.2	0.2	1.0	0.5	0.3	0.1	0.0	2.7	0.1	2.2
	speed	4.7	.	6.3	7.6	2.1	1.0	1.0	0.6	0.0	2.8	0.2	0.6
	accur.	0.6	.	3.7	8.2	1.1	1.4	0.1	1.1	0.2	0.1	0.0	0.6
COM	power	6.8	.	1.5	3.2	4.0	0.0	3.5	8.1	0.4	0.8	0.0	2.2
	speed	2.8	.	3.3	7.1	4.7	0.5	2.2	9.3	0.0	1.2	2.1	0.7
	accur.	0.1	.	2.0	2.4	1.0	1.7	0.4	0.6	1.2	0.0	2.6	0.8
MAT	power	3.2	.	0.8	0.3	0.3	1.1	0.8	7.0	0.8	0.0	0.6	2.1
	speed	3.1	.	1.1	0.0	0.5	4.6	1.9	7.7	3.4	0.2	3.9	3.8
	accur.	0.4	.	3.3	0.8	0.2	2.8	1.3	0.0	0.3	0.0	0.0	5.4
MEM	power	0.0	.	0.1	0.2	0.1	0.1	0.3	0.0	1.4	2.9	0.3	2.6
	speed	0.0	.	0.7	0.0	0.2	0.1	2.3	0.0	0.0	3.1	0.1	2.3
	accur.	0.3	.	5.0	0.4	0.1	0.3	0.2	0.2	2.4	0.6	1.3	0.7
NUM	power	.	.	.	.	2.0	.	0.1	1.1	1.8	0.3	4.1	2.4
	speed	.	.	.	.	2.2	.	0.1	0.3	0.3	0.5	3.6	0.0
	accur.	.	.	.	.	0.1	.	0.0	0.7	0.1	0.1	0.0	1.8
PAT	power	.	.	.	.	0.3	0.7	0.0	0.6	0.4	0.0	0.0	1.5
	speed	.	.	.	.	2.8	4.8	1.0	0.0	0.8	0.2	0.3	0.3
	accur.	.	.	.	.	1.8	2.6	0.2	1.0	0.1	0.2	0.0	1.4
PEG TEST		.	.	.	.	3.4	.	5.2	0.0	6.0	3.9	0.5	3.3
WRITING SPEED		7.8	.	0.3	0.1	0.7	0.2	4.1	2.2	0.2	0.0	2.8	0.3
SRT	1	.	.	.	.	0.3	3.5	0.5	3.5	0.4	2.8	0.6	5.7
	2	.	.	.	.	8.2	0.9	0.0	8.9	1.3	0.0	0.1	0.8
	3	.	.	.	.	2.2	.	3.7	13.	0.0	1.1	0.6	2.2
CRT	1	.	.	.	.	0.0	0.2	2.2	1.3	0.1	0.0	1.3	2.2
	2	.	.	.	.	0.5	0.7	0.2	0.7	6.1	8.9	0.2	0.1
	3	.	.	.	.	1.5	.	0.5	8.6	0.1	1.4	2.8	0.3

Table 3.4-3: Percentage of variation attributable to room temperature.

Obviously these percentages are dependent on the total variation encountered for a certain standard and a certain test. To put the results in proportion, the means of the coefficients of variation encountered in all control experiments for a certain standard and a certain test are given in Table 3.6-1.

3.4.4.3 SUMMARY TABLES

To highlight structures in the results, summary tables are given. These tables are only intended as a conceptual aid. They are not intended as input for statistical analysis because the sums are derived from samples of different size, for example the number as well as the percentage of Standard 6 children contributing to a certain sum may be different in every column of a table. The tables should therefore be used only with care and common sense. The result Table 3.4-3 contains missing values. To allow comparison between certain conditions, part of the data had to be dropped in each comparison, for there were no results for 19°C in Grade 2, so the summary comparison of temperatures had to exclude all of Grade 2. Details are given at each summary table.

Room Temperature

Excluded due to missing values were:

- all data from Grade 2
- Number Series,
- SRT3 and CRT3.

	14°C	19°C	29°C	34°C
power	0.9	0.9	0.6	1.1
speed	1.5	1.9	1.5	2.5
accuracy	0.8	1.0	0.6	1.2
SRT	2.6	1.8	0.3	4.7
CRT	1.7	2.5	1.0	1.1

Table 3.4-4: Mean percentage of variation attributable to room temperature for different score types.

For four out of five score types the effect of temperature is greatest at 34°C, the only exception being CRT. The effect is smallest at 29°C in all cases, with only speed having an equally low effect at 14°C (Table 3.4-4). Table 3.4-3 shows that the effect at 34°C is in a considerable number of cases smaller than the one at 29°C, but in the cases where it is bigger, it is much bigger. This leads to the stronger effect for 34°C in Table 3.4-4.

Educational Standard

Excluded due to missing values were:

- all data at 19°C,
- Number Series,
- Pattern Completion,

	Grade 2	Standard 3	Standard 6
power	1.7	2.1	1.1
speed	3.1	2.7	1.4
accuracy	2.3	0.5	1.3
SRT	.	4.5	1.3
CRT	.	1.7	1.5

Table 3.4-5: Mean percentage of variation attributable to room temperature for score types at different educational standards.

Effects for Grade 2 on power, speed and accuracy are all bigger than for Standard 6. Table 3.4-3 shows that the effect for Grade 2 is in a considerable number of cases smaller than the one for Standard 6, but in the cases where it is bigger, it is much bigger. This leads to the stronger effect for Grade 2 in summary Table 3.4-5.

Performance Test

Excluded due to missing values were:

- all data from Grade 2, and
- all data at 19°C.

	CLA	COM	MAT	MEM	NUM	PAT	SRT	CRT
power	0.6	3.0	1.9	0.8	1.9	0.9	-	-
speed	0.8	3.2	3.5	0.8	1.1	0.5	2.8	1.5
accuracy	0.5	1.1	1.2	0.8	0.5	0.8	-	-

Table 3.4-6: Mean percentage of variation attributable to room temperature for score types of different performance tests and for reaction times

The biggest effect on power is found with Comparison, Mathematics and Number Series. It can be seen in Table 3.4-6 that this effect is due more to a change in speed than to a change in accuracy.

3.5 PREDICTIVE VALUE OF BODY TEMPERATURES AND COMFORT VOTE

3.5.1 AIM OF THE ANALYSIS

Room temperature affects body temperatures and the thermal comfort of individuals. Mental performance is (at least under extreme conditions) affected by body temperatures and thermal comfort. It is therefore likely that body temperature and other associated measures such as oral temperature, finger temperature and comfort vote are better predictors for the change in performance under thermal stress than room temperature.

This analysis sought to compare the predictive value for performance of the following:

- room temperature;
- oral temperature;
- finger temperature; and
- comfort vote.

3.5.2 ORAL TEMPERATURE

Room temperature affects oral temperature, partly by affecting deep body temperature via an increased heat build-up or via increased heat loss. The Figures 3.5-1 to 3.5-3 show the change in oral temperature during the day for different room temperatures and different standards.

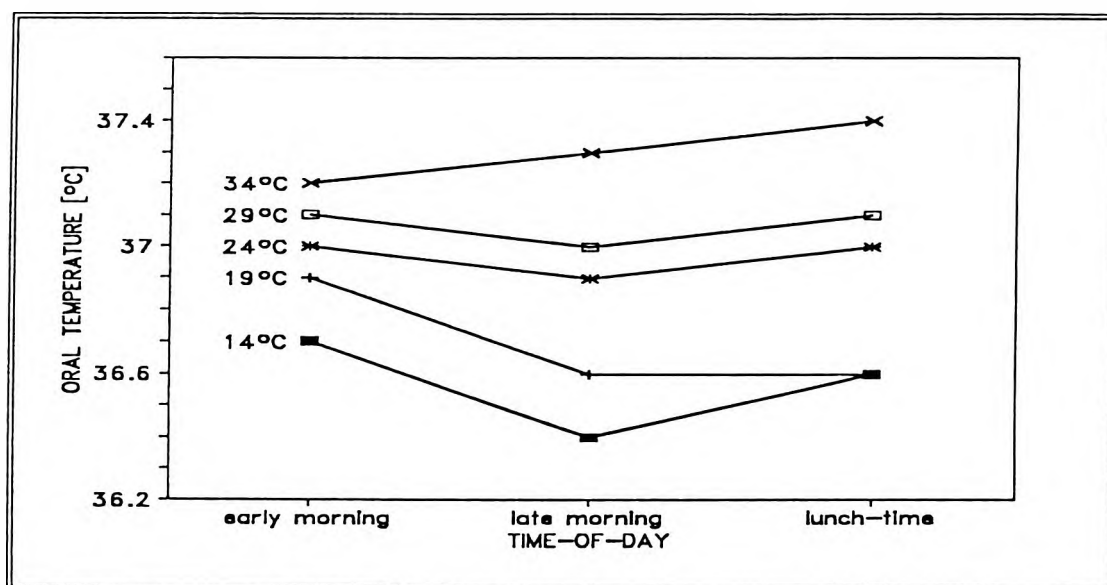


Figure 3.5-1: Oral temperature of Standard 6 children at five experimental temperatures (14, 19, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)

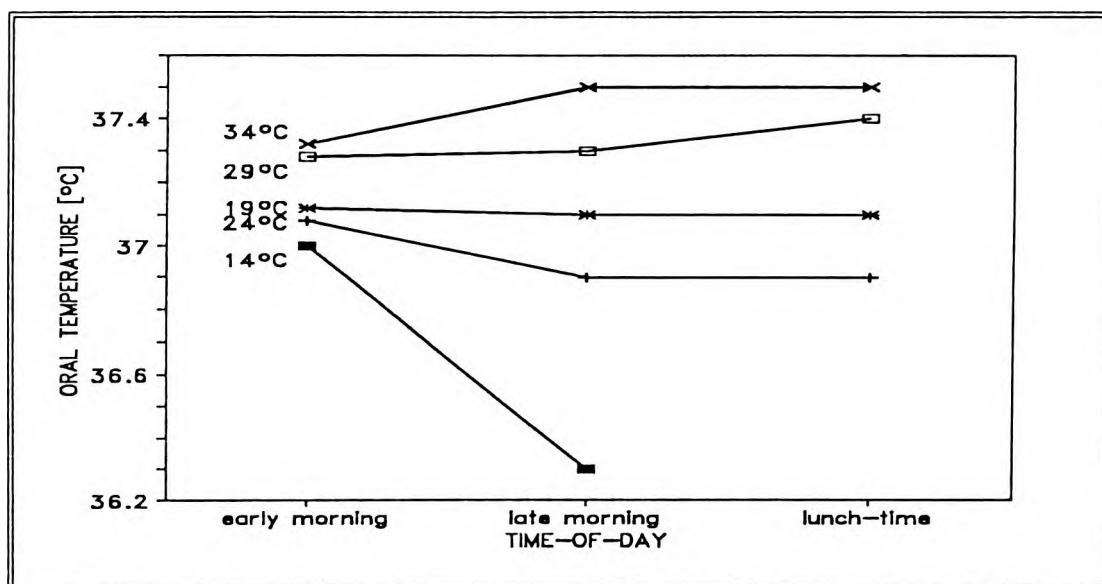


Figure 3.5-2: Oral temperature of Standard 3 children at five experimental temperatures (14, 19, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)

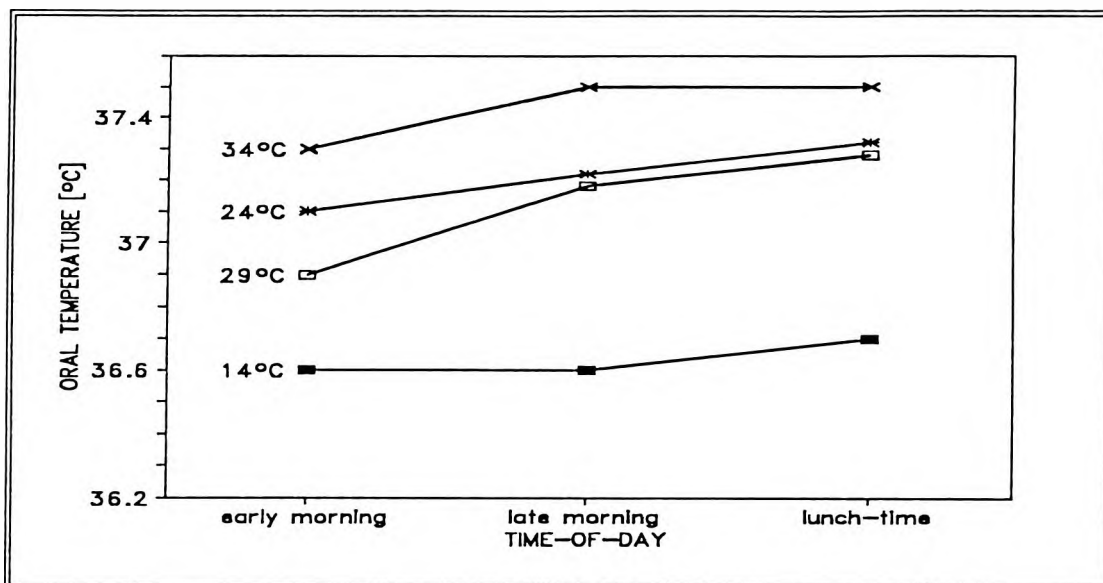


Figure 3.5-3: Oral temperature of Grade 2 children at five experimental temperatures (14, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)

Higher room temperatures are obviously correlated with higher oral temperatures. Trends over time must be viewed with caution, as the standard deviation of the measurements of oral temperature within one experimental temperature condition was in the range of 0.25 to 0.6°C, and because the effects of room temperature are complicated by the circadian fluctuations of the body temperature (Marotte and Timbal, 1982).

To assign the most appropriate oral temperature to a performance test, an interpolation procedure was used on the two measurements closest in time to the test. The temperature values were then assigned to five classes:

- 1: $\leq 36.7^{\circ}\text{C}$
- 2: $> 36.7^{\circ}\text{C}$ and $\leq 36.9^{\circ}\text{C}$
- 3: $> 36.9^{\circ}\text{C}$ and $\leq 37.1^{\circ}\text{C}$
- 4: $> 37.1^{\circ}\text{C}$ and $\leq 37.3^{\circ}\text{C}$
- 5: $> 37.3^{\circ}\text{C}$

The analysis was performed with temperature as a class variable to allow for the modelling of a non-linear relation.

A GLM analysis was performed to assess the predictive qualities of oral temperature for performance:

```
analysis:  GLM
model:     score = experiment, oral
variables: score:
            [Classification, Comparison, Mathematics,
             Memory, Number Series, Pattern Completion]
            x
            [power, speed, accuracy],
            Peg Test, Writing Speed,
            [SRT, CRT] x [first, second, third]
experiment:
            {class variable; each class being a pair of
             a stress day and its control day}
oral:
            {class variable, five classes for five
             temperature intervals}
data:      stress and control days
            [STD6, STD3, GRD2] x [14°C, 19°C, 29°C, 34°C]
```

The analysis was performed by temperature and by standard, and the variable "experiment" was introduced to absorb the variation between the experiments. The results are shown in Table 3.5-1.

test	score type	temperature	standard	signific
MAT	speed	29°C	STD3	0.006
MAT	speed	34°C	STD6	0.008
PAT	speed	34°C	STD6	0.003
PEG	-	34°C	STD6	0.001
WRI	-	29°C	GRD2	0.001

Table 3.5-1: Significant relationships (p<0.01) between oral temperature and test performance

3.5.3 FINGER TEMPERATURE

Figures 3.5-4 to 3.5-6 show the change of finger temperature during the day for different room temperatures and different standards.

Higher room temperature obviously implies higher finger temperatures. At the higher room temperatures the finger temperatures seem not to have stabilised at the first measurement. The standard deviations of finger temperature within one experimental temperature condition lie in the range from 1.5 to 4.0 °C.

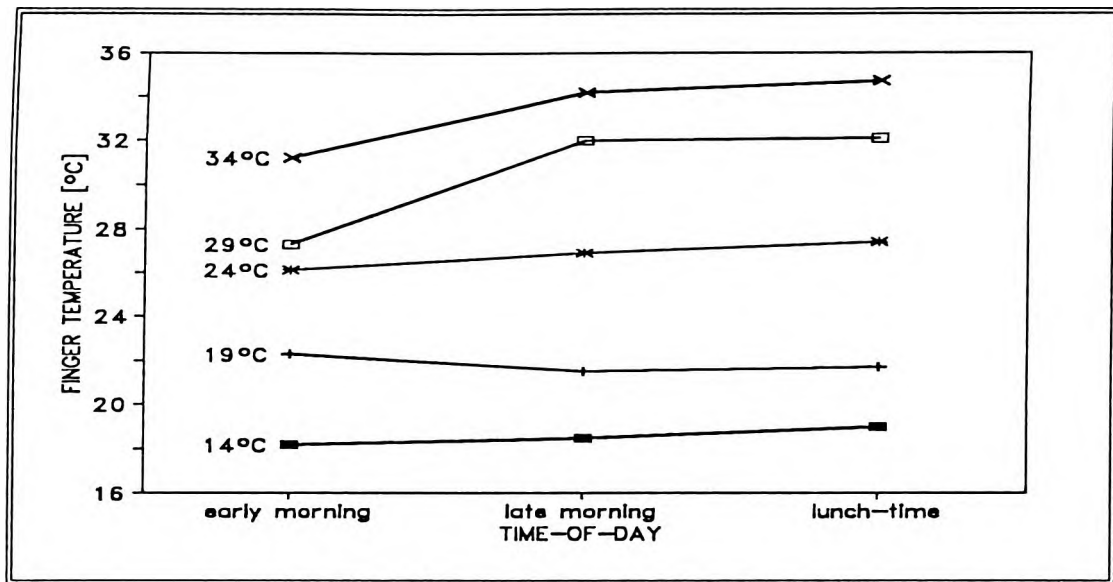


Figure 3.5-4: Finger temperature of Standard 6 children at five experimental temperatures (14, 19, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)

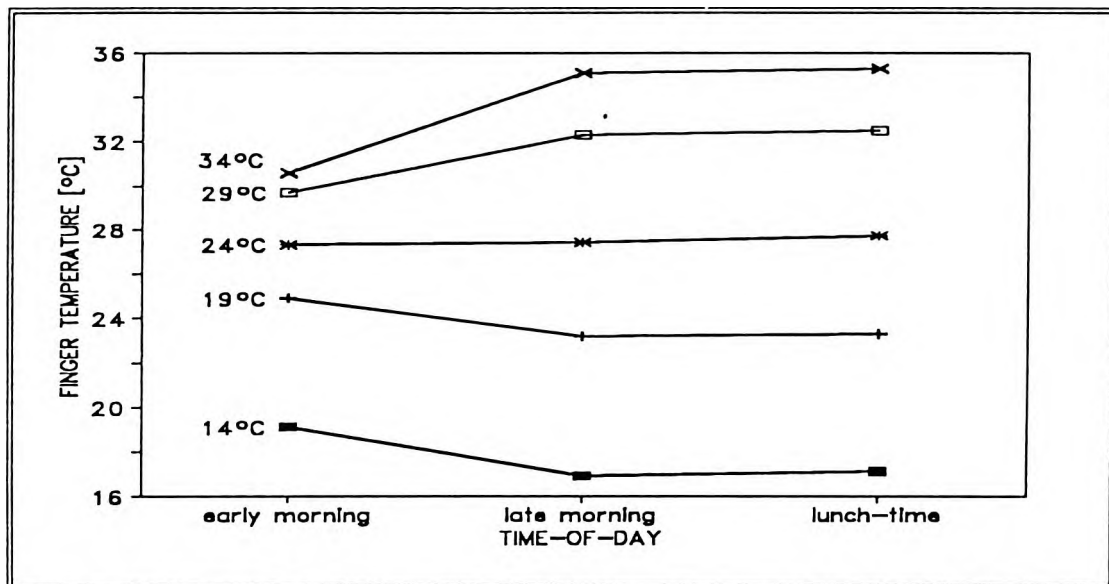


Figure 3.5-5: Finger temperature of Standard 3 children at five experimental temperatures (14, 19, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)

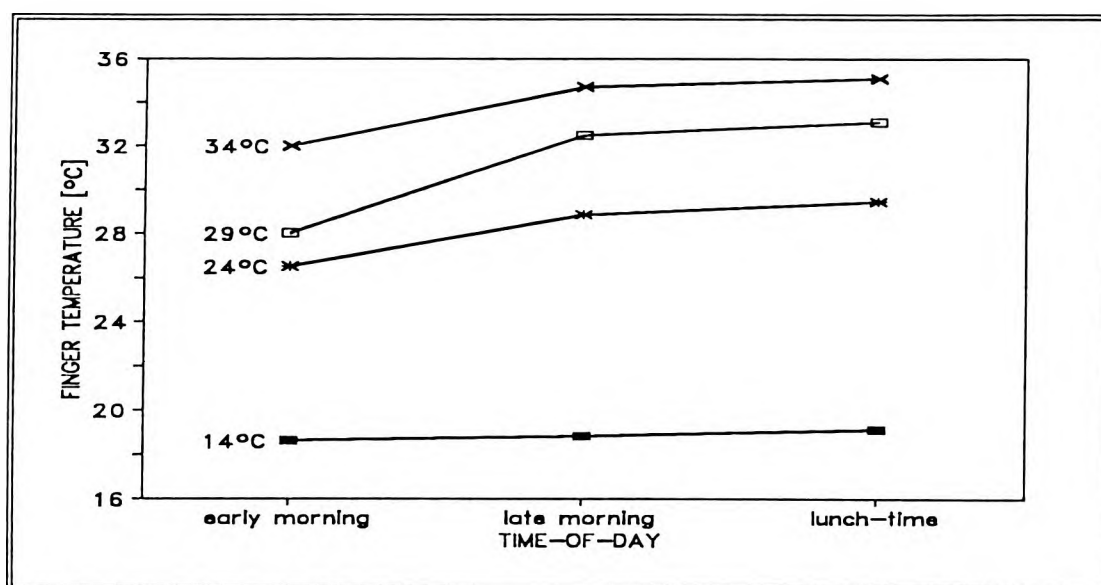


Figure 3.5-6: Finger temperature of Grade 2 children at five experimental temperatures (14, 24, 29 and 34°C) measured on three times-of-day (early morning, mid-morning and early afternoon)

The finger temperatures were matched to the performance values in the same way as the oral temperatures. Thereafter the temperature values were assigned to five classes:

- 1: $\leq 20^{\circ}\text{C}$
- 2: $> 20^{\circ}\text{C}$ and $\leq 23^{\circ}\text{C}$
- 3: $> 23^{\circ}\text{C}$ and $\leq 26^{\circ}\text{C}$
- 4: $> 26^{\circ}\text{C}$ and $\leq 29^{\circ}\text{C}$
- 5: $> 29^{\circ}\text{C}$

A GLM analysis equivalent to that carried out for oral temperature was performed. Variation between experiments was absorbed in a variable named "experiment" and the analysis was performed by temperature and standard. The results are shown in Table 3.5-2.

test	score type	temperature	standard	signific.
COM	power	34°C	STD6	0.001
MAT	speed	34°C	STD6	0.009
MAT	accuracy	34°C	STD6	0.0003
NUM	power	19°C	STD6	0.006
PAT	speed	19°C	STD3	0.001
PAT	accuracy	29°C	STD6	0.004
PEG	-	14°C	STD6	0.009
WRI	-	29°C	STD3	0.004

Table 3.5-2: Significant relationships ($p < 0.01$) between finger temperature and test performance.

3.5.4 COMFORT VOTE

One question in the Personal Questionnaire referred to the individual comfort vote. It read:

How do you feel in the classroom today ?

- A: Too cold
- E: Too hot
- I: Just right

This comfort vote was taken only once, at the beginning of the stress day after about half an hour of acclimation. It can therefore not be matched to the individual performance scores, but represents rather an indicator of sensitivity to temperature. Figures 3.5-7 to 3.5-9 show the change of comfort vote with temperature.

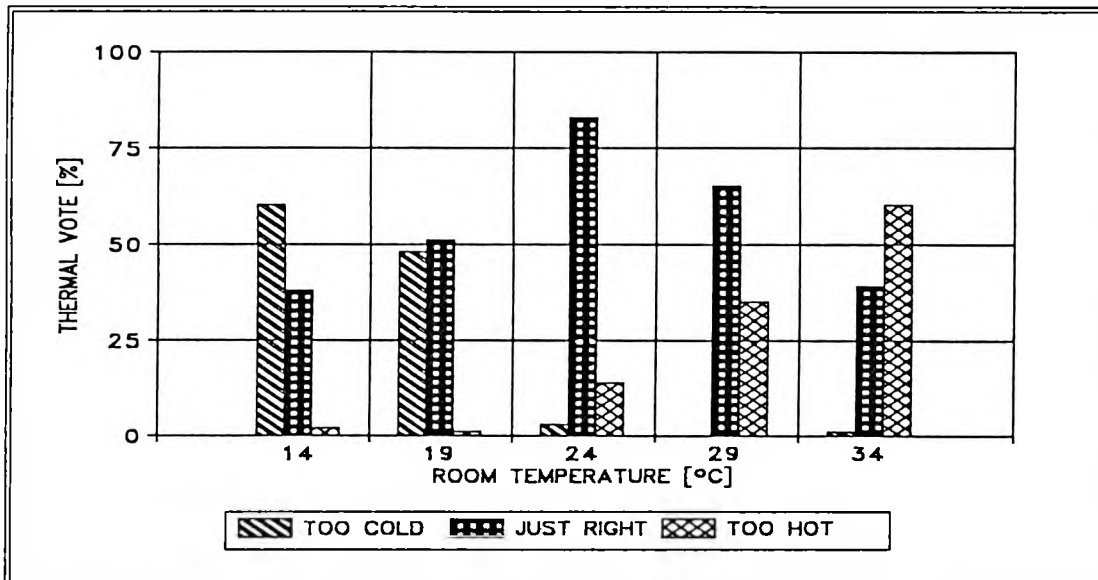


Figure 3.5-7: Comfort vote of Standard 6 children at five experimental temperatures (14, 19, 24, 29 and 34°C) expressed as percentage of the children who voted either: too hot, just right or too cold.

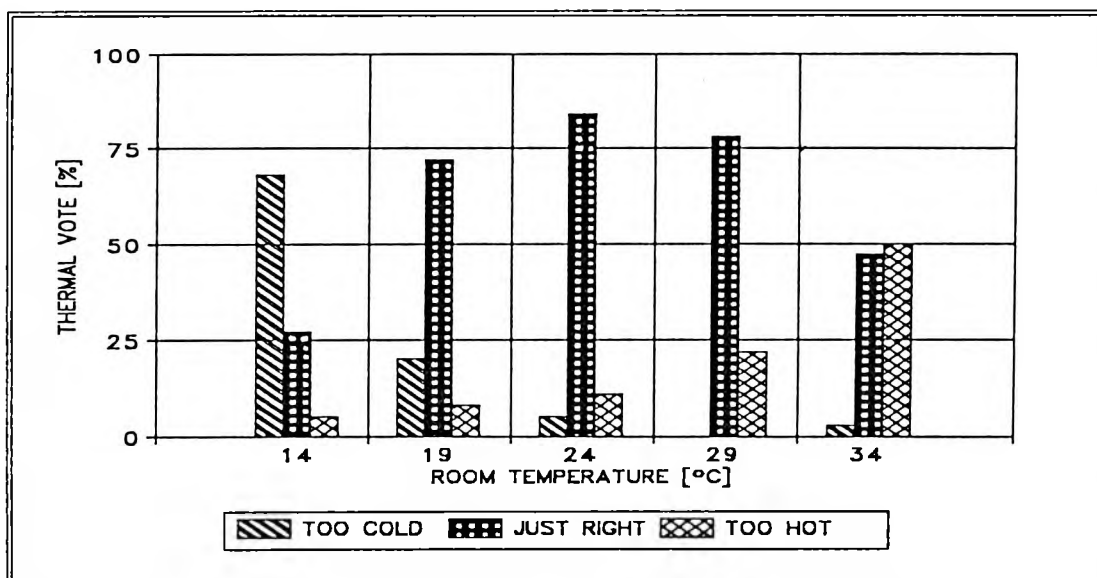


Figure 3.5-8: Comfort vote of Standard 3 children at five experimental temperatures (14, 19, 24, 29 and 34°C) expressed as percentage of the children who voted either: too hot, just right or too cold.

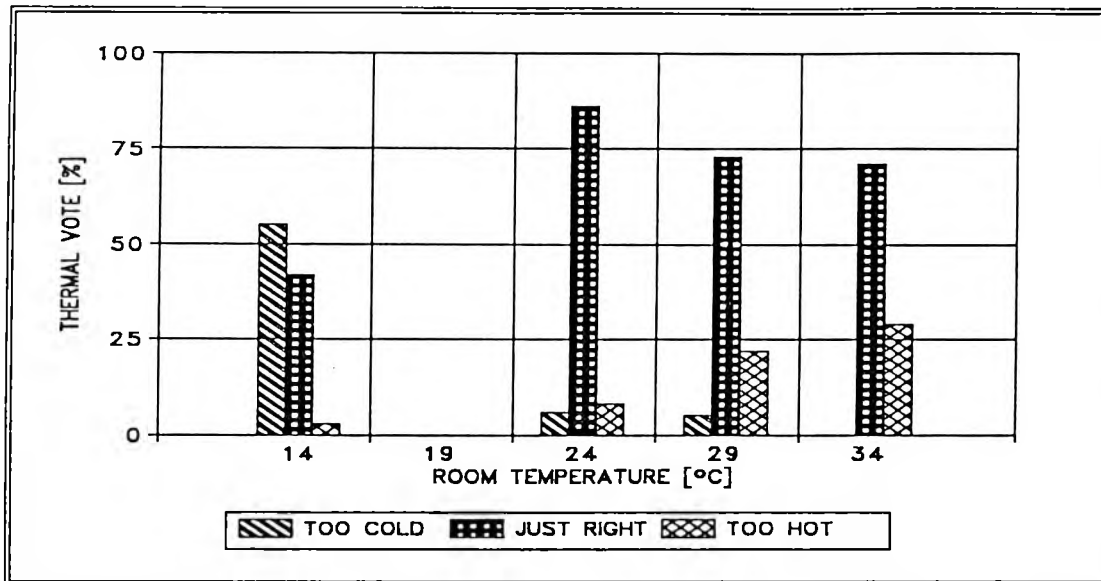


Figure 3.5-9: Comfort vote of Grade 2 children at five experimental temperatures (14, 24, 29 and 34°C) expressed as percentage of the children who voted either: too hot, just right or too cold.

A GLM analysis similar to that for oral temperature was performed. None of the relationships was significant at the $p < 0.01$ level. The presentation of a table has therefore been omitted.

3.5.5 COMPARISON OF THE PREDICTIVE VALUES

The following number of relationships between predictor variables and performance scores was found to be significant at the 1% level:

- 24 for room temperature;
- 8 for finger temperature;
- 5 for oral temperature; and
- 0 for comfort vote.

With three standards tested at four temperature conditions and 26 different scores (although the power, speed and accuracy of each test are not independent) one can expect about three significant relationships at the 1% level to occur by chance. The low predictive value of comfort vote can partially be explained by the fact that comfort vote was not taken three times a day like the other measures, and that the time when it was taken was during the acclimation period at the beginning of the stress day.

3.6 INTER-INDIVIDUAL VARIATION AT DIFFERENT TEMPERATURES

3.6.1 AIM OF THE ANALYSIS

If thermal stress is more detrimental to weak performers than to better performers then the inter-individual variation of the results should be larger on stress days than on control days.

If the weak performers should be more affected by the arousing effect of temperature, which would improve their performance, then the inter-individual variation should be smaller on stress days.

The coefficient of variation (C.V.) was chosen to assess the effect of temperature on inter-individual variation.

3.6.2 CALCULATION OF THE COEFFICIENT OF VARIATION

The coefficient of variation (C.V.) is a measure of the size of variation relative to the mean. It is calculated as:

$$\text{C.V.} = \frac{(\text{standard deviation})}{(\text{mean})} * 100$$

As the C.V. is a measure of variation independent of the absolute value of the measured quantity, it allows a comparison of inter-individual variation on different standards, tests and scores. The mean of the C.V. on control days was calculated by standard, test and score type. The results are shown in Table 3.6-1.

3.6.3 THE COEFFICIENT OF VARIATION AT DIFFERENT TEMPERATURES

Table 3.6-2 compares the number of experiments where the C.V. was larger on the stress day (number before the colon) with those where the C.V. was smaller on the stress day (number after the colon).

In Table 3.6-3 the results of Table 3.6-2 are summarised for the different score types.

		GRD2	STD3	STD6
Classification	power	33	19	15
	speed	30	18	15
	acc.	18	8	8
Comparison	power	21	16	20
	speed	27	17	19
	acc.	16	8	14
Mathematics	power	39	37	32
	speed	40	42	32
	acc.	19	29	33
Memory	power	45	36	33
	speed	39	21	20
	acc.	19	22	22
Number Series	power	.	19	24
	speed	.	17	29
	acc.	.	13	25
Pattern Compl.	power	.	31	27
	speed	.	31	29
	acc.	.	30	33
Peg Test	speed	.	17	14
Writing Speed	speed	22	13	13
Simple RT	first	.	20	20
	second	.	20	20
	third	.	25	19
Choice RT	first	.	48	33
	second	.	38	28
	third	.	38	26

Table 3.6-1: Means of coefficients of variation of scores on all control days at different temperatures and standards.

		Grade 2				Standard 3				Standard 6			
°C		14	19	29	34	14	19	29	34	14	19	29	34
CLA	power	1:2	.	0:2	2:0	1:1	1:0	0:2	0:1	2:2	3:2	0:3	1:4
	speed	2:1	.	0:2	2:0	1:1	1:0	1:1	0:1	2:2	3:2	0:3	3:2
	accur.	2:1	.	1:1	2:0	1:1	0:1	2:0	0:1	2:2	2:3	1:2	1:4
COM	power	2:1	.	1:1	1:1	1:1	1:0	2:0	1:0	2:2	3:2	2:1	2:3
	speed	1:2	.	1:1	1:1	1:1	1:0	1:1	1:0	2:2	2:3	2:1	2:3
	accur.	2:1	.	2:0	2:0	0:2	1:0	0:2	1:0	1:3	2:3	0:3	1:4
MAT	power	1:1	.	1:1	0:2	0:2	1:0	0:2	0:1	1:3	3:2	1:2	3:2
	speed	0:2	.	2:0	2:0	1:1	1:0	1:1	1:0	3:1	3:2	0:3	0:5
	accur.	1:1	.	2:0	1:1	0:2	0:1	1:1	0:1	3:1	3:2	1:2	1:4
MEM	power	2:1	.	1:1	2:0	0:2	0:1	1:1	1:0	1:3	4:1	2:1	3:2
	speed	1:2	.	1:1	2:0	1:1	1:0	1:1	1:0	1:3	3:2	1:2	4:1
	accur.	2:1	.	1:1	1:1	0:2	0:1	2:0	1:0	2:2	4:1	2:1	3:2
NUM	power	.	.	.	.	1:1	.	0:2	0:1	3:1	2:3	1:2	2:3
	speed	.	.	.	.	1:1	.	1:1	0:1	2:2	2:3	0:3	2:3
	accur.	.	.	.	.	1:1	.	0:2	0:1	2:2	2:3	0:3	0:5
PAT	power	.	.	.	.	0:2	0:1	0:2	1:0	1:3	2:3	2:1	3:2
	speed	.	.	.	.	1:1	1:0	1:1	1:0	3:1	2:3	1:2	2:3
	accur.	.	.	.	.	0:2	1:0	0:2	1:0	2:2	1:4	1:2	1:4
PEG TEST		.	.	.	.	1:1	1:0	1:1	0:1	2:2	4:1	3:0	3:2
WRITING SPEED		0:2	.	1:0	2:0	2:0	1:0	1:1	0:1	3:1	3:2	1:2	4:1
SRT	1	.	.	.	.	2:0	1:0	0:2	0:1	2:2	2:3	0:3	2:3
	2	.	.	.	.	1:1	0:1	1:1	0:1	1:3	2:3	2:1	3:2
	3	.	.	.	.	1:1	1:0	2:0	0:1	2:1	5:0	3:0	2:3
CRT	1	.	.	.	.	1:1	1:0	1:1	0:1	3:1	3:2	1:2	1:4
	2	.	.	.	.	0:2	1:0	0:2	0:1	0:4	4:1	1:2	2:3
	3	.	.	.	.	0:2	1:0	2:0	0:1	1:2	3:2	2:1	2:3

Table 3.6-2: Number of experiments where C.V. was higher on the stress day (left of colon) versus number of experiments where C.V. was smaller on the stress day (right of colon).

		Grade 2				Standard 3				Standard 6			
score	relation	14	19	29	34	14	19	29	34	14	19	29	34
power	S > C	6	.	3	5	3	3	3	3	10	17	8	14
	S < C	5	.	5	3	9	2	9	3	14	13	10	16
speed	S > C	4	.	4	7	6	5	6	4	13	15	4	13
	S < C	7	.	4	1	6	0	6	2	11	15	14	17
accur.	S > C	7	.	6	6	2	2	5	3	12	14	5	7
	S < C	4	.	2	1	10	3	7	3	12	16	13	23
SRT	S > C	.	.	.	.	4	2	3	0	5	9	5	7
	S < C	.	.	.	.	2	1	3	3	6	6	4	8
CRT	S > C	.	.	.	.	1	3	3	0	4	10	4	5
	S < C	.	.	.	.	5	0	3	3	7	5	5	10

Table 3.6-3: Number of test applications where the C.V. was higher on the stress day (S>C) and where the C.V. was smaller on the stress day (S<C) for different score types and experimental conditions.

A two-tailed sign test (described in 2.8.2) was used to assess if the number of test applications with a larger C.V. on the stress day or the control day was significantly different from a chance distribution. The following results were significant:

- Standard 6, 29°C, speed (p<0.05), and
- Standard 6, 34°C, accuracy (p<0.01).

Within 49 applications of the sign test (49 pairs of numbers in Table 3.6-3) these findings can easily be explained as due to chance.

3.7 FACET ANALYSIS

3.7.1 AIM OF THE ANALYSIS

Facet Analysis was developed to detect structure in "soft" data, for example in the results of surveys where subjective opinions are sought. It is especially suited for applications where the correlations are weak, and structures can only be detected and interpreted when the experience and the common sense of the analyst are integrated in the analysis procedure. A critical attitude is justified, because one person's common sense can be another person's bias.

The aim of this part of the analysis was to find structures in the relationships between different scores, and possible changes of these relationships with temperature. These structures can either be defended as valid results or they can be used as indicators for further conventional analyses.

Points representing scores are arranged in a space of defined dimensionality, for easy comprehension two dimensions were chosen for this analysis. The closer two points are in a Facet Diagram, the higher they are correlated. The analysis is based on finding regions that are exclusively, or nearly exclusively populated by a certain class of data points. A description of the principles of Facet Analysis is given in 2.8.3.

The scores of the reaction time tests were all expressed as "performance scores" as described in 2.7.4; the higher the numerical value of such a score, the better the performance.

3.7.2 DATA STRUCTURES AT THE CONTROL TEMPERATURE

A wide variety of possible data structures can be imagined. Two hypothesis are:

- A) children who perform especially well on a certain test will score higher in power, speed and accuracy on the test. When they are weaker in a test, all three types of scores on this test will be lower. This would imply that the scores of each test form a closely defined region in the Facet Diagram; and
- B) children who are fast tend to be fast on all tests. Children who are accurate tend to be accurate on all tests. This effect dominates all the other factors involved. This would imply that "power", "speed" and "accuracy" scores form distinctly separated regions.

Figures 3.7-1 to 3.7-3 show clearly that "B" is the case. These regional structures imply that the correlation between two accuracy scores is in most cases stronger than the correlation between the speed and the accuracy score of the same test. They imply also that the accuracy score on test "A" is usually a better predictor for the accuracy score on test "B" than for the speed score on test "A". In the language of Facet Analysis it can be said that the two-dimensional spatial representation of the correlations

between tests scores of individuals allows a nearly non-controversial partitioning into regions corresponding to the elements of the facet "score type", which are: power, speed, accuracy and reaction time.

The Writing Speed score lies in all cases close to or within the region of the power scores. The O'Connor peg test shows this association to a lesser extent.

The reaction time scores (performance scores as defined in 2.7.4) form an own region which implies that they are strongly correlated with each other. This region is clearly separated from the regions of all the other scores, which implies that the reaction time scores are not highly correlated with all the other scores, and that reaction time scores are not very useful as predictors of performance of other tests.

3.7.3 DATA STRUCTURES AT DIFFERENT STRESS TEMPERATURES

Figures 3.7-4 to 3.7-7 show the data structures for Standard 6 at different stress temperatures. The scores can be grouped into the same regions as those at the control temperature (Figure 3.7-1).

Figures 3.7-8 and 3.7-9 show Facet Diagrams for Standard 3 at the coldest (14°C) and the hottest (34°C) stress temperature, the Figures 3.7-10 and 3.7-11 show the same for Grade 2. Again the scores can be grouped into the same

regions as those at the control temperature (Figure 3.7-2 and Figure 3.7-3).

The Facet Analysis revealed interesting details of the relations between test scores, but did not give any indication of a change in this relations due to temperature.

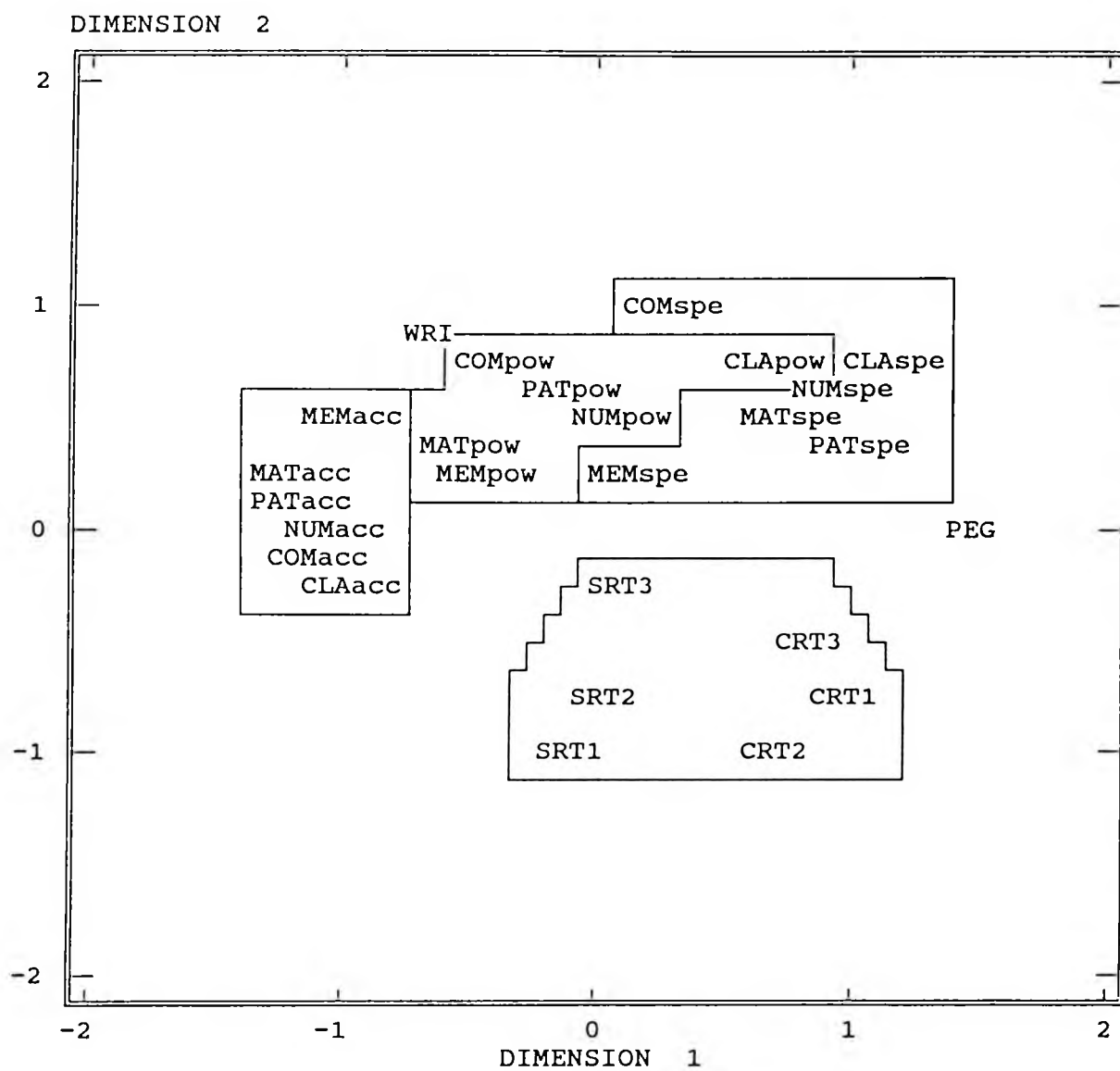


Figure 3.7-1: Facet Diagram of the test scores of Standard 6 children at 24°C (Coefficient of alienation: 0.24).

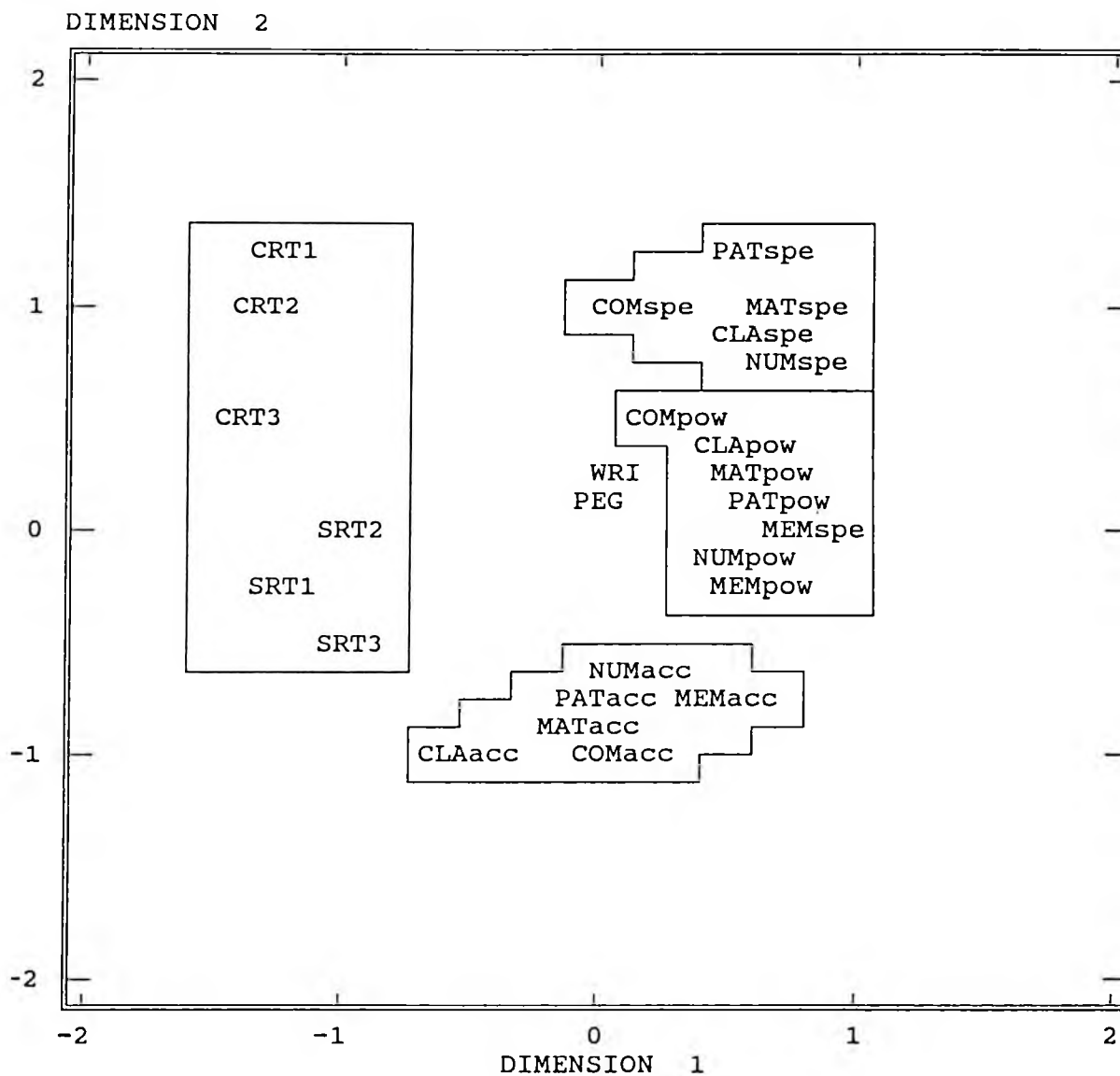


Figure 3.7-2: Facet Diagram of the test scores of Standard 3 children at 24°C. MEMspe falls outside the region of speed scores (Coefficient of alienation: 0.21).

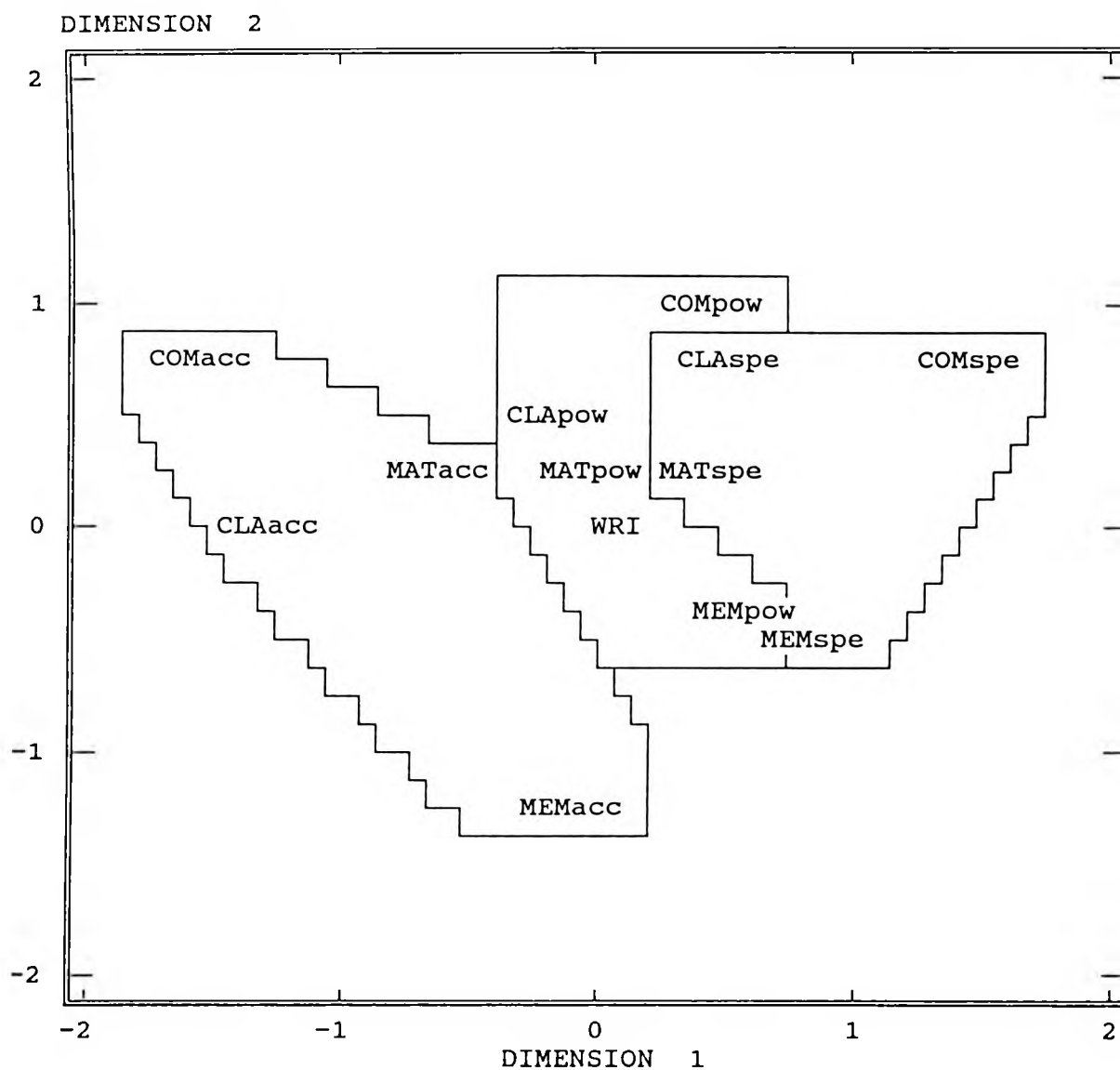


Figure 3.7-3: Facet Diagram of the test scores of Grade 2 children at 24°C (Coefficient of alienation: 0.17).

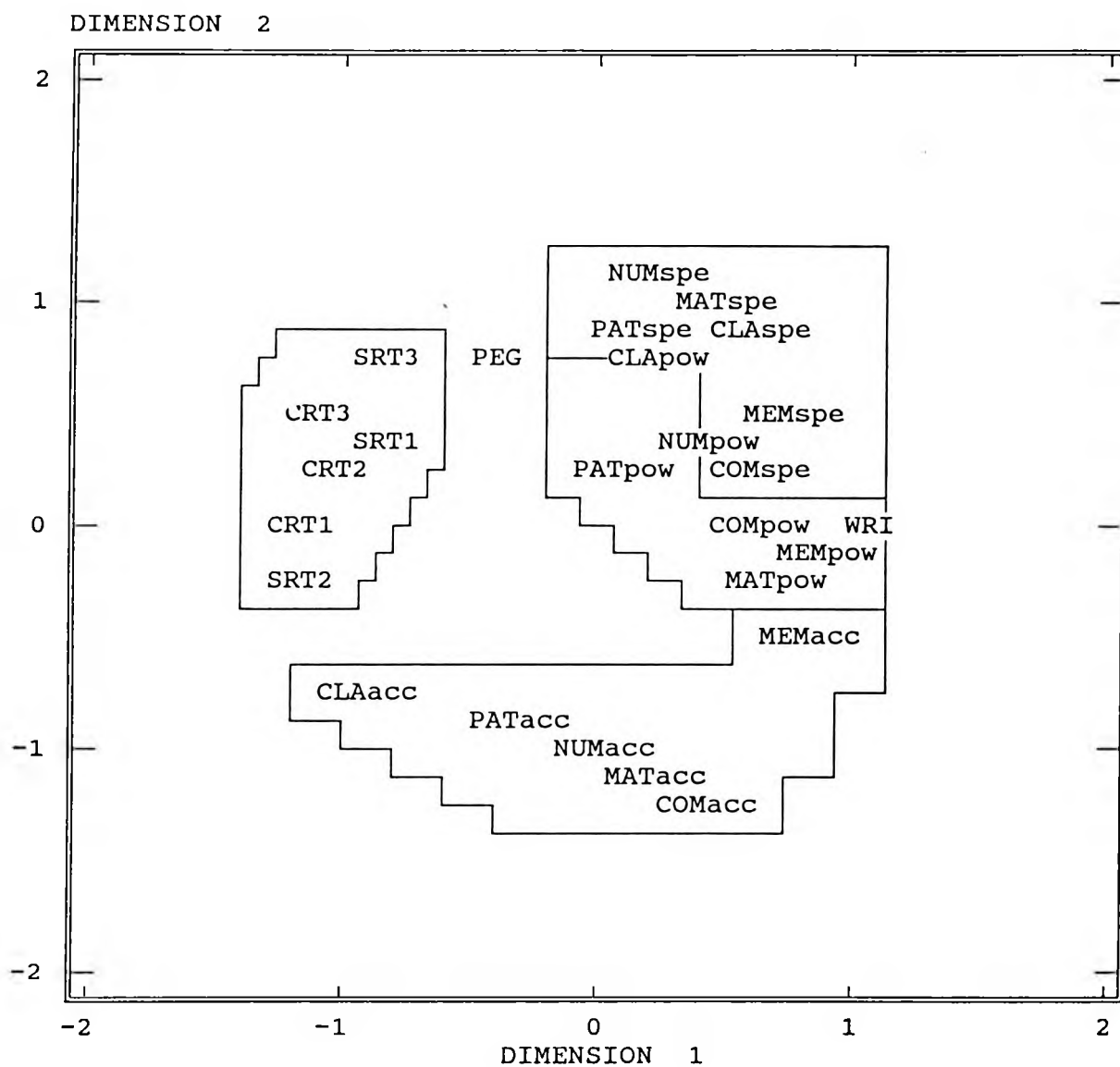


Figure 3.7-4: Facet Diagram of the test scores of Standard 6 children at 14°C (Coefficient of alienation: 0.19).

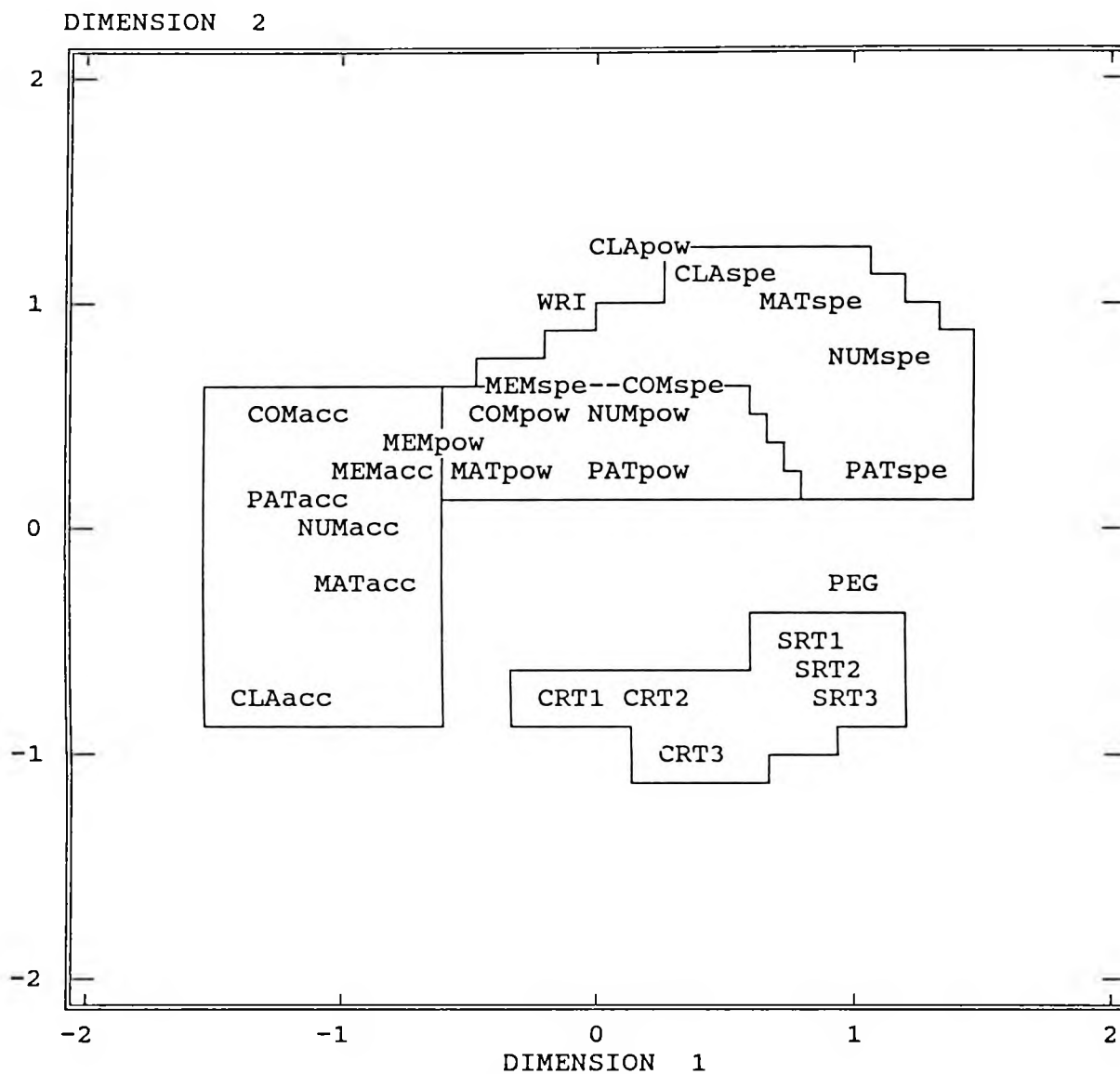


Figure 3.7-5: Facet Diagram of the test scores of Standard 6 children at 19°C. CLApow falls outside the region of power scores (Coefficient of alienation: 0.23).

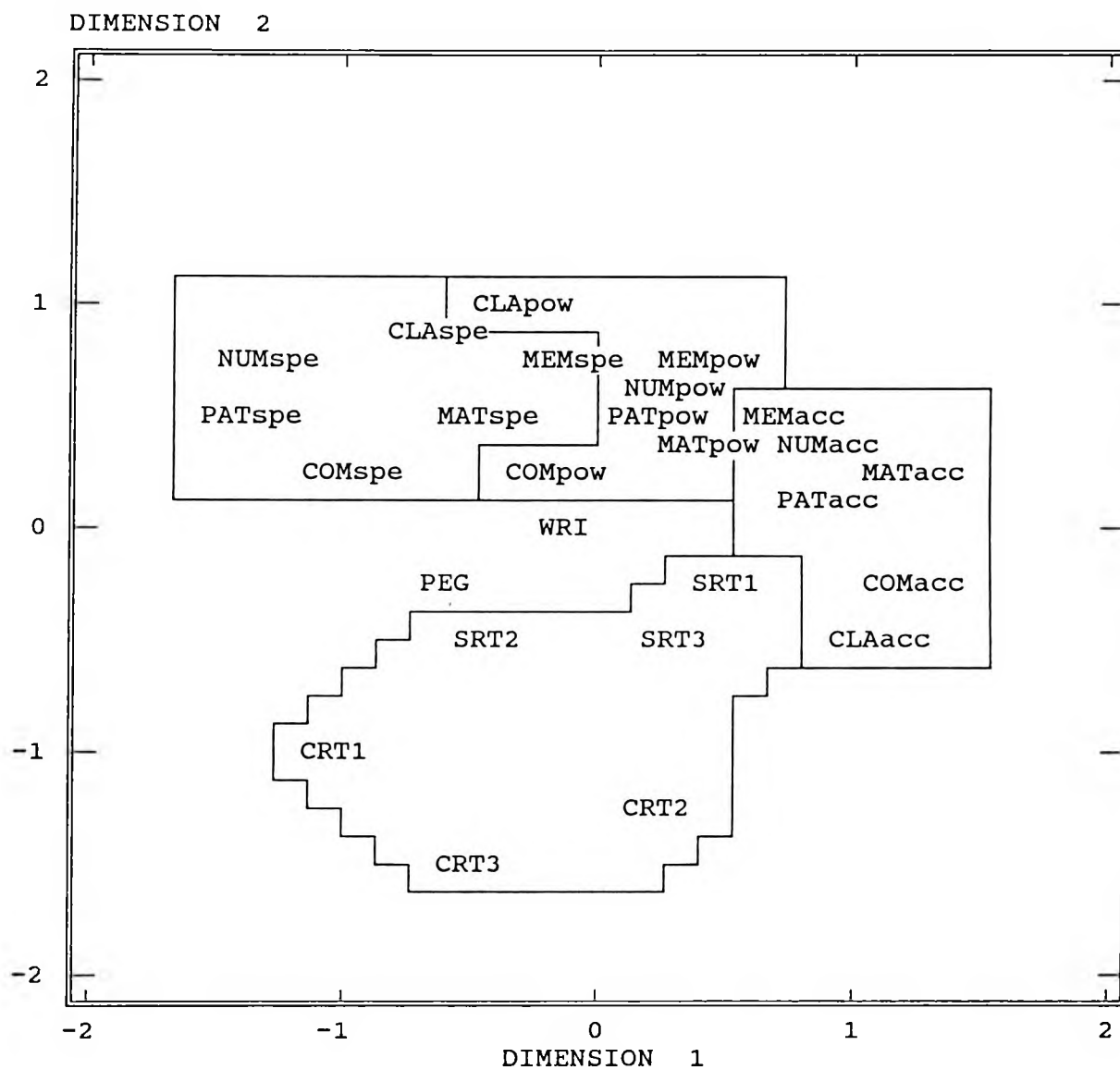


Figure 3.7-6: Facet Diagram of the test scores of Standard 6 children at 29°C (Coefficient of alienation: 0.24).

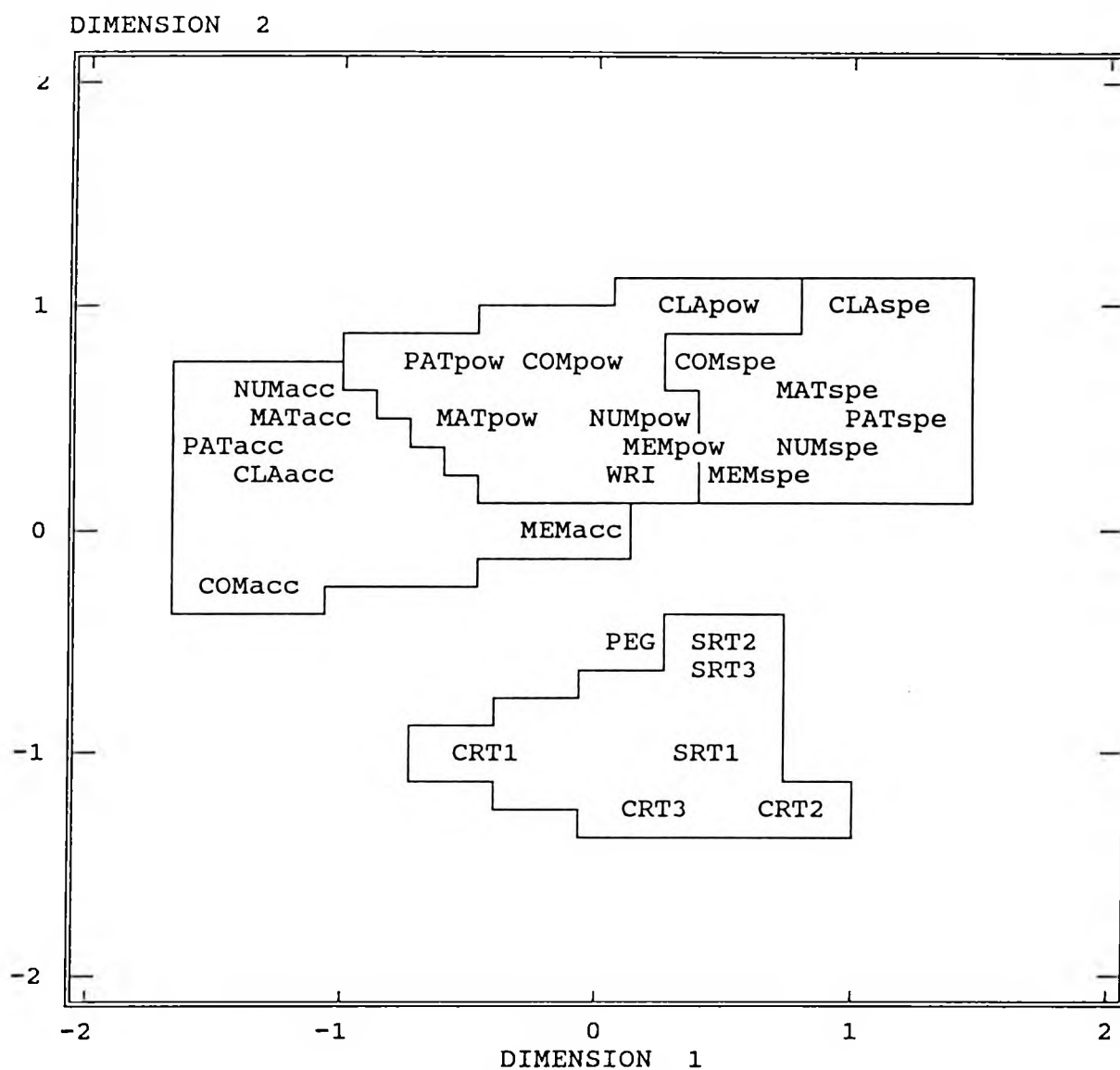


Figure 3.7-7: Facet Diagram of the test scores of Standard 6 children at 34°C (Coefficient of alienation: 0.23).

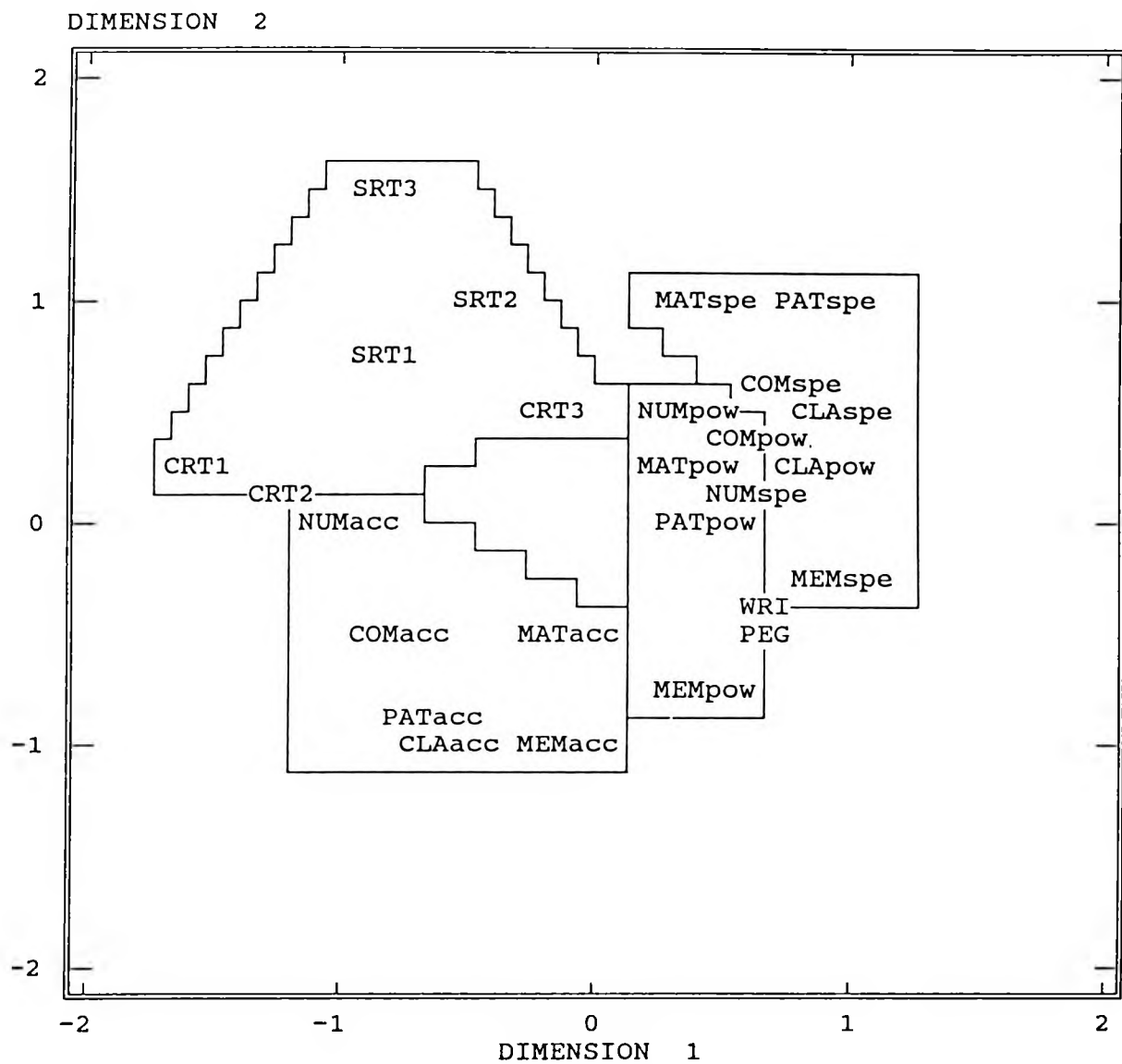


Figure 3.7-8: Facet Diagram of the test scores of Standard 3 children at 14°C (Coefficient of alienation: 0.25).

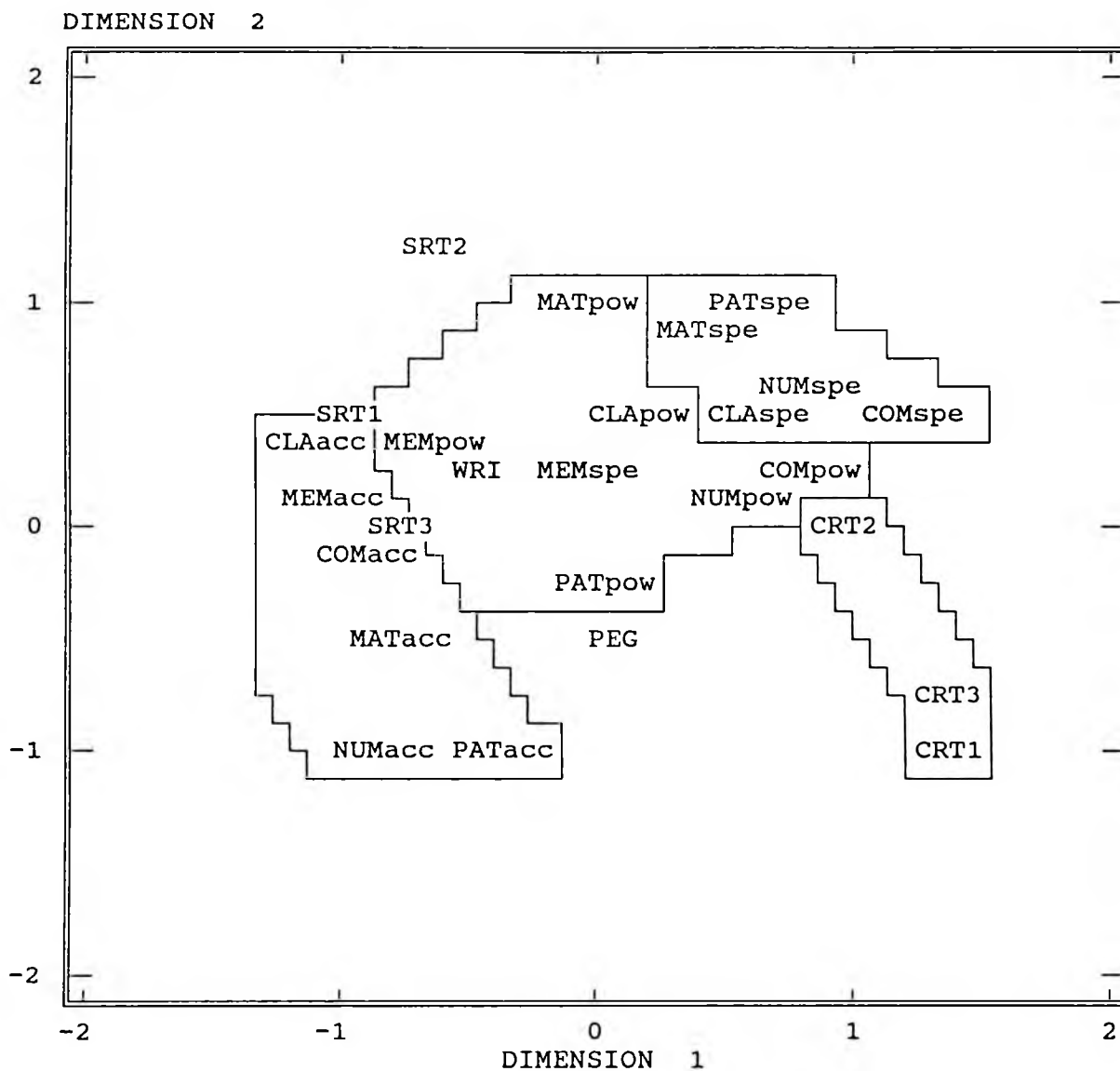


Figure 3.7-9: Facet Diagram of the test scores of Standard 3 children at 34°C. MEMspe falls outside the region of speed scores and the SRT scores do not form a region with the CRT scores (Coefficient of alienation: 0.22).

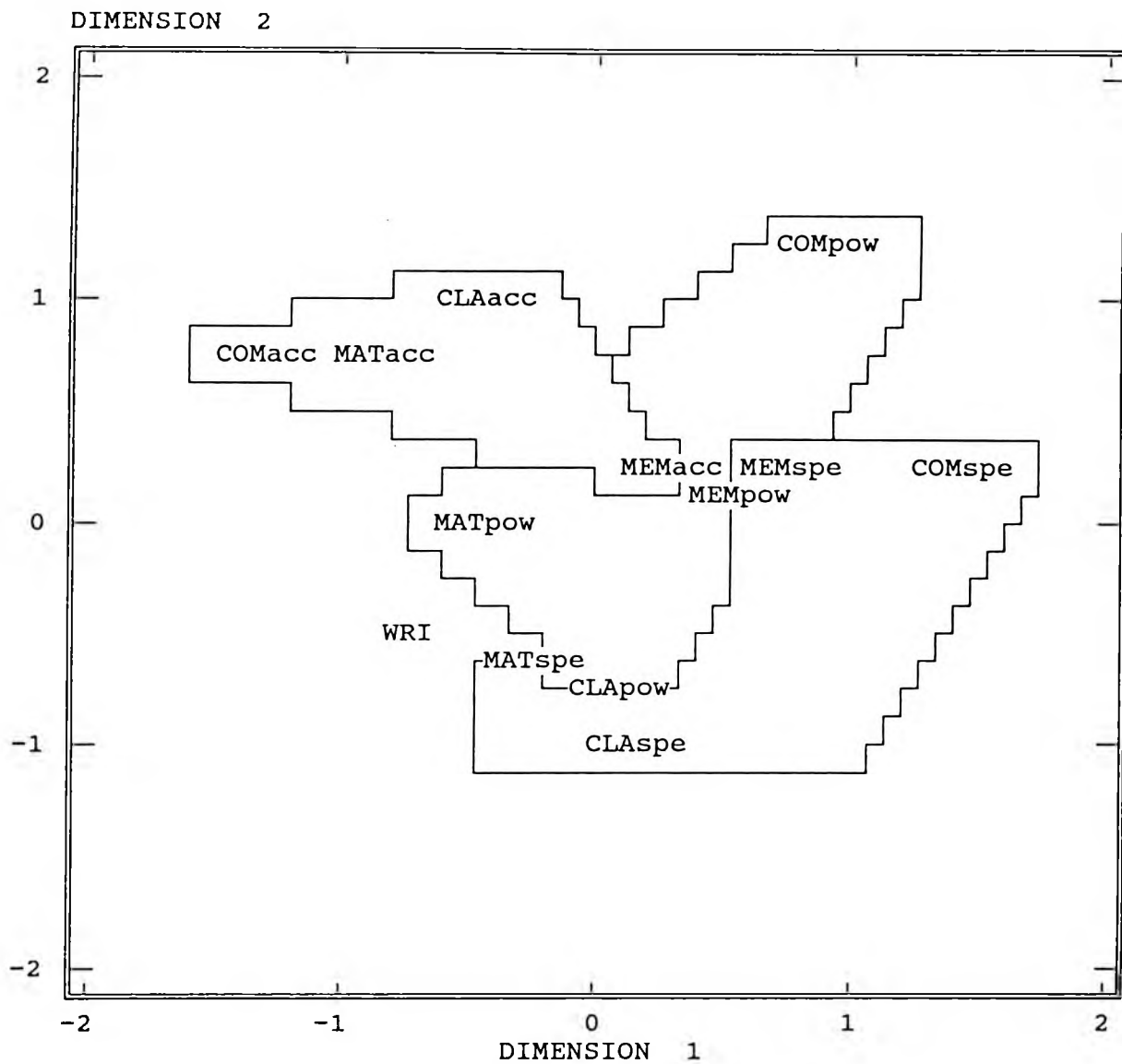


Figure 3.7-10: Facet Diagram of the test scores of Grade 2 children at 14°C (Coefficient of alienation: 0.21).

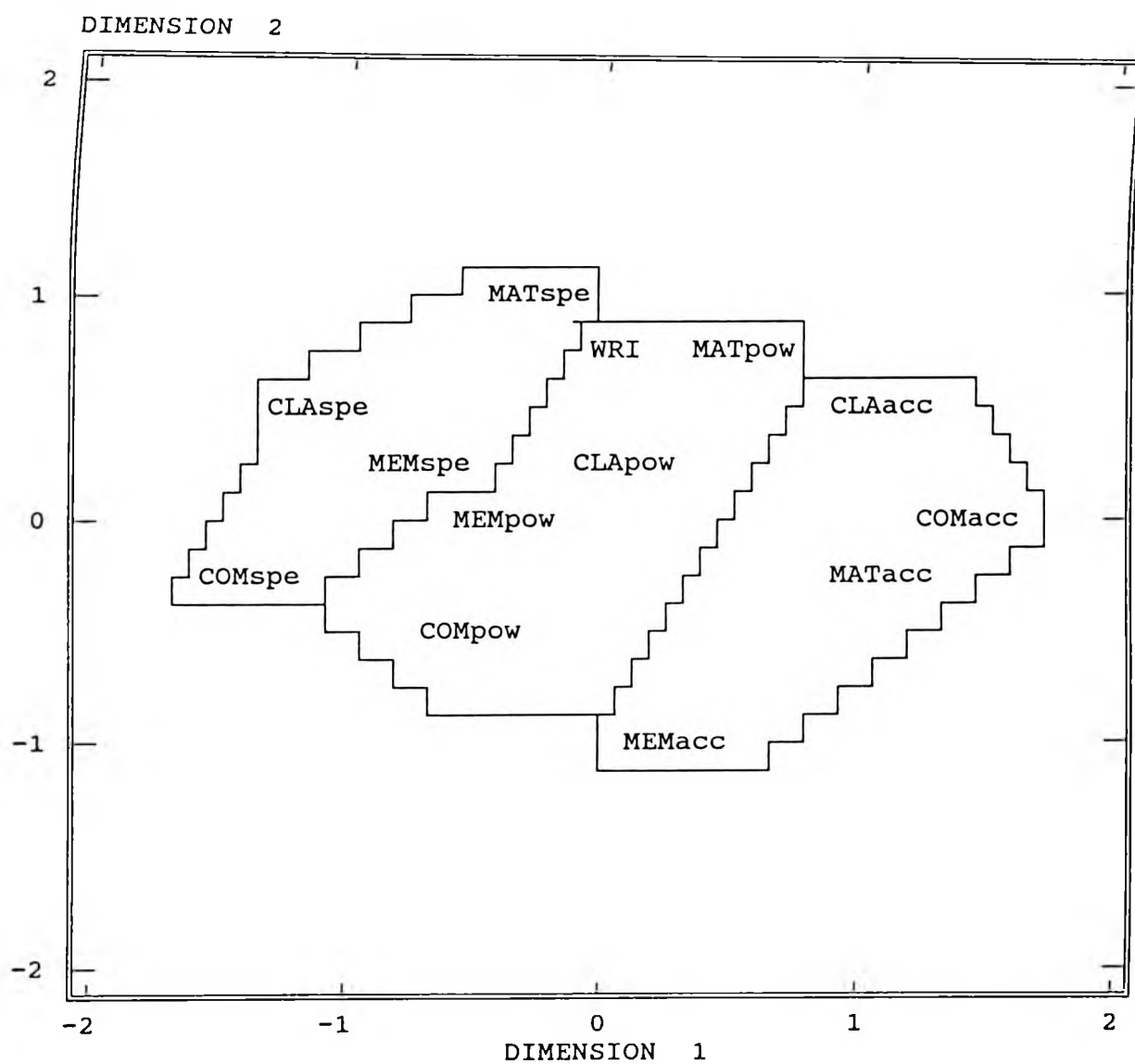


Figure 3.7-11: Facet Diagram of the test scores of Grade 2 children at 34°C (Coefficient of alienation: 0.18).

3.8 EFFECTS OF ROOM TEMPERATURE ON COMBINED SCORES

3.8.1 AIM OF THE ANALYSIS

The results of Facet Analysis described in 3.7 show that scores of the same type, for example power, are usually more strongly correlated than the different types of scores on one test. This justifies combining the scores of all tests into overall power, speed and accuracy scores and investigating these combined scores for sensitivity to room temperature. The high correlation among scores of the same type as shown in 3.7 does not imply that they would be affected by a stressor such as temperature in a similar way. A significant effect of temperature on combined scores, however, would support this speculation. As Facet Analysis had indicated that the reaction times were of little use as predictors of performance on other tests, they were not included in this analysis.

3.8.2 CALCULATION OF COMBINED SCORES

The mean score on the control day was calculated for each experiment, each test and each score type. Thereafter all the scores of each child (stress and control days) were standardised by dividing them by the appropriate mean score on the control day of the experiment, for example the standardised power score for the Comparison Test of child "n" in experiment "x" was calculated by dividing the score of this child by the mean score on power of comparison on the control day of experiment "x".

Thereafter the combined power score was calculated for each child as the arithmetic mean of all the power scores of the tests in which the child had participated. The combined speed and accuracy scores were calculated in the same manner. The combined scores for STD6 and STD3 were derived from six tests each. The combined scores for GRD2 were derived from four tests, as the Number Series and the Pattern Completion Test were not performed in this age group.

3.8.3 TEMPERATURE EFFECT ON COMBINED SCORES

A GLM analysis was performed to assess the predictive qualities of room temperature for the combined scores. The differences in performance between the experiments were compensated for in the standardisation described above. The variable "experiment" was therefore not required. The analysis was performed for each score type by educational standard and room temperature.

analysis:	GLM
model:	score type = type
variables:	score type: power, speed, accuracy type: {class variable, discriminating between stress and control days}
data:	stress and control days [STD6, STD3, GRD2] x [14°C, 19°C, 29°C, 34°C]

Findings where the statistical significance of the effect was $p < 0.05$ are listed in Table 3.8-1.

	Grade 2				Standard 3				Standard 6			
	14	19	29	34	14	19	29	34	14	19	29	34
power	028	.	-	-	-	-	-	-	007	011	-	000
speed	016	.	025	-	-	047	-	-	033	036	-	-
accuracy	-	.	012	-	-	-	-	-	-	-	-	000

Table 3.8-1: Significance levels of differences in combined scores between stress and control days in abbreviated format: "043" stands for " $p < 0.043$ ". For $p < 0.01$ the levels were printed bold and for $p \geq 0.05$ they were replaced by a hyphen. A dot indicates that no experiments were performed.

Significant results with $p < 0.01$ are only found in STD6, the group with the largest sample size, and at the extreme temperatures of 14°C and 34°. The average difference in performance on stress days relative to the performance on control days is shown in Table 3.8-2.

	Grade 2				Standard 3				Standard 6			
	14	19	29	34	14	19	29	34	14	19	29	34
power	-8	.	-1	+2	0	+6	+3	+2	+6	+5	-3	+8
speed	-8	.	+12	+8	-3	+10	+2	+4	+6	+4	-4	0
accuracy	-1	.	-10	-4	+4	-2	+1	-2	+2	+1	0	+8

Table 3.8-2: Percentage increment or decrement of performance on stress days as compared with control days (combined scores).

All score types for Standard 6 show improvement towards the more extreme temperatures (Figure 3.8-1), for Grade 2 all score types show a decline at 14°C (Figure 3.8-3). The significant increase in speed at 19°C for Standard 3 (Figure 3.8-2) is only based on a single experiment with 50 subjects (see Table 3.2-1).

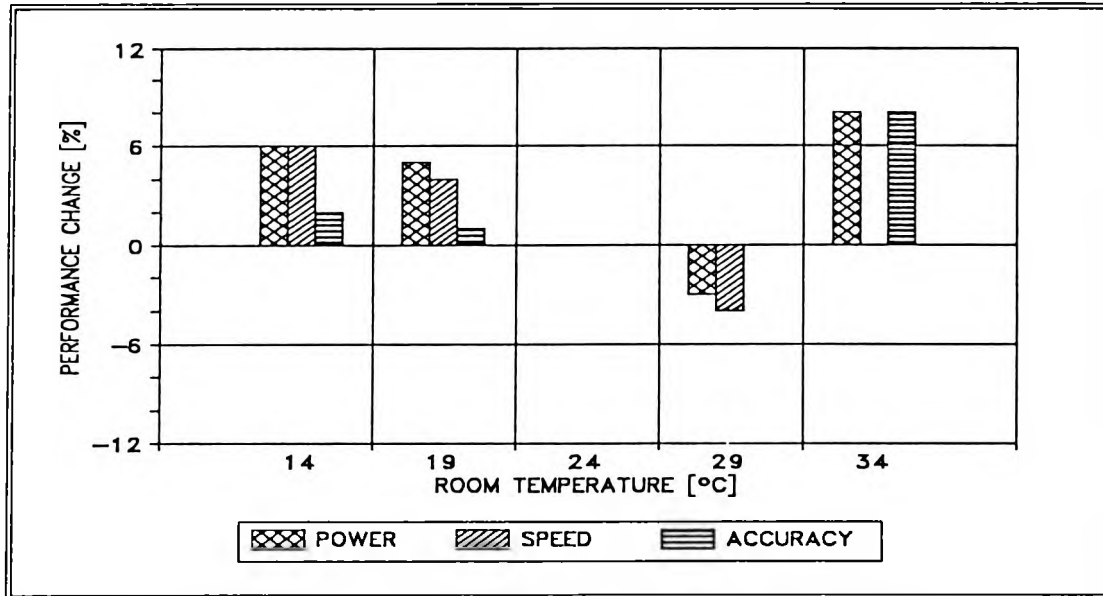


Figure 3.8-1: Percentage change of performance on stress days as compared with control days for the combined power speed and accuracy scores of Standard 6 children.

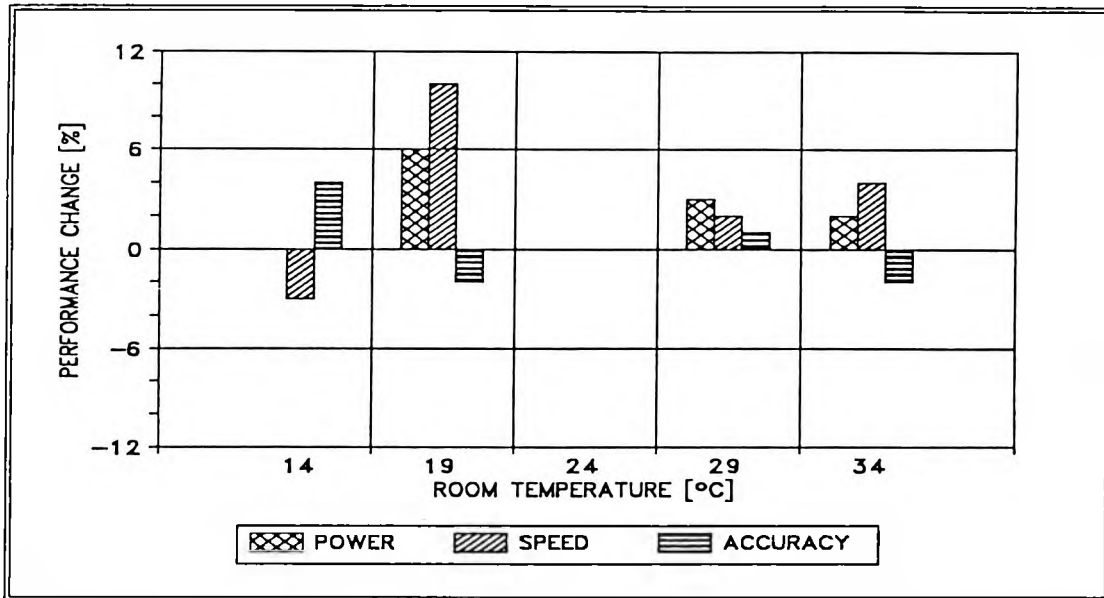


Figure 3.8-2: Percentage change of performance on stress days as compared with control days for the combined power speed and accuracy scores of Standard 3 children.

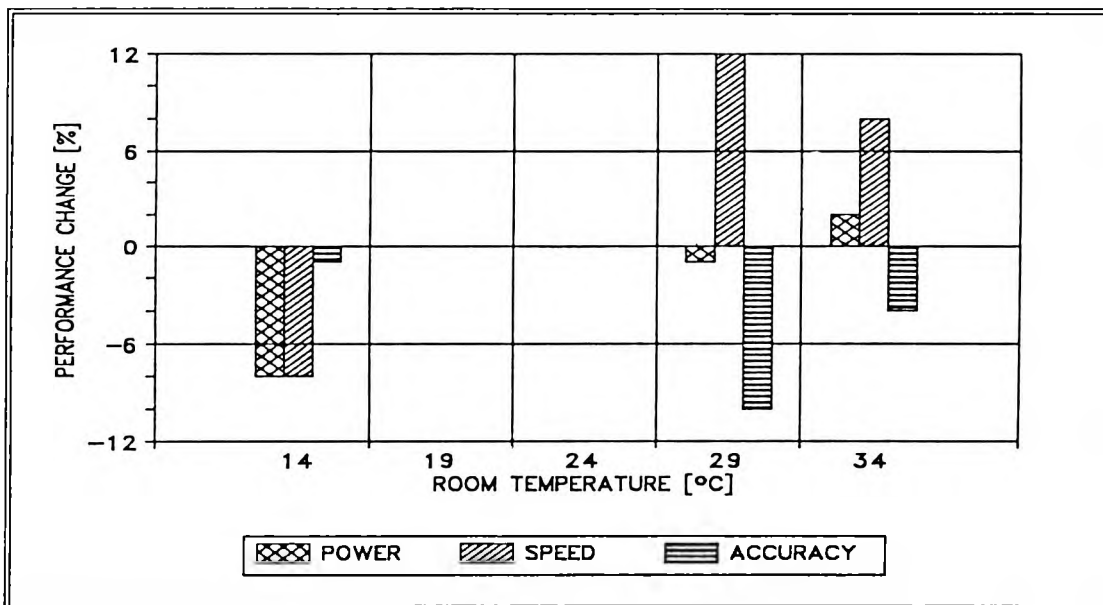


Figure 3.8-3: Percentage change of performance on stress days as compared with control days for the combined power speed and accuracy scores of Grade 2 children.

4.1 STRUCTURE OF THE DISCUSSION

PART	HEADING AND CONTENT
4.2	<u>Temperature effects on the performance of multiple choice type tests</u> Comparison of the results of the present study with findings in the relevant literature. Identification of common patterns.
4.3	<u>Temperature effects on Writing Speed and the O'Connor Peg Test</u> The magnitude of the performance decrement in the cold is compared with other studies.
4.4	<u>Temperature effects on reaction time and its use as a predictor of performance</u> A discussion of reaction time scores in the present study as predictors of performance of other tests and of the temperature effect. Writing Speed is also discussed a predictor.
4.5	<u>The role of concomitant variables</u> Size and statistical significance of the influence of concomitant variables on the effects of temperature on performance in the present study are compared with the findings of other researchers.
4.6	<u>Critical assessment of the methods used</u> The methods of the present study are discussed in the light of the experience gained as well as the extent to which differences in methods can explain different results in other studies. Suggestions for follow-up studies are made.
4.7	<u>Possible improvements in the prediction of thermal effects on performance</u> The use of oral temperature, finger temperature and comfort vote as predictors of performance is investigated. Effects on weak performers and the use of measures such as the EEG are discussed.
4.8	<u>Recommendations for school buildings</u> Practical conclusions for builders and teachers.

4.2 TEMPERATURE EFFECTS ON THE PERFORMANCE OF MULTIPLE-CHOICE-TYPE TESTS

4.2.1 GENERAL

The purpose of this discussion is to establish which findings from the present study concerning the multiple-choice-type performance tests are in agreement with the relevant literature, which findings contradict previous studies and what theoretical basis could explain the results.

The review of literature in the "Introduction" (1.3 to 1.8) showed that findings in the field of moderate stress research are often contradictory. The fact that many of these studies were conducted by well-known and respected researchers may serve as evidence that the conflicting findings result from the complexity of the topic researched and not from any lack of professional rigour. There is no good reason to isolate a small subset of these studies and to state whether the present study agrees with them. A valid discussion of the field must take the complex reality into account and will therefore be closer to pattern recognition than to a discussion based around the current literature.

To compare complex patterns it is necessary to bring the information into a form that makes it easily accessible to the human mind. This is one of the reasons why Facet Analysis was chosen to deal with the correlations between a wide range of test scores (see 3.7). To facilitate comparisons of the effect of temperature found in the present study with other publications a graph of the type

shown in Figure 4.2.1 was used. The horizontal axis represents the room temperature, expressed at the top as WBGT and at the bottom as dry bulb temperature. A relative humidity of 40% was assumed. The vertical axis represents the effect on performance, on a non-metric scale, grouped in classes as indicated on the left side of the graph. The effects were expressed as a percentage of the performance at the condition closest to the middle of the comfort range; about 23 to 24°C.

Results from the present study and from other publications were included in the graphs irrespective of their level of statistical significance since this depends so strongly on sample size. If, for example, the results of several studies show a similar effect then it is worthwhile considering this effect, although none of the results might be significant singly at the 5%-level.

4.2.2 COMPARISON WITH THE RESULTS OF OTHER STUDIES

Wyon (1969a) tested 11-year-old grammar school boys, drawn from the top 30% of the population in terms of ability, at three temperatures (20, 23.5 and 27°C) and at two noise levels. The boys performed an addition task (ADD) and a reading task (RD) which consisted of a passage of text with a choice of three phrases or words inserted after approximately every three lines of text. The subjects had to read the text and underline the correct word at each choice point. Both tests were scored for speed and accuracy. Both the MAT and NUM test of the present study contain elements of addition and Wyon's reading test had some similarities to

the Memory Test of the present study. Wyon's age group corresponds to Standard 3, but as the boys were selected from the best performers and were "ahead" of their peers, it might be of interest to compare them also with the Standard 6 group. In the present study a noise level of 60-67 dB(A) was exceeded for 50% of the time and the L_{eq} ranged between 70 and 75 dB(A) (see 2.6.1.1 and 3.4.3.1). Wyon's quiet condition of 60-70 dB(A) seemed therefore more suited for comparison than his noisy condition at 85-90 dB(A).

Wyon (1969a) found no significant effect of temperature on accuracy or speed, but found a change in sinus arrhythmia that indicated that these well motivated subjects had maintained their performance at the more extreme temperatures by increased effort. This is similar to the findings of Langkilde et al. (1973) who did not find any significant effect of temperature on addition, word memory and cue-utilization but speculated that their well-motivated subjects might have exerted themselves more in the more strenuous conditions.

Figure 4.2-1 shows Wyon's results for the quiet exposure relative to 23.5°C. The addition task (ADD) was negatively affected in cool and warm conditions, with a stronger effect on speed than on accuracy. This corresponds with the results for the low performers in the study of Ryd and Wyon (1970), which are shown in Figure 4.2.7, and with the results of the present study at 29°C: Standard 6 (Figure 4.2-4) shows the same pattern and Standard 3 (Figure 4.2.3) is similar except for MATacc. The results are contradictory in cool conditions, where both Standard 3 and Standard 6 show an improvement of performance at 19°C. This might be due to the fact that the noise level at Wyon's quiet condition was lower. The results of his noisy exposure are given in Figure

4.2-2. The addition task is slightly improved by moderate cooling (which corresponds with the present study) and strongly improved by moderate heat (which overall contradicts the present study, except for MATacc for Standard 3).

During Wyon's quiet exposure (Figure 4.2-1) the reading test (RD) improved under cool and warm conditions whereas under noisy conditions this effect was much smaller and for RDacc at 20°C was negative (Figure 4.2-2). The pattern for the MEM tests of the present study lies between the noisy and the quiet condition. The Standard 3 results indicate little effect of temperature at 19°C and are neutral to positive at 29°C (Figure 4.2-5), whereas for Standard 6 they show a positive effect at 19°C and little effect at 29°C (Figure 4.2-6). It should be noted that the Comparison Test (COM) of the present study, which also required reading and short term memory, was affected in a similar way as the Memory Test (Figures 4.2-5 and 4.2-6) and as Wyon's reading test.

The results of the present study were in between those of Wyon's quiet and noisy conditions. This seems to suggest that the non-thermal stress on the children was slightly higher in the present study than in Wyon's quiet condition. This might be explained by the higher noise level in the present study or by the fact that the subjects in the present study were randomly chosen school children, whereas the subjects in the study of Wyon were a selected elite. Wyon (1969a) wrote that:

"Moderate heat stress appears to lower the level of arousal. The effect of this on poorly motivated subjects was to decrease performance on routine tasks demanding concentration, while from the present results

it appears that well motivated subjects maintain performance only by exerting increased effort."

Results derived from average school children should therefore match the findings of the present study better. Ryd and Wyon (1970) tested 12-year-old children to determine the room temperatures at which heat stress shows a significant reduction in performance. The age of the children was between that of the Standard 3 (11 years) and the Standard 6 (14 years) group in the present study. As in the present study the tests were conducted in a school building to provide realistic environmental conditions. Additional heating was provided by heater fans at the back of the classroom.

Four classes were each exposed to two conditions: the reference temperature of 22-23°C and either 25 or 27°C. The authors used other tests (no details given) to separate the classes into the "more able" (high performers) and "less able" (low performers). Figure 4.2-7 shows the change in performance of a multiplication task at the warm conditions relative to that at 22-23°C. Detailed presentation of the results in this paper enables one to compare the power, speed and accuracy components of the multiplication test for high (H) and low performers (L) of each class. The data are presented irrespective of their statistical significance.

The 29°C condition of the present study is fairly close to the 27°C condition of Ryd and Wyon (1970) and elements of their multiplication task can be found in the Mathematics Test and the Number Series Test of the present study. The results are shown in Figure 4.2-3 for Standard 3 and in

Figure 4.2-4 for Standard 6. A comparison between Figures 4.2-3, 4.2-4 and 4.2-7 indicates:

- a trend towards performance decrement for the above mentioned "mathematical" tests under warm conditions (25-29°C). In the present study the results for the Standard 6 children show a clear decrement, but those for the Standard 3 children do not:
- that the speed score shows a stronger decrement than the accuracy score. The power score is obviously a product of accuracy and speed.

The results of the present study do not contradict that of Ryd and Wyon (1970) and are supported by the results of Reddy and Ramsey (1976) who found that the performance on a multiplication task was worst at warm conditions (29°C). Beshir et al. (1981) found that a temperature increase from 20 to 26°C doubled the amount of tracking errors, while the further increase to 30°C did not decrease performance much further. Their group of subjects, which was homogeneous for performance in a thermally neutral environment, became heterogeneous when working under hot conditions.

The findings fit into the framework of the arousal theory (see 1.6.3) which states that tasks requiring concentration are performed better at a high level of arousal, while tasks such as the Tsai-Partington test are performed better at low levels of arousal. Whereas the performance of mathematical tests seems to suffer in warm conditions, Wyon (1969a) found a significant ($p < 0.05$) increase in performance of the Tsai-Partington test at 27°C as compared to 20°C and 23.5°C.

Pepler and Warner (1968) measured the progress of students in learning a programmed instruction text at different temperatures and also recorded a subjective effort rating by the students. At 27°C the effort was perceived as lowest, working speed was lowest and accuracy was highest. The results are shown in Figure 4.2-8 relative to the findings at 23°C. The dry bulb temperatures in the figure are slightly higher than the temperatures given by Pepler and Warner, as they measured at 45% RH whereas the scale in the figure refers to 40% RH. None of the tests in the present study was of the kind used by Pepler and Warner, but the Memory Test had related components. The results for speed of the Memory Test for Standard 6 (Figure 4.2.6) correspond well with the working speed measure of Pepler and Warner. The performance was lowest in warm conditions (29°C for the present study and 27°C in Pepler and Warner), improved when the temperature was further increased (34 and 33°C), was highest under cool conditions (19 and 20°C) and fell off in the cold (14 and 17°C). The accuracy score of Pepler and Warner shows an inverted U-shape with the best performance at 27°C whereas MEMacc in the present study showed an improvement at all stress temperatures of between four and eight percent, without any discernable pattern (see also Table 3.3-1). The subjects of Pepler and Warner were exposed on six occasions, whereas the subjects in the present study were only exposed once; they had less time to get used to the experimental situation, and it can therefore be assumed that they were in a higher state of arousal. This, and the differences in the task content might account for the differences in the effect of temperature on the accuracy score.

WBGT	10°C	15°C	20°C	25°C	30°C
more than +20%			■RDacc		
+11% to +20%			■RDspe	■RDacc ■RDspe	
+6% to +10%			■RTZO		
+1% to +5%			■NE		
-1% to -5%				■ADDacc	
-6% TO -10%		■ADDacc	■COMFO		
-11% to -20%			■RTZO	■ADDspe	
less than -20%		■ADDspe	■NE		
DRY BULB	14°C	20°C	26°C	32°C	38°C

Figure 4.2-1: Effect of temperature on performance of an addition task (ADD) and a reading test (RD) by 11-year-old boys under quiet conditions (Wyon, 1969a).

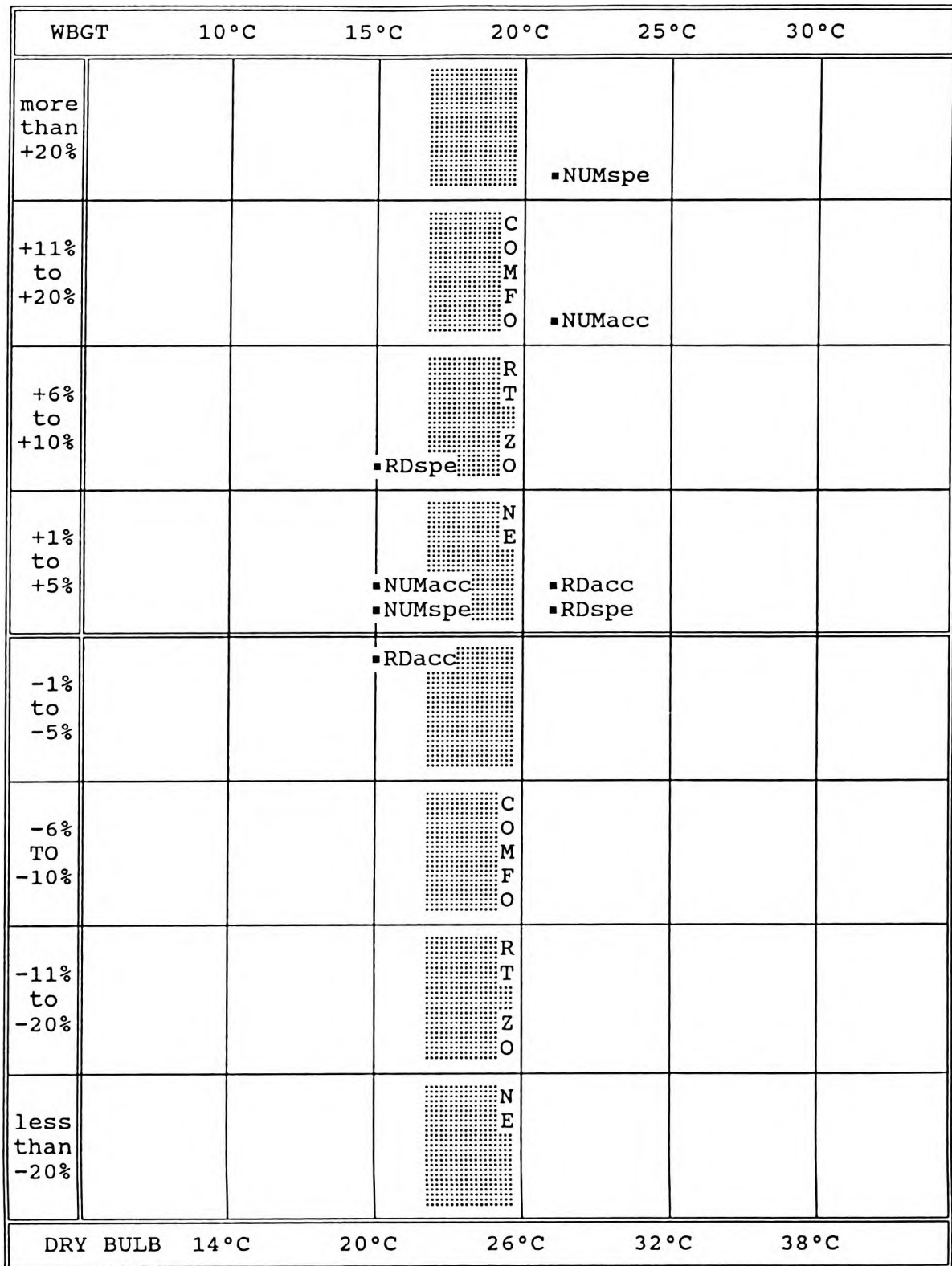


Figure 4.2-2: Effect of temperature on performance of an addition task (ADD) and a reading test (RD) by 11-year-old boys under noisy conditions (Wyon, 1969a).

WBGT	10°C	15°C	20°C	25°C	30°C
more than +20%		■MATspe			
+11% to +20%		■MATpow	COMFO	■MATpow ■MATspe	
+6% to +10%			RTZO	■MATacc	
+1% to +5%		■MATacc	NE	■NUMpow ■NUMspe ■MATacc	
-1% to -5%		■NUMacc ■MATpow	■MATacc	■NUMacc ■NUMspe ■NUMpow	
-6% TO -10%		■NUMspe ■NUMpow ■MATspe	COMFO	■MATpow	
-11% to -20%			RTZO	■MATspe	
less than -20%			NE		
DRY BULB	14°C	20°C	26°C	32°C	38°C

Figure 4.2-3: Effect of temperature on performance of the MAT and NUM test (Table 3.3-1) by Standard 3 children in the present study.

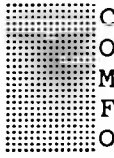
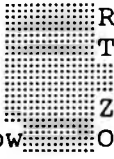
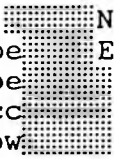
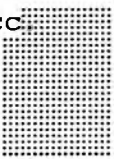
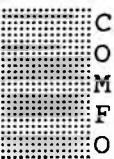
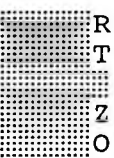
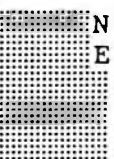
WBGT	10°C	15°C	20°C	25°C	30°C
more than +20%					■MATacc
+11% to +20%		■MATspe	 COMFO		
+6% to +10%		■NUMpow ■MATpow	 RTZO	■NUMacc ■NUMpow ■MATpow	
+1% to +5%		■NUMspe ■MATspe ■NUMacc ■MATpow	 NE	■MATacc	
-1% to -5%		■MATacc ■NUMacc		■NUMacc ■NUMspe	
-6% to -10%			 COMFO	■MATpow ■NUMpow	
-11% to -20%			 RTZO	■MATspe ■MATspe ■NUMspe	
less than -20%			 NE		
DRY BULB	14°C	20°C	26°C	32°C	38°C

Figure 4.2-4: Effect of temperature on performance of the MAT and NUM test (Table 3.3-1) by Standard 6 children in the present study.

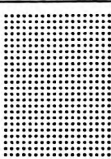
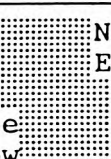
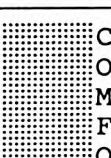
WBGT	10°C	15°C	20°C	25°C	30°C
more than +20%					
+11% to +20%			 COMFO	■ COMspe	
+6% to +10%			 RTZO	■ COMpow ■ COMspe ■ MEMspe ■ MEMspe ■ COMpow	
+1% to +5%		■ COMacc ■ MEMpow ■ MEMspe ■ MEMspe ■ MEMacc ■ MEMpow	 NE		■ MEMspe ■ MEMpow
-1% to -5%		■ MEMacc ■ COMacc ■ COMspe ■ COMpow		■ MEMacc ■ MEMacc ■ COMacc ■ COMacc	
-6% TO -10%			 COMFO		
-11% to -20%		■ COMpow ■ COMspe	 RTZO		
less than -20%			 NE		
DRY BULB	14°C	20°C	26°C	32°C	38°C

Figure 4.2-5: Effect of temperature on performance of the COM and MEM test (Table 3.3-1) by Standard 3 children in the present study.

WBGT	10°C	15°C	20°C	25°C	30°C
more than +20%					
+11% to +20%		■MEMpow	■MEMpow ■MEMspe	■MEMpow	
+6% to +10%		■MEMacc		■MEMacc	■COMpow ■MEMspe ■MEMacc
+1% to +5%		■COMpow ■COMacc ■MEMspe ■COMspe	■MEMacc ■COMpow ■COMspe ■COMacc	■COMacc ■MEMpow ■COMacc	■COMspe
-1% to -5%				■COMpow ■MEMspe ■COMspe	
-6% to -10%					
-11% to -20%					
less than -20%					
DRY BULB	14°C	20°C	26°C	32°C	38°

Figure 4.2-6: Effect of temperature on performance of the COM and MEM test (Table 3.3-1) by Standard 6 children in the present study.

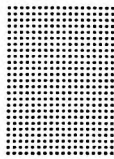
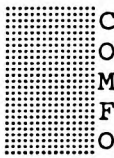
WBGT	10°C	15°C	20°C	25°C	30°C
more than +20%					
+11% to +20%			 C O M F O		
+6% to +10%			 R T Z O		
+1% to +5%			 N E	*acCH *powH *powH *acCH *speH	
-1% to -5%			acCH* accL* acCH* accL* speH*	*speL *speH *accL *powL *accL	
-6% TO -10%			powH* powH* speH* 	*speL	
-11% to -20%			speL* powL* speL* 	*powL	
less than -20%			powL* 		
DRY BULB	14°C	20°C	26°C	32°C	38°C

Figure 4.2-7: Effect of temperature on performance of a multiplication task by 12-year-old children (Ryd and Wyon, 1970). "L" refers to low and "H" to high performers of two classes at each condition.

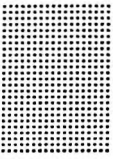
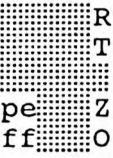
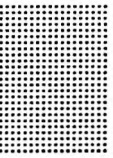
WBGT	10°C	15°C	20°C	25°C	30°C
more than +20%		■eff		■eff ■eff	
+11% to +20%			 C O M F O		
+6% to +10%			 R T Z O ■spe ■eff	■acc	
+1% to +5%		■spe	 N E	■acc ■spe	■spe
-1% to -5%				■eff ■spe	■acc
-6% TO -10%			■acc  C O M F O		
-11% to -20%		■acc	 R T Z O		
less than -20%			 N E		
DRY BULB	14°C	20°C	26°C	32°C	38°

Figure 4.2-8: Effect of temperature on learning a programmed instruction text by college students (Pepler and Warner, 1968). "eff" is an abbreviation for "effort rating" by the students.

WBGT	10°C	15°C	20°C	25°C	30°C
more than +20%					
+11% to +20%		■PATacc ■PATspe	 COMFO	■PATspe	
+6% to +10%			 RTZO		
+1% to +5%		■CLAacc ■PATpow ■PATpow	 NE	■CLAacc ■CLApow ■PATspe ■CLAacc	
-1% to -5%		■CLApow ■CLAspe ■CLAspe ■CLApow ■CLAacc ■PATacc	 NE	■CLAacc ■CLApow ■PATspe ■CLAspe ■PATpow ■PATacc	
-6% TO -10%		■PATspe	 COMFO	■PATacc	
-11% to -20%			 RTZO		
less than -20%			 NE		
DRY BULB	14°C	20°C	26°C	32°C	38°

Figure 4.2-9: Effect of temperature on performance of the CLA and PAT tests (Table 3.3-1) by Standard 3 children in the present study.

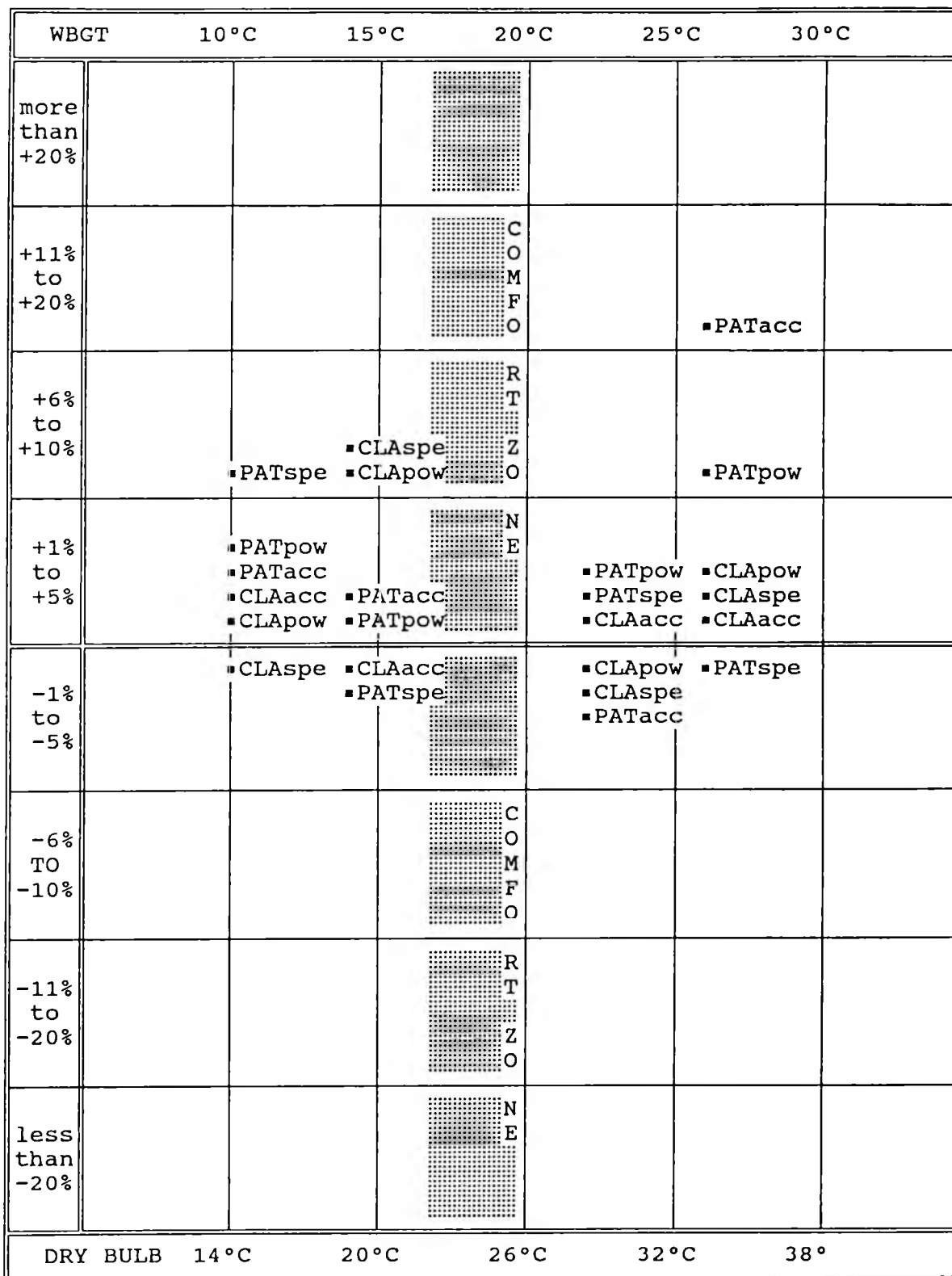


Figure 4.2-10: Effect of temperature on performance of the CLA and PAT tests (Table 3.3-1) by Standard 6 children in the present study.

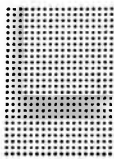
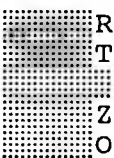
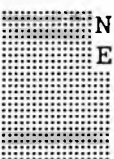
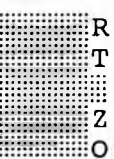
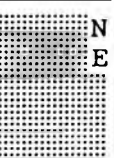
WBGT	10°C	15°C	20°C	25°C	30°C
more than +20%					
+11% to +20%			 COMFO	■ CLAspe ■ MEMspe ■ COMspe ■ CLAspe	
+6% to +10%			 RTZO	■ MATspe ■ CLApow ■ COMpow	
+1% to +5%		■ CLAacc	 NE	■ COMpow	■ MEMpow ■ MEMacc ■ CLApow ■ MEMspe ■ MATspe
-1% to -5%		■ COMacc ■ MEMspe ■ MEMpow ■ MATacc ■ MEMacc		■ COMacc ■ MATacc ■ MATpow ■ COMacc	
-6% TO -10%		■ COMspe ■ CLApow ■ COMpow	 COMFO	■ CLAacc ■ MATpow ■ MATacc	■ CLAacc
-11% to -20%		■ CLAspe ■ MATspe ■ MATpow	 RTZO	■ MEMpow ■ MEMacc	
less than -20%			 NE		
DRY BULB	14°C	20°C	26°C	32°C	38°

Figure 4.2-11: Effect of temperature on performance of the CLA, COM, MAT and MEM tests (Table 3.3-1) by Grade 2 children in the present study.

4.2.3 COMPARISON OF THERMAL EFFECTS ON DIFFERENT PERFORMANCE TESTS

The Facet Diagrams in Figures 3.7-1 to 3.7-11 show that the pattern of correlations between tests does not change visibly with temperature. As the scores form regions according to score types this implies for example that the accuracy score of a test is usually predicted better by the accuracy score of another test than by the speed or power score of the same test. This holds at all temperatures. It does not imply, however, that all scores of the same type are affected by temperature in the same way. To determine similarities in the effect of temperature on different scores, the following procedure was applied:

- the Spearman rank order correlation was calculated between the rows of Table 3.3-1. This table contains the percentage change of performance at different conditions, and a row represents a score type of one test. The reaction time scores were excluded as they were not highly enough correlated with the other scores to allow meaningful prediction;
- the correlations were used to produce a Facet Diagram, which is shown in Figure 4.2-12.

Figure 4.2-12 looks very similar to Figures 3.7-1 to 3.7-11; the score types form clearly distinguishable clusters, indicating that, for example, the temperature effect on the speed score of a test is better predicted by the effect on the speed score of another test than by the effect on the accuracy score of the same test.

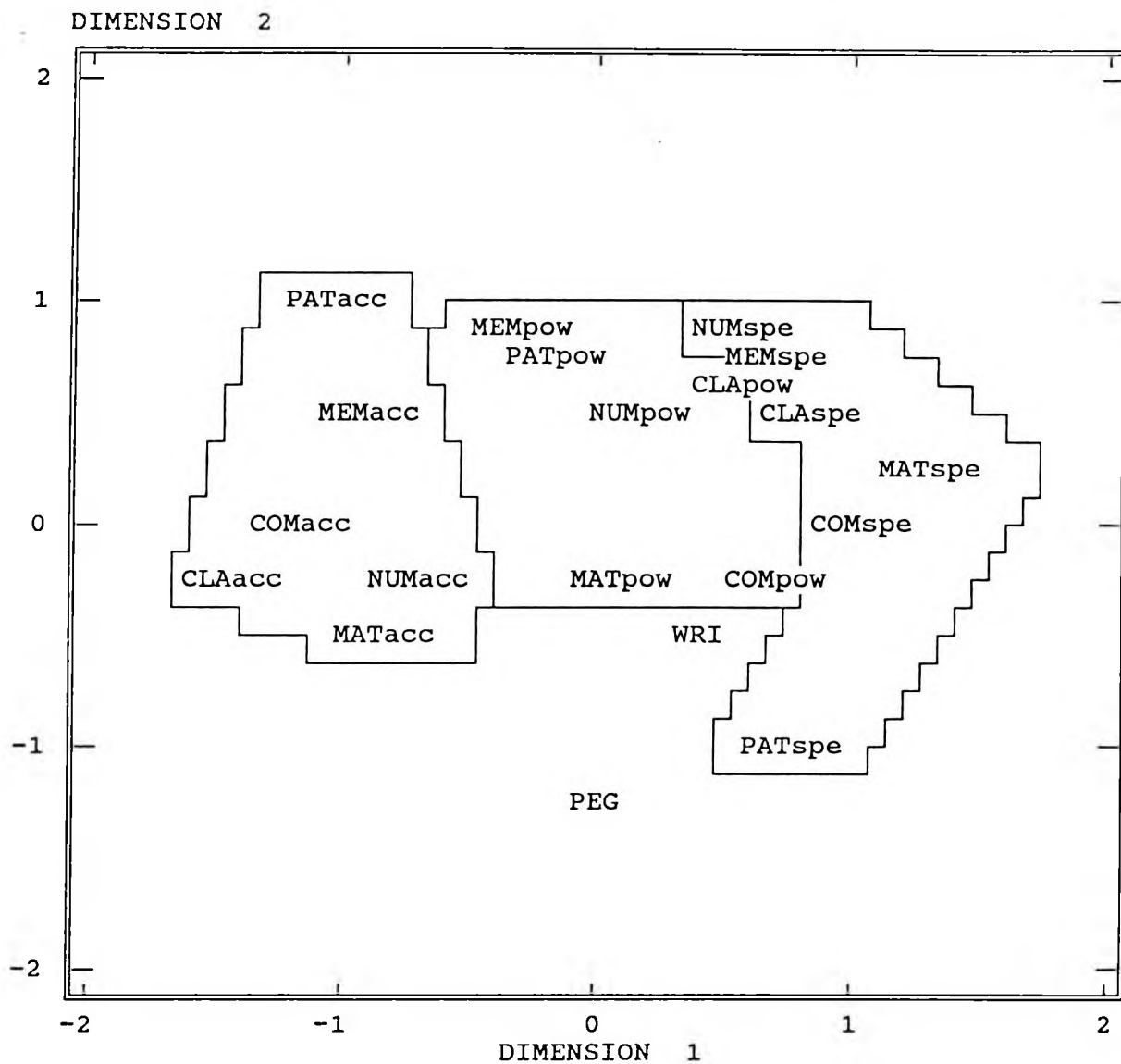


Figure 4.2-12: Facet Diagram of the effects of temperature on test scores of all children (Coefficient of alienation: 0.21).

These results emphasise the usefulness of the combined scores as described in 3.8. If the individual tests were all affected in different ways, the combined scores should not produce any significant findings. If, however they produced clear and statistically significant patterns this would indicate that all or at least most performance tests were affected in a similar way. Tables 3.8-1 and 3.8-2 and the Figures 3.8-1 to 3.8-3 indicate that the latter was the case, as the results showed:

- for Grade 2 a drop in power at 14°C ($p < 0.03$) due to a drop in speed ($p < 0.02$);
- for Standard 6 an increase in power at 14 and 19°C ($p < 0.01$ and $p < 0.001$) due to an increase in speed ($p < 0.03$ and $p < 0.04$) and an increase in power at 34°C ($p < 0.001$) due to an increase in accuracy ($p < 0.001$);
- for Standard 6 a drop in power at 29°C due to a drop in speed. These effects were not significant.
- for Standard 3 little effect of temperature was found and only one score was significantly affected (increase in speed at 19°C, $p < 0.05$).

The results of the combined scores are very similar to those of the individual tests. An analysis based only on the combined scores would have identified all the major trends in the data, except the drop in performance for Standard 6 at 29°C. It might therefore be possible to discover most major effects of temperature on performance by using only one or two tests instead of a test battery.

The similarities of the effect of temperature on the tests does not imply that different cognitive abilities are affected by temperature in the same way. Although the tests focused on different cognitive abilities they involved a series of activities and processing steps such as turning the pages in the test booklet, reading the test items and comprehending the task at hand, selecting a response among different options and finally pressing the response key, that were common to all tests. It might be the preponderance of common activities in each task that was responsible for the pattern of the temperature effects. Similarly the work children perform during a normal school day in different lessons such as Mathematics or English contains a series of activities and processing steps that are common to most lessons.

4.2.4 DIFFERENCES IN THERMAL EFFECTS ON SPEED AND ACCURACY

The results of Ryd and Wyon (1970) and other studies indicate that speed and accuracy are affected differently by temperature. In the present study the number of speed scores on all tests, temperature conditions and educational levels on which the effect on the speed score exceeded ten percent was 19. The equivalent number for the accuracy score was four, indicating that temperature has a greater effect on the number of items a test subject will attempt than on the percentage of correct answers. The ratio of speed versus accuracy scores with a temperature effect greater than 10% was:

- Grade 2: speed : accuracy = 7 : 1;
- Standard 3: speed : accuracy = 7 : 1;
- Standard 6: speed : accuracy = 2.5 : 1.

A view of the corresponding graphs shows that this ratio was 4:2 for the quiet and 1:1 for the noisy condition of Wyon (1969a) and 2:0 for Ryd and Wyon (1970). Only for Pepler and Warner, who tested college students, was the ratio 0:1. This supports the findings that speed is more strongly affected by temperature than accuracy and also indicates that this effect was more pronounced in younger children.

The ratio of the percentage of variation attributable to room temperature (Table 3.4-5) for speed versus accuracy scores was:

- Grade 2: speed : accuracy = 1.3 : 1;
- Standard 3: speed : accuracy = 5.4 : 1;
- Standard 6: speed : accuracy = 1.1 : 1.

In all cases a higher percentage of the total variation could be attributed to temperature for speed than for accuracy. The ratio between significant effects ($p < 0.05$) on all tests for speed versus accuracy was:

- Grade 2: speed : accuracy = 5 : 1;
- Standard 3: speed : accuracy = 3 : 0;
- Standard 6: speed : accuracy = 1.4 : 1.

All results indicate that the effect of temperature on the performance of cognitive tests is mainly due to an alteration of working speed rather than to a change of the

accuracy with which the work is performed. Speed and accuracy might be effected differently by temperature because they represent different attributes of cognitive performance. Bridges (1985) found that test completion speed was unrelated to performance. Bridges' performance measure related to the number of correct responses in a test of fixed length and is therefore equivalent to the speed score in the present study. Verster (1983) wrote that speed and accuracy tend to vary independently over a wide range of cognitive processes.

4.2.5 SUMMARY

The discussion of thermal effects on the performance of multiple-choice-type tests showed that:

- the results of the present study are compatible with those of other studies;
- thermal effects on performance tests show a pattern that is largely independent of the nature of the performance test;
- correlations between score types of different tests are stronger than those between different types of scores of the same test. This pattern was found at all temperatures;
- when the power, speed and accuracy scores on all tests were combined for each subject, they showed the same patterns for the effect of temperature as the individual test scores.

- Standard 6 children showed a drop in performance at 29°C as compared with 24 or 34°C. This effect is well documented in literature for adults as well as for children. The results of the present study suggest that this effect is less pronounced in younger children;
- thermal stress improved the performance of the Standard 6 children in the cold as well as in the heat. This may be due to increased arousal and similar effects have been documented in the relevant literature. It has to be considered that the experiments lasted only for one day; long term effects of the same conditions may be different. However, the younger the children the more they were affected by cold conditions. Grade 2 children showed a clear overall decrement in performance where the Standard 6 children showed a clear improvement; and
- the effect of temperature on performance is mainly due to an alteration of work speed and less to a change of the percentage of correct solutions.

In order to provide a graphical overview of the effect of temperature the mean of the differences between stress and control days (in percent) for the power scores of all performance tests (Table 3.3-1) was calculated for each experimental condition and each age group. These means plus and minus one standard deviation are displayed in Figures 4.2-13 to 4.2-15.

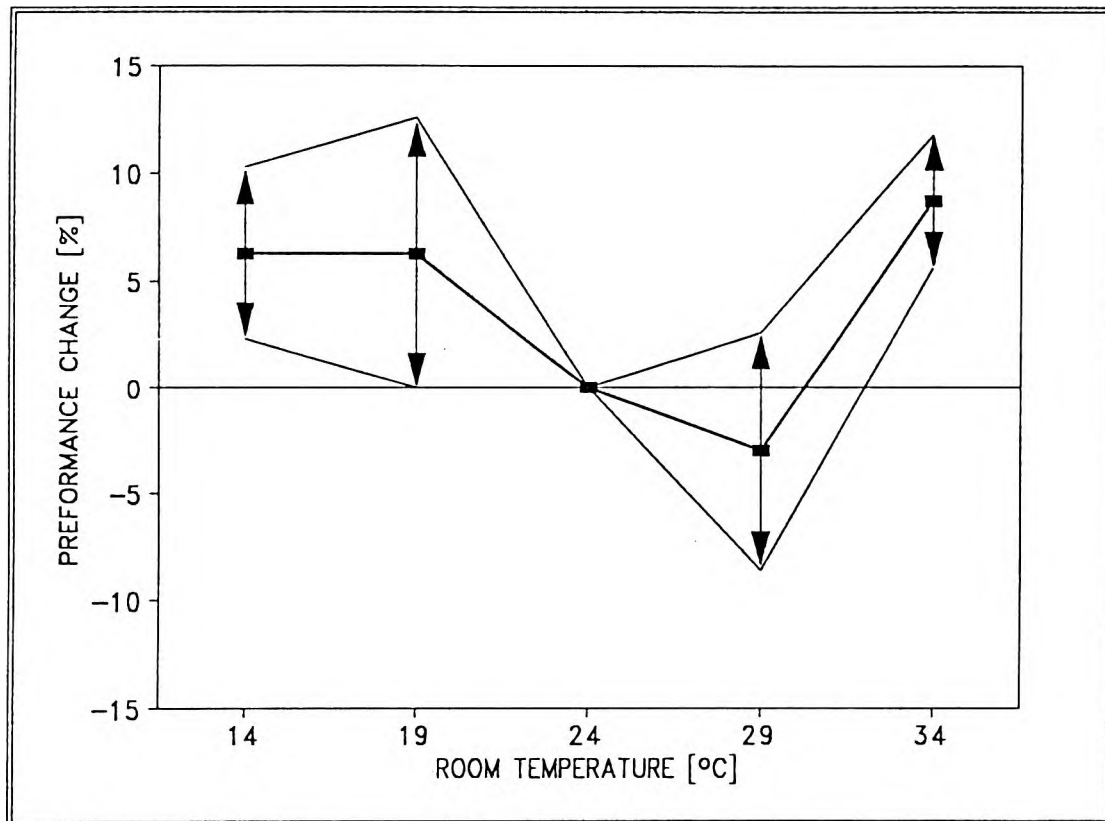


Figure 4.2-13: Means plus and minus one standard deviation of the differences in performance between stress and control days (Table 3.3-1) for the power scores of all tests. Standard 6 children only.

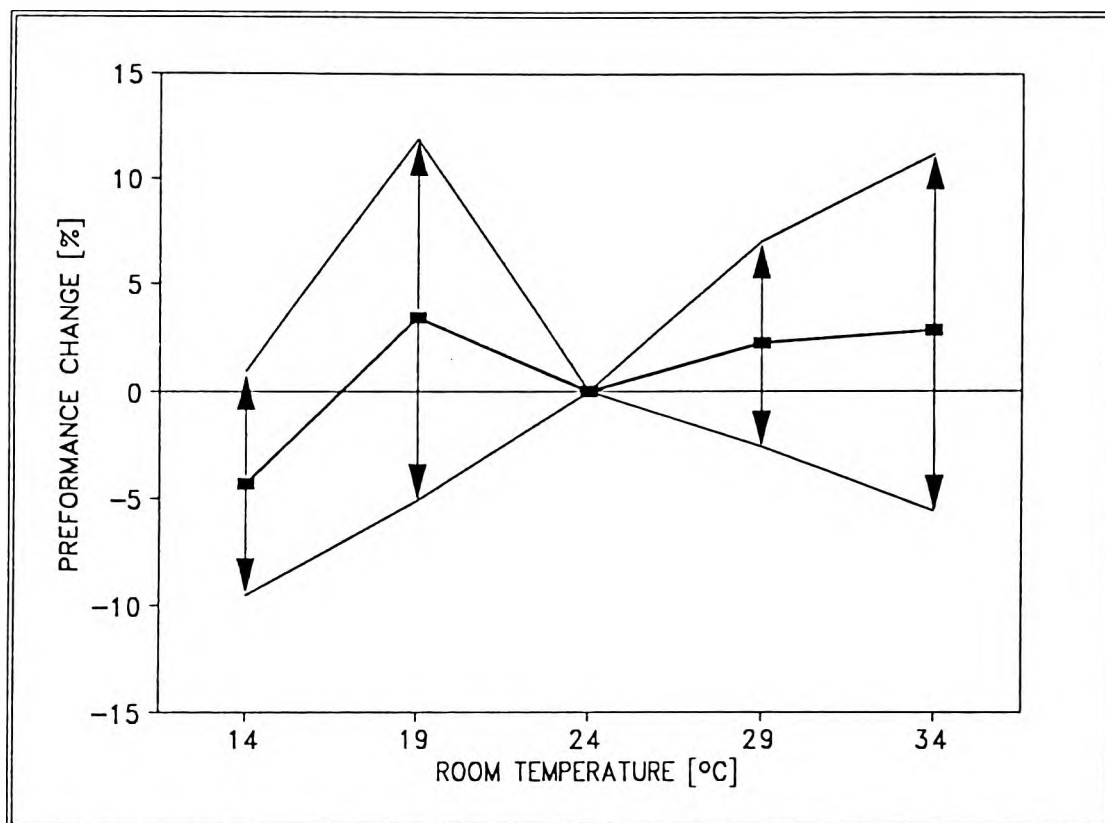


Figure 4.2-14: Means plus and minus one standard deviation of the differences in performance between stress and control days (Table 3.3-1) for the power scores of all tests. Standard 3 children only.

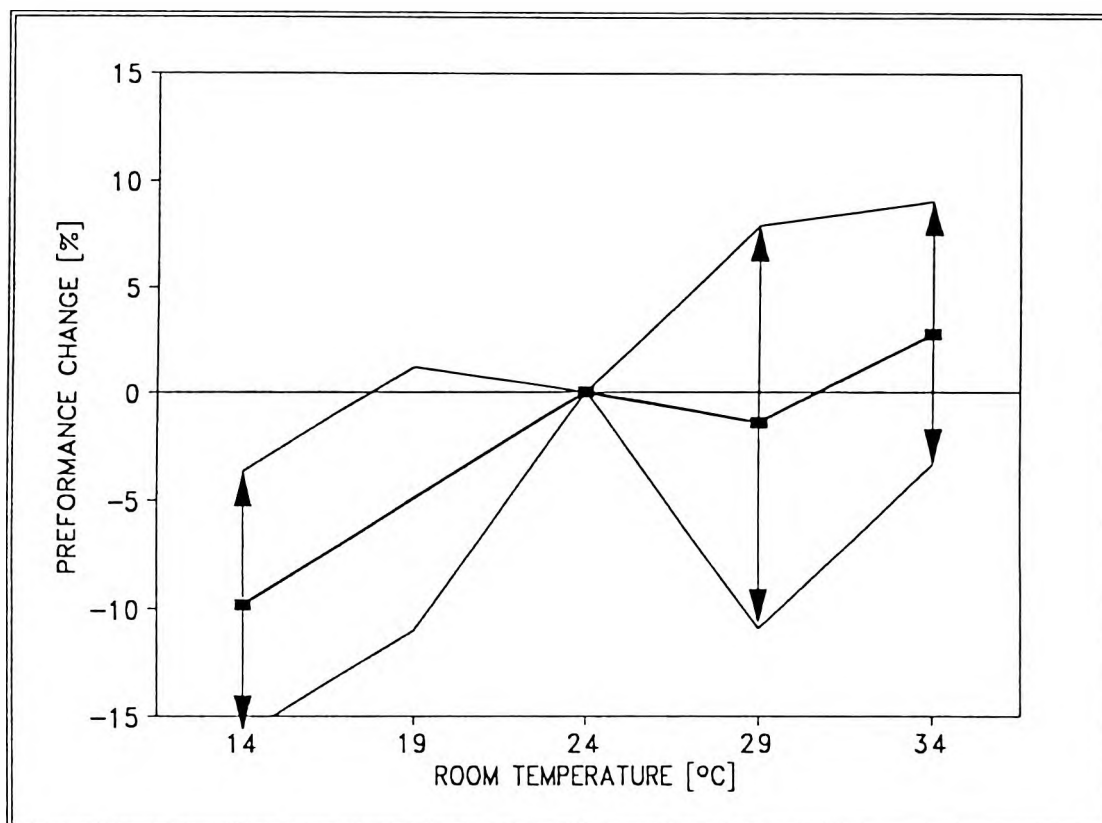


Figure 4.2-15: Means plus and minus one standard deviation of the differences in performance between stress and control days (Table 3.3-1) for the power scores of all tests. Grade 2 children only.

4.3 TEMPERATURE EFFECTS ON WRITING SPEED AND THE O'CONNOR PEG TEST

The effect of temperature on the performance of finger dexterity tasks is much less under hot than under cold conditions (Meese et al., 1981). In the cold the performance decrement is mainly caused by a physiological effect (Hunter et al. 1952). In warm or hot conditions physiological effects on finger dexterity are small and it would be difficult to isolate these small effects from the performance changes caused by altered arousal or motivation. This discussion focuses therefore on the cold, and as the database for the 19°C condition is rather small, mainly on the results at 14°C.

For Grade 2 children the Writing Speed Test shows a clear, significant ($p < 0.01$) decrease in performance at 14°C (Table 3.3-1). The effect on the Standard 3 children was much smaller and not significant whereas the Standard 6 children did not seem to be affected at all.

The performance of Grade 2 children on the O'Connor peg test was not assessed in the present study, but similar measurements have been made by Wentzel and Meese (1983), who measured the performance of White Grade 2 children at 6°C. The performance decrement on the O'Connor Peg Test was found to be 20% as compared with the performance at 25-27°C.

It was shown by Schiefer et al. (1984a) that in a given thermal environment adults of different population groups have different finger skin temperatures. At 14°C they would be 24°C for White males, 22°C for White females and 19°C for

Black males and females. In the 14°C condition of the present study the mean finger temperatures for the children of the youngest and the oldest group were similar, on average 18.7°C which is slightly lower than that of the most temperature sensitive group of adults and clearly lower than the finger temperatures of adults of their own population group (Schiefer et al. 1984a). This was expected, as young children are more sensitive to cold than adults (Araki et al. 1982). White males would show a finger temperature of 18.7°C at a room temperature of about 8°C and White females at a room temperature of about 10°C. In a study of Meese et al. (1981) the drop in performance on the O'Connor Peg Test compared to 24°C was 14% at 12°C and 17% at 6°C for White males; for White females it was 14% at 12°C and 16% at 6°C. Assuming that an equal drop in finger skin temperature leads to a comparable drop in performance, interpolation leads to an expected performance drop between 13% and 16% at 14°C for the present study. The experimental results were close to the expected value: 10% drop in performance for Standard 3 and 13% for Standard 6

Enander (1987) tested twelve male office workers at 21 and 6°C. They performed a manual dexterity test in which they had to pick up ten screws, put them into holes in a metal plate and screw them in with a screwdriver until they fell out on the other side. The performance decrement in the cold on this task, which has similarities to the O'Connor Peg Test, was 13%.

The performance of the O'Connor Peg Test was affected by temperature in both age groups, whereas the Writing Speed Test showed a clear increase of the effect of cold with decreasing age. A possible explanation lies in the higher skill content of the Writing Speed Test. Writing is a

complex skill that is acquired over many years and the Standard 6 children were obviously better performers in writing than the Grade 2 children. A summary of published data by Hancock (1986) suggests that individuals who are skillful at the task are better able to withstand detrimental effects of stress than their unskilled counterparts. Performing the O'Connor Peg Test, on the other hand, is mainly a mechanical activity, and all the children in the present study performed it for the first time. This could explain why cold had a comparable effect on the performance of both age groups.

4.4 TEMPERATURE EFFECTS ON REACTION TIME AND ITS USE AS A PREDICTOR OF PERFORMANCE

4.4.1 REACTION TIME AS A PREDICTOR OF PERFORMANCE

A contribution to the efficiency of research into moderate stress could take the form of a quick, simple test that correlates well enough with established cognitive tests to allow prediction of their scores. Such a simple test could be substituted in many cases for tests that are complicated to administer and score or take a long time to perform.

Reaction time has been extensively discussed as a predictor of intellectual performance (for instance Jensen and Munro, 1979) and it was an objective of this study to investigate the use of simple or choice reaction time as a general "barometer" for changes in cognitive performance.

The Facet Diagrams in Figures 3.7-1 to 3.7-11 express the correlation between test scores in a graphical manner. The closer two test scores are in the Facet Diagram space, the higher they are correlated. It can be seen in the diagrams for all three age groups and five temperature conditions that:

- the three measures of Simple Reaction Time taken at three different times during the day are strongly correlated with each other. The same is true for the three measures of Choice Reaction Time;
- Simple and Choice Reaction Time scores are strongly correlated with each other and in all but one diagram

(Standard 3, 34°C) all reaction time scores can be found in a single undivided area;

- in the diagrams the region of the reaction time scores is clearly separate from the regions formed by the different score types of the cognitive performance tests. This implies that neither Simple nor Choice Reaction Time is a good predictor of performance on multiple-choice-type tests as used in the present study.

The Writing Speed score is in all cases closer to the region of power scores than the region of either Simple or Choice Reaction Time scores. There is also no indication that the more complex CRT is more highly correlated with scores on the multiple-choice-type tests than the SRT, as might have been expected according to Vernon and Jensen (1984). This result might be explained by the way the reaction time tests were applied in the present study. As a result of time constraints and functional limitations of the ADCS:

- the number of repeat measurements was relatively low. In total each child performed the SRT only nine and the CRT only six times. In the study of Jensen and Munro (1979) each subject performed these tests 150 times;
- no training could be given to establish a performance plateau, although the CRT was a relatively complex task,;
- the children were tested sequentially, one at a time, to achieve a sufficient resolution for the reaction time measurement (see 2.4.3.9 and 2.4.3.10). This implied that most children had to wait until their answer box was addressed. It was observed that some of

the children got restless during this waiting period and did not fully attend to the task, which resulted in some abnormally long reaction times.

4.4.2 EFFECT OF TEMPERATURE ON REACTION TIMES

The low correlation between the reaction time scores and the scores of the multiple-choice-type tests did not justify searching for a common pattern. The reaction time tests had to be viewed on their own, judging the value of the results by their statistical significance. The following results showed a decrement of performance (see 2.7.4) significant at the 5%-level:

- SRT, Standard 3, 14°C: -11%;
- CRT, Standard 6, 14°C: -13%; and
- CRT, Standard 6, 19°C: -22%.

An improvement of performance was found for:

- SRT, Standard 3, 34°C: +16%;
- SRT, Standard 6, 34°C: +10%;
- SRT, Standard 6, 34°C: + 6%; and
- SRT, Standard 6, 19°C: + 6%.

Performance on the Simple and the Choice Reaction Time Test was reduced at the coldest condition (longer reaction times) and improved on the Simple Reaction Time Test at the hottest condition. At 19°C the performance of Standard 6 children was improved on the SRT but reduced on the CRT.

Other studies have found no effect of temperature on reaction time. According to Teichner (1954) the relevant literature at the time indicated that there was little or no effect of temperature on simple reaction time between 10 and 47°C. The reports on the effect of cold temperatures on reaction time range from inconclusive to detrimental - which reflects the findings of the present study. Enander (1987) tested twelve male office workers at 6°C and found no effect on mean RT in a simple reaction time test. In a study of Ellis (1982) eight male subjects, exposed for two hours to -12°C showed no effect of temperature on the performance of a simple reaction time test. Meese et al. (1981), however, found a clear trend for reduced performance from 18 to 6°C for the response rate on a serial reaction time task. The overall trend was statistically not significant, and pair-wise comparison of performance at different temperatures led to $p < 0.07$ for 18°C versus 6°C and $p < 0.09$ for 18°C versus 12°C.

In the heat (35°C, 38% RH) Nicholl (1978) found no change in performance of a simple reaction time test by young, adult males. Reddy and Ramsey (1976) applied a reaction time task at 20, 26 and 29°C DB and also found no effect of temperature. In a study by Bell et al. (1982) reaction time increased at 38°C as compared with 22°C, but the effect was statistically weak ($p < 0.08$). Meese et al. (1981) tested subjects of different population groups at 20, 26, 32 and 38°C on a serial choice reaction time task. They report an improvement in the rate of response with temperature. The overall temperature effect was significant ($p < 0.02$). The peak performance was achieved at 32°C. Their findings correspond well with the results of the present study.

In the present study all significant effects at the coldest condition were detrimental and all effects at the hottest condition showed an improvement of performance. Equivalent effects have been reported in the relevant literature, although most results were inconclusive.

4.4.3 WRITING SPEED AS AN ALTERNATIVE PREDICTOR OF PERFORMANCE

All Facet Diagrams show the score of the Writing Speed Test to be either within the region of the power scores or very close to it. In all cases it is closer than the reaction time scores. The Writing Speed Test might therefore be suitable as a quick and simple performance test that allows the prediction of scores of cognitive tests - a role initially intended for the reaction time tests. It is easy to administer; one sheet of paper per child (see Figure 2.4-7), a pencil and a stopwatch would be sufficient. The children would be given a fixed time to write as many symbols as possible - too short for the fastest to finish - and the number of symbols per child would be counted at the end.

The coefficients of correlation between Writing Speed and the power scores of cognitive tests for the different age groups are given in Table 4.3-1.

T E S T	GRD2	STD3	STD6
Classification	0.27	0.32	0.16
Comparison	0.18	0.45	0.42
Mathematics	0.45	0.28	0.30
Memory	0.33	0.30	0.34
Number Series	.	0.21	0.19
Pattern Completion	.	0.26	0.09

Table 4.3-1: Spearman rank order correlation between the Writing Speed score and the power scores of cognitive performance tests for different age groups. The values shown are the means of the correlations at 14, 19, 24, 29 and 34°C.

Twelve of the sixteen correlations in Table 4.3-1 are in the range 0.16 to 0.34 and no differences between tests, age groups or temperature conditions are apparent (Figures 3.7-1 to 3.7-11). The score on the Writing Speed Test might, however, be an indication of an individual's motivation to perform well, rather than of his performance potential. The possibilities for the prediction of performance are furthermore quite limited, as a correlation coefficient of about 0.3 indicates that the Writing Speed Test predicts only about 10% of the variation in the dependent variable.

Writing Speed scores are of some use for a qualitative prediction of thermal effects on performance, for example of the direction of the temperature effect or of the temperature where the strongest effect occurs. Tables 3.3-1 and 3.4-1 show that generalising the significant results of the Writing Speed Test would predict that performance is:

- strongly reduced for Grade 2 children at 14°C. This effect was indeed found with all other tests;

- lowered for Standard 6 children at 29°C, which was the case for four of six power scores and significant for one of them; and
- increased for Standard 3 children at 29°C, which was the case for five out of six power scores and significant for one of them.

The highly significant increase in the performance of Standard 6 children at 14, 19 and 34°C would not have been predicted by the Writing Speed Test, and a general increase in performance at 29°C is in contradiction to the theory of arousal, but two major effects would be indicated correctly. Further research into the use of "indicator tests" for determining the effect of stressors might therefore be worthwhile.

4.5 THE ROLE OF CONCOMITANT VARIABLES

4.5.1 GENERAL

None of the concomitant variables analysed in 3.4.3 showed an interaction with the effect of temperature on performance that could not be explained by chance. Therefore it was necessary to consider these results in terms of the relevant literature. The variables under consideration were:

- time-of-day at which the test was performed;
- the sex of the children;
- the nutritional state of the children at the time of the test; and
- answers to the personal questionnaire.

The first three variables are discussed in detail below. The present study was not designed to measure the effect of factors to which the questions of the Personal Questionnaire pertain. One of the reasons for including the Personal Questionnaire was to keep the children busy during the adaptation time and to make them familiar with their answer box. The Questionnaire was made to be meaningful, but the following limitations have to be kept in mind:

- the experimental design and the analysis of the present study were based on the comparison of group means. This is suitable to detect the effect on the whole group, or on a sizable subgroup, but will not reveal subtle inter-individual differences;

- the answers to the Personal Questionnaire reflect only the children's perception of their situation. The validity of the answers was not investigated;
- the urban areas in which the study was conducted showed different levels of affluence. No schools in informal settlements were included. The range of the socioeconomic background was therefore limited; and
- the present study was only concerned with the relevance of concomitant variables for the analysis of temperature effects. Their direct effects on the level of performance was not investigated.

The absence of any significant interactions between answers to the Personal Questionnaire and the effects of temperature on performance was therefore not surprising.

4.5.2 TIME-OF-DAY EFFECTS

No interaction between the effect of temperature and the effect of "schedule" on performance was found (see 3.4.3.3). The "schedule" of an experiment defined the order in which the tests were presented (see 2.6.4). Such an interaction might be expected for two reasons:

- physiological parameters such as body temperature are subject to circadian changes (Faria and Drummond, 1982) which can effect the sensitivity to thermal stress (Hildebrandt, 1984); and

- circadian variations of arousal (Monk, 1982) might overlap with the arousing and de-arousing effects of temperature.

The present study was not designed to identify time-of-day effects. To compare performance at different times it would have been necessary to ensure that the groups for exposure at different times-of-day had a comparable standard of performance. In the present study time-of-day was only used as a concomitant variable.

A typical experimental day started at 08:00. Preparations and acclimation lasted for about 1.5 hours (see 2.6.4), so that the first performance test was likely to start at 09:30. For Standard 3 and Standard 6 children the experimental day lasted to approximately 13:30. As the O'Connor Peg Test was always presented at the end of the experiment, the last of the tests applied at different times-of-day was likely to be completed at 13:15. The time at which a test was presented varied on average by less than 2.5 hours (see Tables 2.6-1 and 2.6-2). For Grade 2 children, who had a shorter exposure time, this time variation was even smaller.

The relatively small variation in the time-of-day might be misleading, as it is possible that physiological parameters, temperature sensitivity, arousal or test performance change especially rapidly during this time. Changes in these parameters during the performance phase (PP) were therefore investigated in the relevant literature. For this purpose PP was assumed to stretch from 10:00 to 13:00, a timespan in the middle of the performance phase and slightly longer

than the average variation in the time for the presentation of a test.

Table 4.5.1 lists several physiological parameters, the maximum daily variation (the difference between the highest and the lowest value during a day) and the change in this parameter during PP expressed as a percentage of the maximum variation. Faria and Drummond (1982), for example, present a graph of oral temperature versus time-of-day. The highest oral temperature found in this graph is 37.0°C at 18:00 and the lowest is 36.1°C at 06:00. The maximum variation is therefore 0.9°C. At 10:00 oral temperature is given as 36.7 and at 13:00 as 36.4°C. The difference is 0.3°C, 33% of the total daily variation.

AUTHOR(S)	MEASURE	MAX	%PP
Faria and Drummond (1982)	oral temperature (°C)	0.9	33
	heart rate (beats per minute)	5.7	2
	maximum O ₂ uptake (ml/kg/min)	2.6	12
Hildebrandt (1984)	rectal temperature (rest, °C)	0.5	22
Marotte and Timbal (1981)	rectal temperature (rest, °C)	0.5	8
	mean skin temperature (°C)	1.3	2
Aschoff (1983) (means from six publications calculated by the author)	rectal temperature (rest, °C)	0.7	21
	rectal (active during day, °C)	0.9	29

Table 4.5.1: Maximum daily variation of different physiological measures (MAX) expressed in the dimensions described and the variation of these measures between 10:00 and 13:00 expressed as a percentage of the maximum variation (%PP).

It must be pointed out that the values in the Tables 4.5-1 to 4.5-4 are derived from interpolations on graphs found in publications. Their accuracy should be sufficient for qualitative comparison, but they should not be over-interpreted.

A value with a daily variation in the shape of a sinus curve will change from the minimum to the maximum in 12 hours, and within 3 hours (from 10:00 to 13:00) on average 25%. A lower value will indicate that the period falls in the flat part of the sinus, whereas a value much higher will indicate that the daily change deviates from a sinus pattern and that the period coincides with the time of fast change.

Two of the values of %PP in Table 4.5.1 are above 25%, six are below, indicating that PP was overall a time of slow change for those physiological parameters.

Table 4.5-2 shows the change in some parameters that were described as indicators of sensitivity to thermal stress. The values in Tables 4.5-2 to 4.5-4 are labelled as follows:

- PEAK TIME: time-of-day when the highest value occurred;
- LOWEST TIME: time-of-day when the lowest value occurred;
- FAST CHANGE: time-of-day when the fastest change occurred (estimated from the published graphs);
- DAILY VAR: difference between the peak value and the lowest value expressed as a percentage of the peak value; and
- PP VAR: variation during PP expressed as a percentage of the daily variation (DAILY VAR).

AUTHOR and MEASURE	PEAK TIME	LOWEST TIME	FAST CHANGE	DAILY VAR(%)	PP VAR (%)
Marotte and Timbal (1982) - time to onset of sweating	13:00	03:00	15:00	67	8
Hildebrandt (1984) - hand rewarming, half-time	09:00	01:00	06:00	49	24
- sweat reaction	01:00	09:00	03:00	100	17

Table 4.5.2: Daily variation of physiological parameters described as indicators of sensitivity to thermal stress.

Marotte and Timbal (1982) measured the diurnal change in time it took from raising the ambient temperature abruptly to 40°C to the onset of sweating; the longer this time, the less heat sensitive the subjects. Heat sensitivity changes over 24 hours along a sinus-shaped function, reaching its maximum between 00:00 and 03:00 and its minimum at about 13:00. The change in heat sensitivity during PP was low and the heat-sensitivity had nearly reached its daily minimum.

Hildebrandt (1984) measured the half-time for hand rewarming after immersion in a cold water bath and the sweat reaction at the middle of the forehead after ingestion of 200 ml diaphoretic (sweat-inducing) tea. Rewarming time can be used as a measure of cold-sensitivity. The subjects were most cold-sensitive at 09:00 and least cold sensitive at 01:00. The sweat reaction can be used as an indicator of heat sensitivity and the subjects were most heat-sensitive at 01:00 and least sensitive at 09:00. The time of fastest change on heat or cold sensitivity was around 03:00 to 06:00 - at least three hours before testing started in the present study. Hildebrandt's results indicate that cold sensitivity was high during PP and, in agreement with the results of

Marotte and Timbal (1982), that heat sensitivity during PP was low.

Table 4.5-3 shows the change of subjective alertness during the day. Folkard (1983) plotted the results of five different publications; they differ little and all follow an inverted U-shape with a peak at about 13:00. As no absolute alertness values were given, "DAILY VAR" could not be calculated.

AUTHOR and MEASURE	PEAK TIME	LOWEST TIME	FAST CHANGE	DAILY VAR (%)	PP VAR (%)
Monk et al. (1983) - subjective alertness	12:00	22:00	21:00	55	7
Folkard (1983) - subjective alertness (means of results from five quoted publications)	13:00	08:00	09:00	-	15

Table 4.5.3: Daily variation of subjective alertness.

The fastest change in subjective alertness happens either in the early morning or in the evening. As PP coincided approximately with the arousal peak, the change during this time was rather slow.

Table 4.5-4 shows the daily variation in some performance tests. The list is by far not complete and cannot be seen as representative of the effect of time-of-day on performance, but illustrates that the daily change of subjective alertness and test performance do not seem to follow the

same pattern and that there is no indication that PP coincides with a rapid change in the performance potential.

AUTHOR and MEASURE	PEAK TIME	LOWEST TIME	FAST CHANGE	DAILY VAR(%)	PP VAR (%)
Monk and Leng (1982) - speed of serial search (mean of results from five quoted publications) - serial search	20:00 17:00	08:00 08:00	09:00 10:00	- 6	17 35
Colquhoun et al. (1968) - signals detected - response time	17:00 17:00	05:00 05:00	22:00 22:00	25 9	11 28
Folkard et al. (1976) - visual search (low memory demand) - visual search (high memory demand)	16:00 01:00	08:00 16:00	15:00 15:00	31 15	25 31

Table 4.5.4: Daily variation in the performance of some cognitive tests.

It can therefore be concluded that the lack of a significant interaction between the effect of temperature and the effect of "schedule" is in agreement with the relevant literature as:

- the time at which performance tests were presented varied only by about 2.5 hours;
- the speed of change of physiological parameters and temperature sensitivity during PP were below the daily average, as deduced from literature;
- the change of subjective alertness during PP was below the daily average; and

- the link between the parameters that would make the above mentioned interaction likely and the scores of performance tests is rather weak.

4.5.3 EFFECTS OF SEX

Significant differences in the effect of temperature on performance have been reported for adults (Meese et al. 1981) but children's bodies react differently to thermal stress (Araki et al. 1982) and findings for adults can therefore not be uncritically applied to children. Davies (1981) measured the thermal response of pre-pubertal boys (13 years old), adolescent girls (14 years old) and adults (35 years old). The subjects worked at 68% VO_2max under moderate thermal conditions (21°C DB) for one hour. The heart rate of the children (mean of boys and girls) was 32 beats per minute higher than that of the adults, but the difference between boys and girls was only 12 beats per minute. The skin temperature of the children was 3.2°C above that of the adults, the difference between boys and girls was 0.95°C, and whereas the sweat rate of boys and girls was virtually identical, it was less than half than that of the adults. The results show that children have a different thermal response than adults, and that the differences between children and adults are larger than those between boys and girls of similar age.

Several studies indicate that the differences in mental performance and motor abilities between boys and girls are rather small. Pissanos et al. (1983) investigated the effect of sex, age and body composition on a range of basic motor

abilities such as jumping power, balance and agility of children aged between six and ten years. Sex differences were only significant for flexibility and cardiovascular function. The authors wrote that: "In view of no significant sex differences in predicting performance on the other variables and no physiological explanation for the differences on the flexibility and cardiovascular function variables, social value judgements may be responsible for many of the current practises in physical education programs". Hertzog and Carter (1982) performed a comparative factor analysis on intelligence data of parents and their children (between 16 and 22 years of age). The results were consistent with the hypothesis that males and females have a similar intellectual structure. This hypothesis is also supported by:

- Löfberg et al. (1975), who measured the effect of temperature on visual acuity and the performance of an addition task by 10-year-old children and found no difference in the response of boys and girls;
- Bell (1978), who tested the effects of noise and heat stress on the performance of a primary task (pursuit rotor) and a subsidiary task (number processing) by undergraduate students and found that neither the main effect of sex of subject nor any interactions were reliable;
- Pepler and Warner (1968), who wrote that the effects of different room temperature on learning efficiency of psychology students were similar for both sexes; and
- the present study.

Behavioural differences between the sexes were found by Wyon and Holmberg (1972), who observed 9-year-old children at different temperatures and found boys to be less attentive and girls to be more restless at 27°C. They wrote:

"The difference between the behavioral reactions of boys and girls was probably due to different levels of motivation. The boys gave up and ceased to attend during moderate thermal stress, whereas the girls, in trying to maintain attention, became uncomfortable and restless. It is unlikely that there was a marked sex difference in the physiological response for these 9-year-old children".

Wyon et al. (1979a) reported sex differences in the effect of temperatures of 20-29°C on the performance of 17-year-old subjects. Male subjects performed least well on a multiplication task at 28°C whereas female subjects were unaffected. Word recognition memory was improved by moderate heat stress, and the improvement was larger for males than for females. Both sex differences were significant ($p < 0.05$). Positive and negative effects of moderate levels of heat stress seem greater for men than for women. The results of the present study indicate that the effect of moderate heat stress (29°C) increases with age (see 4.2). The mean age of the oldest group in the present study was 14 years, whereas the subjects in the study of Wyon et al. (1979a) were 17 years old. This might explain why, in spite of the large sample size no interaction between sex and temperature was found at the 29°C condition of the present study. However, the majority of the relevant studies found no difference in the effect of temperature on the mental and motor performance of boys and girls, and this corresponds to the findings of the present study.

4.5.4 EFFECTS OF NUTRITION

The analysis showed that nutrition, as assessed by the Personal Questionnaire, plays no role in the effect of temperature on performance (see 3.4.3.4). The children in the present study were mainly drawn from the White working and middle class of the area around Pretoria, where the socioeconomic status of this population group makes severe malnutrition unlikely. It is also doubtful if the effects of malnutrition could be identified with a questionnaire pertaining to present eating habits. Malnutrition in early childhood, which is still common in South Africa (Wyndham, 1983), could have permanent effects on neural functioning (Nelson and Dean, 1959) which affects performance and the response to stressors such as temperature in later years (Kotch, 1970). In studies dealing with population groups where malnutrition is likely it would be necessary to investigate the nutritional history of the children.

Children in the present study either brought sandwiches from home or bought snacks from a stall at their school. The food was eaten either during the morning break (around 10:00) or the lunch break (around 12:00). Three-course lunches that have been shown to reduce performance (Craig et al. 1981; Smith and Miles, 1986) were never observed.

Dauncey and Bingham (1983) determined an effect of nutritional composition on energy expenditure which might have relevance for the effect of thermal stress. However, direct observation by the experimenters indicated that the type of food eaten by the children did not vary greatly and therefore the nutrient composition was unlikely to have varied significantly.

Studies on the effect of omission or consumption of breakfast are contradictory. Whereas Dickie and Bender (1982) found no effects, Conners et al. (1982) found that performance of a computerised arithmetic task improved after a good breakfast. A study by Wyon and Wyon (1990) involved children of four Swedish school classes who were given a "good" breakfast for one week and a "bad" breakfast for another. The "good" breakfast was characterised by nutritional variety and good dietary balance. The "bad" breakfast had a lack of variety, low protein and high energy content (sweet drink, bread and jam), but was not limited in amount. Children with "good" breakfast:

- performed addition nine percent faster ($p < 0.1$);
- made 40 percent fewer errors in addition ($p < 0.05$);
- performed multiplication seven percent faster ($p < 0.2$);
- made 30 percent fewer errors in multiplication ($p < 0.07$); and
- made 13 percent fewer errors in grammatical logic ($p < 0.08$).

Although the statistical significance on each individual test is rather weak, the overall trend seems convincing. A model to explain a possible interaction between food intake and the effect of temperature on performance was given by Wyon and Wyon (1990). They speculated that hunger increases arousal and so reduces performance by over-stimulating the children. However, no significant effect was found in the present study. This might be due to the fact that the food intake of the children was not measured. The children were only asked to answer according to their own perception.

4.6 CRITICAL ASSESSMENT OF THE METHODS USED

4.6.1 PURPOSE OF THE DISCUSSION OF METHODS

The experiences gained during the field tests and the results of the present study were evaluated to determine the limits of accuracy and reliability, to identify possible weaknesses in the methods and to suggest improvements for future studies.

All methods were tested in pilot studies before they were applied in the main study. Special attention was given to the feasibility and functionality of the ADCS, the mobile air-conditioning unit, the video system for test explanation and the test battery. The same equipment was used throughout the study and none of the systems was changed, for example the use of the answer boxes, or the content of the tests was not altered in any way. This discussion of the methods is therefore focused on:

- experimental design;
- adaptation to thermal conditions;
- sensitivity of the present study;
- effects of noise;
- experimental conditions; and
- selection of schools and subjects.

4.6.2 EXPERIMENTAL DESIGN

In the present study it was an organisational necessity that each child was tested for only one day. It was not possible to fit two thermal adaptation periods and the time for completion of two test batteries into one experimental day, therefore the analysis of thermal effects was limited to the comparison of group means. Exposing each subject to a stress and a control condition would have been preferable. However, the present experimental design has advantages over within-subject experimental designs with multiple exposures. Skills acquired by the subjects under one condition can lead to improved performance under other conditions. Skills acquired in the heat result in improved performance during repeated exposure in the heat more than in the cold. The "transfer" of skill is greatest between conditions that are very similar. Conditions in the middle of the range of exposures benefit most, which introduces a systematic bias in the results (Poulton, 1973). The experimental design of the present study avoided this problem.

The work children do during a normal school day does not lend itself to the precise scoring of performance that is necessary to determine the effect of environmental stressors on the basis of a one-day experiment. It was therefore necessary to use performance tests. Although those tests were chosen to resemble school activities it has to be kept in mind that:

- children do not complete multiple-choice tests on a daily basis. Although the tests involved skills that the children used regularly, those skills had to be applied in a way that was new. Results obtained from

"untrained" people do not necessarily apply to trained people (Poulton, 1973); and

- the purpose of schooling is the learning of new skills. The demonstration of existing skills in examinations serves only to measure the success of previous learning. Pepler and Warner (1968) measured the effect of temperature on the progress in learning a programmed text and their results do correspond to others based on intelligence-type tests, but it can not be generalised that results from testing of skills apply to the learning of skills.

To make the children familiar with a task and to measure the effects of temperature on learning would have required a series of exposures for each child, every exposure consisting of a thermal adaptation phase and a work phase. As this was not an option for the present study, an indication of the extent to which the findings could be generalised had to be derived from:

- the consistency of findings within the present study, for example if a certain effect can be found for several different performance tests; and
- comparison with other studies and investigating whether small differences in the experimental conditions, the content of the tests or the selection of subjects led to a qualitatively different result.

Result patterns that were found in several studies could be considered as "rugged" towards small changes in the experimental conditions and this "ruggedness" was used as

justification for extrapolating these patterns beyond the scope of direct experimental evidence.

The performance tests used in the present study were developed by the HSRC. This had the advantage that the test could be adapted for the abilities of the children tested and made to suit a given equipment and experimental routine. It had the disadvantage that the results could not be directly compared to other studies of mental performance that use standardised tests. Poulton (1965) wrote that:

"If an S-shaped relationship is assumed to hold between performance and an independent variable for any level of task difficulty ... the region on each function which is the most sensitive to small changes in the independent variable is the almost straight section on either side of the point indicating 50 percent of performance."

Observation during pilot studies showed that children became frustrated if their tasks were too difficult. As they were accustomed to asking the teacher if they had problems, they tended to approach the experimenters for advice. This distracted the other children, and assistance in completing performance tests was obviously incompatible with a controlled experiment. The tests were therefore made easier to provide sufficient positive feedback, especially for the smaller children. The mean percentage of correct responses at 24°C was:

- 65% for Standard 6;
- 72% for Standard 3; and
- 75% for Grade 2.

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- 65% for Standard 6;
- 72% for Standard 3; and
- 75% for Grade 2.

(Details are given in Table 2.7-2.) Assuming an S-shaped relationship as described by Poulton (1965) the level of difficulty of the tests was not at the point of optimal sensitivity and the tests for the younger children were slightly less sensitive than those for the Standard 6 children.

Each test in the present study involved a variety of basic skills such as reading, short term memory, selecting the correct answer from a series of given answers and the mechanical action of pressing an answer key. Tests involving less basic skills would have been better suited to determine thermal effects on basic mental activities. However, there is no reliable model that allows prediction of the effect of a stressor on complex tasks such as the performance on a mathematics test from the effect of this stressor on a series of basic mental abilities. The tests of the present study had to resemble normal school work, although this implied less information about the effects of temperature on basic mental abilities.

4.6.3 ADAPTATION TO THERMAL CONDITIONS

An adaptation period of insufficient length in combination with a large change in performance after sufficient adaptation time would have resulted in a significant contribution of the parameter "schedule" in the analysis of variation. This was not the case.

Figures 3.5-4 to 3.5-6 show that the finger temperatures in the cold and hot exposures changed as expected between the first measurement at the beginning of the adaptation period and the second measurement about two hours later. Between the second and the third measurement little change took place. This was expected and agrees with other findings (Kok et al. 1982), from which it can be assumed that nearly all the change in finger temperature happened within the first hour.

The oral temperatures in Figures 3.5-1 to 3.5-3 show changes between the second and the third measurement, but they indicate an increase in oral temperature in all cases, even for the coldest condition. An increase in core temperature in the morning due to an internal circadian rhythm has been documented by Aschoff (1983), Monk et al. (1983), Hildebrandt (1984) and others. The size of the increase, about 0.2°C during the late morning, corresponds with these studies. These changes in oral temperature between the second and the third measurement are therefore probably not due to a slow adaptation to environmental conditions but to circadian rhythm in core body temperature.

The adaptation period used in the present study was also in line with other studies. Ryd and Wyon (1970) exposed children to thermal conditions from comfortable (22°C) to warm (27°C). Tests were performed in a school classroom during the first hour of the school day. The authors write that "In order to allow the pupils to adapt themselves to the ambient temperature, they were given non-assessed tests during the first third of the lesson". This corresponds to an adaptation time of 20 minutes. From the description given for the conduct of the sessions in Wyon (1969a) it can be

concluded that hardly any adaptation time was given. Pepler and Warner (1968) used an adaptation period of one hour.

It can be concluded that there is no indication in the performance data, the measured body temperatures or in other publications that the period allowed for adaptation to the thermal conditions of the experiment was insufficient.

4.6.4 SENSITIVITY OF THE PRESENT STUDY

An estimate of the sensitivity of the measures employed in the present study can be gained by comparing the smallest changes that produced significant results with that of other studies. Should the present study require a larger sample size or a bigger change in performance to produce a significant result than other studies, this would have to be taken into account in the interpretation of the results.

Table 1.4-1 lists a summary of studies on temperature. The smallest effect significant on the $p < 0.05$ level was two percent. It was reported by Ramsey and Beshir (1980) on a combined perceptual motor score which was derived from the scores of four single tests. The smallest significant effect described for a single test score was four percent.

The present study fits into this pattern. Table 4.6-1 lists the results with the smallest performance change significant on the $p < 0.05$ level for GRD2, STD3 and STD6.

grade	GRD2	STD3	STD6
difference [%]	9	7	5
test	Comparison	Comparison	Comparison
score type	speed	power	accuracy
No. of subjects	146	134	133
C.V.	27	16	14

Table 4.6-1: Details of the smallest difference in performance between stress and control days that was significant at $p < 0.05$, for different educational levels.

The Standard 6 pupils, with an average age of 14 years were closest to adults and had the lowest coefficient of variation of all age groups (see Table 3.6-1). The smallest significant effect found for Standard 6 children was five percent, similar to the studies on adults listed in Table 1.4-1. The Grade 2 children had the largest coefficient of variation and therefore the effects had to be larger to be significant with a given sample size.

4.6.5 EFFECTS OF NOISE

At 14°C the noise level exceeded for 50% of the time was 6 dB(A) higher on stress days than on control days. It was not possible to test for the significance of a noise effect as the louder condition occurred at a different environmental temperature, which made noise and temperature effects inseparable. Literature on the effect of noise on performance, reviewed in 1.7.2, supports the assumption that a difference of 6 dB(A) in meaningless noise will not have a significant effect on performance.

Loeb (1981) conducted a review of the relevant literature and found that there "appears to be some agreement that performance tests of a broad intellectual function, such as general intelligence tests, are not influenced by noise exposure ... though not everyone would agree".. Lambert and Hafner (1979) state that "steady, meaningless noise does not seem to interfere with human performance unless the level exceeds about 90 dB(A).

Although it seems justified to ignore the noise effects in the present study, the experimental procedure could be improved by keeping the noise level constant. This might become necessary if noisier air-conditioning plants are used. A simple way to achieve this would be to tape the noise of the air-conditioning plant, and to add the taped noise to the plant noise during the quiet modes of operation (feedback control).

4.6.6 EXPERIMENTAL CONDITIONS

Hawthorne Effect

The present study aimed to make the test environment as familiar as possible to the children. Therefore all tests were performed in a classroom of the children's own school. Nevertheless, the classroom had to be fitted with a highly visible air-conditioning plant, it contained unfamiliar equipment such as the video unit and the answer boxes, and the children had to perform unfamiliar tasks. This was bound to create some form of Hawthorne Effect (Roethlisberger and Dickson, 1939). Although the children were not explicitly informed about the purpose of the experiment, listening to

their conversations during the breaks revealed that most of them were aware. Wyon (1969a) mentioned that he introduced two noise conditions to a temperature experiment in order to conceal the nature of the experiment and lead the subjects to believe that the effects of noise were under investigation. This was most likely successful as the temperatures deviated little from the comfort zone (20 to 27°C). At room temperatures of 14 or 34°C, as used in the present study, it was hardly possible to conceal the fact that temperature played an important role in the experiment. It can therefore be assumed that the children had a higher level of arousal and a different level of motivation for work during the experiment than during a normal school day. Such effects could only be reduced by conducting the experiments in schools that already have an air-conditioning system installed.

Thermal conditions of the outside environment

The environmental conditions for the present study were chosen to cover the whole range of temperatures that might occur in schools. The relative humidity was kept at about 40%. To minimise temperature differences between interior and exterior conditions the cold tests were performed in winter and the hot tests in summer. Some information about the local climate in Pretoria might help the interpretation of the results and is given in Table 4.6-2. The actual temperature exceeds the 10% design temperature at a given time on 10% of the days in summer; it is lower on 10% of the days in winter.

time		08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00
summer	°C	22	24	26	27	28	29	30	31
	%RH	70	61	55	49	42	37	34	31
winter	°C	4	9	13	15	17	18	18	19
	%RH	80	61	52	44	38	33	31	29

Table 4.6-2: Design air temperature and associated humidity for 10% design day in summer and winter for Pretoria, Lynnwood (from Wentzel et al. 1985).

Table 4.6-2 shows that the temperatures in winter can fall well below 14°C, the coldest condition in the present study, but exposing children in controlled experiments to such temperatures would not have been acceptable. The hottest design condition in summer is 31°C, but it has to be pointed out that this refers to air temperature in the shade. The radiant temperature on summer days is significantly higher and the temperature in buildings depends on the way a building is constructed. The temperature in a lightweight construction without roof insulation, such as often used for temporary classrooms, can exceed the 34°C used as hottest condition in the present study. Since the start of the present study no new studies indicating that different thermal conditions would have been more appropriate have been published.

Dehydration

The degree of dehydration of an individual effects the physiological response to thermal stress (Francesconi et al.

1984). The children in the present study did not perform any physical exercise. It was therefore not thought necessary to encourage them to drink, but they were not prevented from drinking and they had access to water and could buy cool drinks during the breaks. None of the children complained of thirst during the hot exposures.

4.6.7 SELECTION OF SCHOOLS AND SUBJECTS

The equipment used in the present study required access to a power point with 60 kVA, either in the school or at a circuit breaker nearby. This was only possible in areas with a fair infrastructure, but excluded all areas with a poor infrastructure such as rural and deprived urban areas. The selection of the schools was therefore biased in favour of higher socioeconomic suburbs.

Testing in schools for the present study required the permission of the Transvaal Education Department (TED), which also determined the schools in which testing was permitted. It was requested that the selection of schools should not include a systematic bias, and no such bias was detected except that noted above.

4.7 POSSIBLE IMPROVEMENTS IN THE PREDICTION OF THERMAL EFFECTS ON PERFORMANCE

4.7.1 GENERAL

A major goal for the research of stressors is the ability to predict their effects. Exposing test subjects to different thermal conditions and recording the effects on their performance produces results that are strictly only valid for those subjects, conditions and tests and for the time at which the experiment was carried out. Prediction requires assumptions, for example that the tests used are characteristic of a whole class of tests, and that the responses of the subjects were typical for a whole class of subjects. Suitable assumptions, based on patterns in results reported in the literature, can improve the reliability of predictions or reduce the experimental effort required as a basis for predictions. In 4.7, potential improvements in the prediction of thermal effects on performance are discussed, which include:

- the use of variables such as body temperatures for prediction;
- the use of additional personality measures of individuals; and
- the determination of a simple indicator for predicting changes of performance due to thermal stress.

4.7.2 BODY TEMPERATURES AND SUBJECTIVE COMFORT VOTE AS PREDICTORS OF PERFORMANCE

Room temperature affects the performance of people. It can be assumed that there is a chain of cause and effect that leads to this result, for example:

"The increased room temperature
affects dissipation of body heat,
which increases core body temperature,
which increases brain temperature,
which affects the performance."

Because of inter-individual differences in body structure there will be a variation in the magnitude of effects, for example a certain room temperature will raise the core body temperature of some people more than of others. The use of a measure as a predictor should improve the closer the effect it represents is to the final effect that has to be predicted. In the above example core body temperature should be a better predictor of performance than room temperature, and brain temperature should in turn give better results than core body temperature. This was the rationale for using finger temperature and oral temperature as predictors for performance. The analysis is described in 3.5.

Oral temperature was significant ($p < 0.01$) for five analyses, which are listed in Table 3.5-1. Among the 241 analyses conducted about two to three can be expected to be significant at the 1%-level by chance. A comparison with Table 3.4-1 shows that room temperature was significant for two of the five parameter combinations described in Table

3.5-1. The three other combinations were likely to have occurred by chance.

Finger temperature was significant ($p < 0.01$) for eight analyses, which are listed in Table 3.5-2. A comparison with Table 3.4-1 shows that room temperature was significant for four of the eight parameter combinations described in Table 3.5-2. The four other combinations were likely to have occurred by chance.

Both body temperature measures were found to be poor predictors of the effect of room temperature on performance, but this does not allow the conclusion that finger temperature or core body temperature measured via oral temperature are not relevant links in the chain of cause and effect that leads to a change in performance under thermal stress. Individuals show a variation in finger temperature and core body temperature also under thermoneutral conditions. Small changes due to a change in the thermal environment will be obscured by this inter-individual variation. A more appropriate measure of the effects of temperature might be the difference that a change in the thermal environment made to an individual's body temperature. Measurements of body temperatures in a thermoneutral environment before each exposure could not be obtained in the present study as the air-conditioning plant had to be switched on well in advance of the experiment to achieve the desired experimental temperatures and the answer boxes that were used to measure finger temperature were installed inside the experimental classroom.

If perceived discomfort is a link in the chain of cause and effect mentioned above then the children's perception of

thermal comfort would be a good predictor of performance. As described in 3.5.4, this was not the case. Comfort vote had no value as a predictor of thermal effects on performance. The Figures 3.5-7 to 3.5-9 show that the mean response of all age groups followed a systematic pattern, for example most children felt comfortable at comfort temperature and the number of children feeling too hot increased with temperature. This implies that the children understood the question and answered appropriately. At any given temperature there is a variation in the subjective comfort vote (Fanger, 1972). If the subjects that feel too cold in a cold experiment would be more strongly affected by the same room temperature than those who feel comfortable, then comfort vote should be a better predictor of performance than room temperature. If the inter-individual variation in perceived comfort is independent of the effect of temperature on performance, then room temperature should be the better predictor. The results of the present study show that the latter is the case. As the inter-individual variation for the effect of temperature on performance as well as the inter-individual variation for the effect of temperature on comfort vote were fairly large, and as those variations seemed independent of each other, no significant correlations between comfort vote and performance were found.

A series of studies have shown that comfort votes have little predictive value for the effect of thermal stress on the performance of children, for example Pepler and Warner (1968) and Pepler (1971). McCardle (1965) found no correlation between comfort vote and performance in an ideal thermal environment. It was shown on adults that comfort vote is influenced by non-thermal factors; Meese et al. (1985) wrote that: "Trained subjects who were familiar with the experimenters and the experimental situation gave

different comfort votes to those given by untrained workers". A study by Meese et al. (1986) found that twelve percent of the variation in performance data collected between 6 and 24°C could be attributed to room temperature, whereas only six percent could be attributed to comfort vote. All these results support the finding of the present study that air temperature is a better predictor for the effect of thermal stress on performance than comfort vote.

4.7.3 INFORMATION ABOUT THE INDIVIDUALS

The response to an environmental stressor can be affected by the individual's personality (Zaky, 1984). In the present study the Personal Questionnaire was an attempt to gain information about the individuals that might be significant in the prediction of their changes in performance due to thermal stress. As described in 4.5.1 these personal data did not have a strong enough effect to be significant with the experimental design used.

The level of performance individuals achieve in comparison with their peers can also aid the prediction of stressor effects. Ryd and Wyon (1970) found that weaker performers were more strongly affected than better performers. Comparing the effects on good and weak performers requires a measure of performance that is obtained for all subjects under comparable environmental conditions, as the weakest performers in the heat would not necessarily have been the weakest performers under control conditions. Such a performance measure was not obtained in the present study, but some conclusions can be drawn from the inter-individual

variation in the different experiments. If heat, for example, were to reduce the performance of weak performers more strongly than that of good performers, the gap between them would widen and the variation in the data would therefore increase. The coefficient of variation, which is the standard deviation expressed as a percentage of the mean, was chosen as a means to compare variation.

The number of experiments at which the C.V. was larger on the stress day versus the number of those where the C.V. was larger on the control day is shown in Table 3.6-2 for all age groups, conditions, tests and score types. No pattern was found. The totals for the power, speed and accuracy scores are shown in Table 3.6-3. In two cases the number of test applications in which the C.V.'s was smaller on the control day was significant ($p < 0.05$), but this may have been due to a chance effect. The present study therefore provides no additional evidence that weak performers are affected more by thermal stress than strong performers.

4.7.4 THE USE OF INDICATORS FOR PERFORMANCE PREDICTION

The use of the reaction time scores and the Writing Speed results as indicator tests for the effect of temperature on performance has been discussed in 4.4, and the use of body temperatures and comfort vote as predictors in 4.7.2.

Effects on performance tests are not necessarily representative for the effects on performance in real life (see 4.6.2). In order to improve research into the effect of

moderate stress on performance, better measures have to be found that can be applied while a subject is performing a normal work routine.

A step in this direction was taken by Wyon (1969a) who used a 4-channel ECG recording to derive a measure of sinus arrhythmia by digitising and analysing the recorded signals. The results showed that well motivated subjects tend to maintain rather than drop performance under strenuous conditions. Ryzhikov et al. (1981) described a correlation between amplitude and frequency of EEG waves and autonomic indices of arousal such as heart rate and psychogalvanic reflex in pupils aged 15-17 years. Reeves (1983) measured the effect of temperature on sensorily evoked, computer-summed brain potentials and found that an increase in brain temperature of 1.2°C accelerated electrophysiological activity by three to nine percent. However, no study was found that attempted to relate changes in the performance of cognitive tasks to EEG patterns.

To achieve a better understanding of the effects of temperature it might also be helpful to investigate its effects on simpler, more precisely defined sub-tasks. The benefits of complex tasks and simple sub-tasks could possibly be combined by designing complex tasks on an interactive terminal in such a way that their sub-tasks could be monitored individually.

4.8 RECOMMENDATIONS FOR SCHOOL BUILDINGS

4.8.1 RELEVANT EFFECTS OF TEMPERATURE ON PERFORMANCE

Recommendations for practical applications need to be unambiguous. In cases where not enough hard data are available but where decisions have to be made it may be necessary to attempt an educated guess. It is up to the expert to select the patterns relevant for practical application and to do the guessing where necessary, as he is better equipped for this task than the layman. It is also a good test for a scientific study to determine how many "hard and fast" rules it can produce. The recommendations of the present study for the design of schools are as follows:

- small children (Grade 2) are more sensitive to cold than older children. No experiments were conducted at 19°C for Grade 2 children, but extrapolating from other studies on adults, temperatures below 18°C should be avoided in primary schools;
- the effects of temperature on the Standard 3 children were in between those for the Grade 2 and the Standard 6 children. Detrimental effects of cold should also be considered with Standard 3 children;
- Standard 6 children showed an improved performance on all tests at 14, 19 and 34°C. This does not imply that unpleasant thermal conditions make for better schools. The improvement in performance would most likely disappear once the children got used to it. Nevertheless, the results indicate that avoidance of cold conditions is far less important with children of this age than with younger children; and

- Standard 6 children showed a small but significant drop in performance at 29°C. The reduction was on average three percent. The effect is well documented in literature, but it was not found with the younger children. Schools should therefore be designed to reduce the occurrence of temperature conditions above 25°C. The hotter the conditions the smaller should be the proportion of instruction time during which they are allowed to occur.

All tests of mental performance were affected in a similar way by temperature and restructuring of the time tables in order to schedule certain tasks for a cooler or warmer part of the day promises little gain with older children. Small children (below Standard 3) performing tasks that require fine motor control such as writing or drawing are especially disadvantaged in the cold. In primary schools where sufficient heating is not available scheduling such tasks during winter for the late morning when it is warmer should be considered (see Table 4.6-2).

The potentially most severe problem, the effect of cold on small children, can be overcome by heating; a solution that does not require high investment or building alterations. The present study was not concerned with a systematic investigation of the school facilities in South Africa, but during the experiments the following observations were made:

- many heating facilities seem insufficient and their use is often considered a luxury; and
- teachers often insist that a series of windows stay opened, even on a cold winter morning. This is certainly not a normal practise in European schools at

equivalent temperatures and it should be investigated how the necessary ventilation can be achieved without an unnecessary drop in room temperature.

The occurrence of uncomfortably hot conditions can be reduced either by appropriate building design or by an air-conditioning system. If resources are limited, appropriate building design is the obvious choice, but it is often argued that air-conditioning is the best solution for those who can afford it. Study of the relevant literature revealed that this is not necessarily the case. To relate the findings of the present study to potential technical solutions, background information is provided below on:

- potentially negative effects of air-conditioning on the performance of school children;
- air-conditioning and teachers' morale; and
- some suggestions for the design of classrooms.

4.8.2 AIR-CONDITIONING AND PUPILS' SCHOLASTIC PERFORMANCE

Air-conditioning makes it possible to transform the outdoor climate into practically any indoor climate required, and it is widely accepted that air-conditioning would be the ideal solution for all problems of the indoor climate, were it not for its high cost and the environmental impact of the cooling medium (Freon) and of the systems that provide the required energy. This might be a misconception.

Pepler (1971) showed in a long-term study that pupils in schools with climate control became accustomed to an environment with small temperature variation; thereafter their performance was influenced by much smaller temperature changes than that of children in schools without climate control. Teachers also became used to small temperature variations. Pepler (1971a) showed that the range of temperatures considered "neutral" (neither warm nor cool) was smaller for teachers in schools with climate control than for those in schools without climate control.

An increased sensitivity to temperature changes may cause additional problems due to the unavoidable gradient between the controlled thermal environment indoors and the natural outdoor environment. The use of air-conditioning in schools should therefore be considered carefully, even if the cost is not a problem.

Air-conditioning systems do not necessarily provide an ideal thermal environment. The simplest way to regulate air-conditioning is to run the fans continuously while switching the heater or the cooling coils on and off whenever the room becomes too cold or hot. According to Wyon and Tennstedt (1988) this on-off regulation has several disadvantages, for example increased turbulence resulting in complaints of draught and a bi-modal thermal environment in which the total heat loss from the body is 60-90% greater in the cold phase than in the hot phase of the on-off cycle.

Wyon recommended "proportional-integral regulation" for air-conditioning systems, a method which modifies the intensity of heating or cooling on a continuous scale and thereby

eliminates the disadvantages mentioned above but increases the cost.

4.8.3 AIR-CONDITIONING AND TEACHERS' MORALE

Most arguments put forward in favour of air-conditioning are concerned with productivity, but people's perceptions of its value might be distorted by the fact that air-conditioning is also a status-symbol. This has become apparent in the discussion of teacher burnout, a major international concern. It can be defined as the syndrome resulting from prolonged teacher stress; primarily characterised by physical, emotional and attitudinal exhaustion (Cunningham, 1983). In a review of literature on teacher stress and burnout, Kyriacou (1987) mentions causes such as pupils' poor attitude to work, too heavy workload, disruptive behaviour by pupils and lack of teachers' professional identity. Neither thermal stress nor any other physical environmental stressors are mentioned. Nevertheless, the recommendations proposed by Kyriacou such as giving teachers more preparation time, reducing the size of classes or better communication within the school, are mostly expensive long-term options that require behavioral changes and are hard to verify. Administrators who feel that "something has to be done fast" might well turn to improving physical conditions, as this can be more easily planned, costed and implemented. An example of this attitude can be found in Colvin (1973):

"Few studies have been done to find the relationship between teacher performance and air-conditioning, but teachers' attitudes towards air-conditioning and its

effect on the learning process have been surveyed and not surprisingly the teachers overwhelmingly affirmed that air-conditioning aids the learning process. If a happier teacher is a better teacher than air-conditioning will predictably improve teachers performance."

It might be acceptable if wealthy countries air-condition schools to motivate teachers. In developing countries such as South Africa this is not a suitable option.

4.8.4 APPROPRIATE DESIGN FOR CLASSROOMS

Some principles for the design of better schools have been identified by Langdon and Laudon (1970) who conducted a survey among teachers of several schools on thermal discomfort in summer. They listed the following problems:

- classrooms that have windows on one only side give most discomfort, as this does not provide cross-ventilation and the windows have to be large to cater for minimum daylight requirements;
- heat discomfort was experienced only in 15% of rooms with a northerly orientation, but in about 60% of all other rooms (the study was carried out in the northern hemisphere);
- complaints were 10% higher in "lightweight" building structures; and

- inside venetian blinds were found to be ineffectual in limiting solar gains.

The findings of Levy and Guttman (1967) are in agreement. A sensible classroom can therefore be imagined as having: solid walls (brick, concrete or mud) and a roof with good heat insulation, windows on the south and north side and outside blinds or overhangs.

The results of the present study can be summarised as follows:

- a significant effect of temperature on performance has been proven for a range of tests and conditions. The temperature conditions were between 14 and 34°C with 24°C acting as a control condition. The size of significant temperature effects ($p < 0.01$) ranged between 5 and 18%;
- the magnitude and direction of the temperature effects were in agreement with the relevant literature. The effects can be explained within the framework of the "arousal theory", although the predictive value of this theory is very limited. The thermal effects on performance tests showed a pattern that was largely independent of the nature of the performance tests;
- the youngest group of children was approximately eight years of age and showed a significant detrimental effect of cold (14°C) on performance. On average, over all performance tests, the number of correct answers given in ten minutes decreased by 10 percent as compared with 24°C. Effects under cool conditions (19°C) and in the heat showed no clear pattern;
- with the oldest group of children, approximately fourteen years of age, most test scores were improved under all thermal stress conditions with the exception

of the 29°C condition which reduced performance of most tests. The improvement in the number of questions answered correctly in ten minutes was on average six percent at 14 and 19°C and nine percent at 34 °C;

- the intermediate group of children, approximately eleven years of age, showed no overall effects of cold and an improvement in performance in the heat that was smaller than that of the older children;
- a drop in performance at warm conditions of about 25 to 30°C has been found by several studies. In the present study this effect was only found for the oldest group. The reduction in performance at 29°C for the Standard 6 children is especially visible as their performance improved at all other stress temperatures when compared to 24°C. The younger children did not show a drop in performance at 29°C;
- the effect of temperature on cognitive test performance was mainly due to a change in work speed and less to a change in the accuracy with which the work was performed. Speed and accuracy might be affected differently by temperature because they represent different attributes of cognitive performance;
- from each cognitive performance test scores of three types were obtained: power, speed and accuracy. Scores of one type, for example all speed scores derived from the different tests, were in most cases more highly correlated with each other than the different score types of the same test. This implies for example that

the accuracy score of a test is usually predicted better by the accuracy score of another test than by the speed or power score of the same test. This pattern of correlations between tests did not change visibly with temperature;

- the detrimental effect of a warm environment (29°C), which can be presumed to cause low arousal was strongest on the Mathematics and the Number Series Test;
- combined power, speed and accuracy scores, derived from all cognitive tests, showed a similar pattern of results to that of the individual test scores. This supported the conclusion derived from the analysis of the individual scores that the direction of the temperature effect was largely independent of the nature of the cognitive test and suggested that such combined scores could be a useful tool to assess the overall effect of temperature on the performance of subjects;
- unprepared reaction time was not found to be a suitable predictor of performance on cognitive tests, nor of the effect of temperature on the performance of those tests;
- on the Writing Speed Test at 14°C the youngest group of children showed a significant performance decrease of 17 percent. Effects on the older groups of children were not significant;

- the performance of the O'Connor Peg Test was significantly affected by the cold condition (14°C) with the intermediate and the oldest group of children. The youngest group of children did not perform this test in the present study, but significant effects on this age group have been shown in another study;
- no significant interactions were found between the effects of temperature and the time-of-day when the test was performed, the sex of the subjects or their nutrition;
- oral temperature and finger temperature were found to have little predictive value for the effect of room temperature on performance. Room temperature was found to be the best predictor;
- subjective comfort vote had no predictive value for the effect of room temperature on performance.

The extent of the present study and comparison with the relevant literature allowed the description of an overall pattern of the effect of temperature on the performance of children. However, the performance of an individual or of a small group of children depends on a variety of factors such as motivation, mood or the weather, and as the nature of these factors was largely unknown, the prediction of the direction and size of the temperature effect in particular cases would be highly unreliable. Because of the size of the effects of moderate stress a reliable predictive tool would be desirable. The limits for improving the present theories

by collecting data on a large scale have been demonstrated by the present study. Qualitative improvements are most likely to come from improved measurement techniques such as an analysis of EEG that allows one to measure the effect of stressors on the functioning of the brain without the need for performance tests.

APPENDIX A: CONTROL PROGRAM FOR ADCS

```

100 REM /// N B R I /// S C H O O L - P R O J E C T ///
120 REM ***** INITIALISING *****
140 REM FTP%= MODE OF TEMP SUBROUTINE
145 REM INIT%= MODE OF INIT SUBROUTINE
160 REM QMODE%= Q. PRACTICE(1) OR MAIN(2)
165 REM SM%= MODE OF INFO SCREEN
180 DIM SM$(7): REM SCREEN TEXT
200 DIM TNAME$(15): REM SHORT NAMES FOR TESTS
220 DIM QANS$(40,99): REM QUESTIONNAIRE: ANSWERS+TIMES
                        (1=KEY,2+3=T.VAL,4=T.EXP)
240 DIM Q%(40): REM QUESTION NUMBERS ON BOXES
260 DIM MISS$(40): REM MISSING BOXES
280 DIM QWARN$(40): REM WARN FLAGS (0=OK, 1=TIMEOUT,
                        2=STEPOUT)
300 DIM FLICK$(40): REM FLICKER MEMORY
320 DIM NX$(40): REM NO OF NEXT CONTROL Q FOR BOX
340 DIM C1$(40): REM FASTEST TIME COUNTER
360 DIM C2$(40): REM MIDDLE " "
380 DIM C3$(40): REM SLOWEST " "
400 DIM CMZ$(40): REM MZ80B TIME COUNTER
420 DIM TSUM!(40): REM ADDS TIME THAT BOX IS BLOCKED
440 DIM QTL$(15): REM TIME LIMITS FOR Q IN TESTS
460 DIM QNP$(15): REM NUM OF PRACTICE Q PER TEST
480 DIM QNM$(15): REM NUM OF MAIN Q PER TEST
500 DIM QPCOR$(15,8): REM CORRECT PRACTICE ANSWERS
520 DIM QX$(15,20): REM IDENTIFY CONTROL QUESTIONS
540 DIM QRM$(15): REM MAX RUNTM FOR A TEST (IN MIN)
560 DIM TPCAL!(40,2): REM TEMP CALIBRATION FACTORS
580 DIM TP!(40): REM TEMP READING
600 DIM TPROOM$(40,50): REM ROOM TEMP
620 DIM TPTM$(50): REM TIMES FOR ROOM TEMP
640 DIM RQUES$(40): REM DISPLAYS FOR UNPREP RT
660 DIM RANS$(40): REM ANSWERS UNPREP RT
680 DIM RTT$(40): REM UNPREPARED REACTION TIMES
700 DIM RSEQ$(40): REM BOXES SEQUENCE FOR UNPREP RT
720 REM
740 SM$(1)="I N P U T ": SM$(2)="S T A R T ":
                        SM$(3)=" PRACTICE "
760 SM$(4)="M A I N Q": SM$(5)="REACTION T":
                        SM$(6)="FINGER TEM"
780 SM$(7)="ROOMT.SCAN"
800 QSTOP%=0: REM FLAG FOR STOP-INTERR OF "QN"
820 TPC%=0: REM COUNTER FOR ROOM TP
840 TPSCAN%=-999: REM "LAST" ROOM TP SCAN
860 REM ----- CHANGE FUNCTION KEYS
880 PRINT CHR$(27);"8";CHR$(0);CHR$(49);CHR$(0)
900 PRINT CHR$(27);"8";CHR$(1);CHR$(50);CHR$(0)
920 PRINT CHR$(27);"8";CHR$(2);CHR$(51);CHR$(0)
940 PRINT CHR$(27);"8";CHR$(3);CHR$(52);CHR$(0)

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960 PRINT CHR$(27);"8";CHR$(4);CHR$(53);CHR$(0)
980 PRINT CHR$(27);"8";CHR$(5);CHR$(54);CHR$(0)
1000 PRINT CHR$(27);"8";CHR$(6);CHR$(55);CHR$(0)
1020 REM ***** DATA INPUT AND BRANCHING *****
1040 SM%=1: GOSUB 9940: PRINT: REM INFO SCREEN
1060 REM ----- PREVENT DATA OVERWRITE
1080 INPUT "NEW DATA DISC (NEW) OR ADD TO OLD ONE (ADD) ";DSC$:
PRINT
1100 IF DSC$<>"NEW" THEN GOTO 1160
1140 FILNR%=0: GOTO 1200
1160 IF DSC$<>"ADD" THEN GOTO 1080
1180 OPEN "I",#4,"A:FLMEMO.DAT": INPUT#4,FILNR%: CLOSE #4
1200 REM -----
1210 INPUT "SCHOOLNAME: ";SNAME$: PRINT
1220 INPUT "EXCODE (EG. W6-34T-105): ";EXCODE$: PRINT
1240 IF LEN(EXCODE$)<>10 THEN GOTO 1220
1260 H$=MID$(EXCODE$,6,1):IF H$<>"T" AND H$<>"C" THEN GOTO 1220
1280 REM -----
1300 INPUT "DATE EG. 05/12/83 ";DATE$: PRINT
1320 DATE$=LEFT$(DATE$,8)
1340 IF LEFT$(DATE$,1)="" OR RIGHT$(DATE$,1)="" OR
LEN(DATE$)<>8 THEN GOTO 1300
1360 H1$=LEFT$(DATE$,2):H2$=MID$(DATE$,4,2):H3$=RIGHT$(DATE$,2)
1380 H1%=VAL(H1$):H2%=VAL(H2$):H3%=VAL(H3$)
1400 IF H1%<1 OR H2%<1 OR H3%<85 OR H1%>31 OR
H2%>12 OR H3%>87 THEN GOTO 1300
1420 DATE$=H1$+H2$+H3$
1440 REM -----
1460 INPUT "TIME EG. 10:55 ";TI$: PRINT
1480 IF LEFT$(TI$,1)="" OR RIGHT$(TI$,1)="" OR LEN(TI$)<>5
THEN GOTO 1460
1500 HOUR$=LEFT$(TI$,2): MIN$=RIGHT$(TI$,2): HOUR%=VAL(HOUR$):
MIN%=VAL(MIN$)
1520 IF HOUR%<0 OR HOUR%>24 OR MIN%<0 OR MIN%>60 THEN GOTO 1460
1540 DA%=0: TIME%=0: CALL SETCLK(DA%,TIME%)
1560 REM -----
1580 INPUT "HIGHEST BOXNUMBER ";BN%: PRINT
1600 IF BN%<0 OR BN%>40 THEN GOTO 1580
1620 CN$=STR$(BN%): IF BN%<10 THEN CN$="0"+RIGHT$(CN$,1) ELSE
CN$=RIGHT$(CN$,2)
1640 NRBOX%=BN%
1660 REM ----- DEFINE MISSING BOXES
1680 FOR I%=1 TO 40: MISS%(I%)=0: NEXT I%
1700 INPUT "MISSING BOXES ? (GIVE ONE AT A TIME, 0=NO(MORE)):";
H%
1720 IF H%=0 THEN GOTO 1760 ELSE IF H%>BN% OR H%<1 THEN
GOTO 1700
1740 MISS%(H%)=1: NRBOX%=NRBOX%-1: GOTO 1700
1760 REM ----- READ CONTROL DATA FOR TESTS
1780 PRINT: INPUT "EDUCATION LEVEL (GRD2W, STD3W, STD6W):";
EDU$: PRINT
1800 IF EDU$<>"GRD2W" AND EDU$<>"STD3W" AND EDU$<>"STD6W" THEN
GOTO 1780

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1820 OPEN "I",#1,"A:"+EDU$+".DAT"
1840 INPUT#1, D$,D$, TPDT$, D$, MINDT!
1860 INPUT#1, D$,D$: FOR I%=1 TO 15: INPUT#1,TNAME$(I%):
                                NEXT I%
1880 INPUT#1, D$: IF LEFT$(D$,1)="=" THEN CLOSE #1:
                                GOTO 2000
1900 INPUT#1, D$,N%: INPUT#1, D$, QNP%(N%), D$, QNM%(N%), D$,
                                QTL%(N%)
1920 INPUT#1, D$, QRMX!(N%), D$
1940 FOR I%=1 TO 8: INPUT#1, QPCOR%(N%,I%): NEXT I%
1960 FOR I%=1 TO 20: INPUT#1, QX%(N%,I%): NEXT I%
1980 GOTO 1880
2000 REM ----- READ TEMPERATURE CALIBRATION DATA
2020 OPEN "I",#1,"A:CAL.DAT"
2040 INPUT#1,D$,D$: FOR I%=1 TO 2: FOR K%=1 TO 40:
                                INPUT#1,TPCAL!(K%,I%):
2060 NEXT K%: INPUT#1,D$: NEXT I%: CLOSE #1
2080 REM ----- WRITE HEADLINE-FILE
2100 IF DSC$<>"NEW" THEN GOTO 2180
2120 GOSUB 9720
2140 PRINT#2,"***== ";EXCODE$;" ";DATE$;" ";
                                SNAME$: CLOSE#2
2160 PRINT#3,"***== ";EXCODE$;" ";DATE$;" ";
                                SNAME$: CLOSE#3
2180 REM -----
2200 FTP%=1: GOSUB 7260: GOSUB 9040: REM TAKE AND STORE
                                FIRST ROOM TEMPERATURE
2220 REM ===== SCAN-LOOP FOR CHOOSING FUNCTION
2240 WORK%=NRBOX%: SM%=2: GOSUB 9940: REM INFO SCREEN
2260 INIT%=1: GOSUB 9440: REM SET BOXES TO "01"
2280 KEY$="": KEY$=INKEY$
2300 IF KEY$="1" THEN GOSUB 2420: GOTO 2220,
2320 IF KEY$="4" THEN FTP%=0: GOSUB 7260: UM%=17:GOSUB 10400:
                                GOTO 2260
2340 IF KEY$="5" THEN FTP%=2: GOSUB 7260: UM%=17:GOSUB 10400:
                                GOTO 2260
2360 IF KEY$="6" THEN GOSUB 5480: UM%=17:GOSUB 10400: GOTO 2260
2380 IF KEY$="7" THEN IF QSTOP%=0 THEN GOSUB 11020:IF X$="Y"
                                THEN GOTO 11120
2400 GOTO 2280
2420 REM ***** SUBROUTINE QUESTIONNAIRE *****
2440 IF QSTOP%=1 THEN GOTO 3020
2460 REM ===== INPUT AND RESETING FOR NEW RUN
2480 REM ----- INPUT TEST IDENTIFIER
2500 UM%=16: GOSUB 10400: REM POSITION CURSOR
2520 PRINT "TEST ( ";: FOR I%=1 TO 15:
                                PRINT LEFT$(TNAME$(I%),3);" ";: NEXT I%
2540 PRINT ") ";
2560 INPUT H$
2580 FOR I%=1 TO 15: IF LEFT$(H$,3)=LEFT$(TNAME$(I%),3)
                                THEN TNO%=I%: GOTO 2620
2600 NEXT I%: GOTO 2520
2620 IF QNM%(TNO%)=0 THEN GOTO 2520: REM NO TEST DATA STORED

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2640 REM ----- SET INITIAL VALUES
2660 QN%=QNM%(TNO%)
2680 IF QNP%(TNO%)=0 THEN GOTO 2720
2700 QMODE%=1:INIT%=1:GOSUB 9440:GOTO 2740: REM START PRACTICE
2720 QMODE%=2: INIT%=1: GOSUB 9440: REM START MAIN TEST
2740 FOR I%= 1 TO 40
2760 C1%(I%)=0: C2%(I%)=0: C3%(I%)=0: Q%(I%)=1: QWARN%(I%)=0:
                                                    NX%(I%)=1

2780 TSUM!(I%)=0
2800 FOR K%=1 TO 99: QANS%(I%,K%)=0: NEXT K%
2820 NEXT I%
2840 QSTOP%=0
2860 REM ----- RESET TIME COUNTERS
2880 OUT 71,0: CALL DELAY: OUT 71,32:CALL DELAY: OUT 71,0
2900 REM ----- SET MZ80B TIME MEMORYS
2920 GOSUB 8440
2940 FOR I%=1 TO BN%: CMZ%(I%)=TIME%: NEXT I%
2960 QSTART$=NOW$
2980 QSTART%=TIME%
3000 GOTO 3140
3020 REM ===== RESETTING IF RUN WAS INTERRUPTED (STOP)
3040 INIT%=2: GOSUB 9440: REM UPDATE BOXES
3060 REM CORRECT MZ80B TIME MEMORIES FOR STOP
3080 CALL GETCLK(DA%,TIME%): H%=TIME%-TSTOP%
3100 FOR I%=1 TO BN%: CMZ%(I%)=CMZ%(I%)+H%: NEXT I%
3120 QSTART%=QSTART%+H%
3140 REM ===== COMMON ACTIONS FOR NEW AND INTERRUPTED RUNS
3160 SM%=2+QMODE%: GOSUB 9940: REM SET INFO SCREEN
3180 OUT 71,8: CALL DELAY: OUT 71,0: REM START COUNTERS
3200 WORKO%=0: QRUNO%=-999
3220 REM ===== BEGIN LOOP FOR QUESTIONAIRE SCAN =====
3240 OUT 69,0: CALL DELAY: REM ENABLE ALL BUFFERS
3260 CALL GETCLK(DA%,TIME%): CMZ%=TIME%: REM TAKE MZ80B-TIME
3280 IF TIME%-QRUNO%<3 THEN GOTO 3340: REM UPDATE RUNTIME
3300 QRUN!=(TIME%-QSTART%)/60: QRUNO%=TIME%: UM%=14:GOSUB 10400
3320 IF QRUN!>QRMAL(TNO%) AND QSTOP%=0 THEN KEY$="7":
                                                    GOTO 5260: REM AUTOSAVE

3340 WORK%=0: REM NO OF KIDS BUSY
3360 REM ===== BEGIN LOOP TO SCAN ALL BOXES ONCE -----
3380 FOR B%=1 TO BN%
3400 IF MISS%(B%)=1 THEN GOTO 5020
3420 IF QMODE%=2 THEN IF Q%(B%)<=QN% THEN GOTO 3480
3440 IF QMODE%=1 THEN IF Q%(B%)<=QNP%(TNO%) GOTO 3480
3460 GOTO 5020
3480 WORK%=WORK%+1
3500 OUT 68,B%:CALL DELAY: REM SEND ADDRESS
3520 OUT 69,1: CALL DELAY: OUT 69,0:CALL DELAY:
REM SEND ADDR LATCH PLSE
3540 OUT 69,8: CALL DELAY: REM DISABLE BUFFER
3560 OUT 69,10:CALL DELAY: REM READ PULSE
3580 A%=INP(68): REM READ DATA
3600 E%=A% AND 30: E%=E%/2+1 REM MASK SIGNAL WITH 011110,
                                                    KEY-CODE= 1 TO 7

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3620 OUT 69,8: CALL DELAY
3640 REM ----- CHECK IF KEY WAS PRESSED
3660 D%=A% AND 1: REM LAST BIT ISOLATED
3680 IF D%<=0 AND QWARN%(B%)<2 THEN GOTO 4920: REM NO KEY PRESS
3700 IF D%> 0 THEN GOTO 3800
3720 FLICK%(B%)=FLICK%(B%)+1
3740 IF FLICK%(B%)=5 THEN C%=153: GOTO 4860
3760 IF FLICK%(B%)>6 THEN FLICK%(B%)=1: GOTO 4840
3780 GOTO 4920
3800 REM ----- READ TIME COUNTERS
3820 OUT 71,16:CALL DELAY: C1%=INP(71): OUT 71,0
3840 OUT 71,17:CALL DELAY: C2%=INP(71): OUT 71,0
3860 OUT 71,18:CALL DELAY: C3%=INP(71): OUT 71,0
3880 REM ----- CALCULATE ELAPSED TIME
3900 TMH!=CMZ%-CMZ%(B%)
3920 IF TMH! > 200 THEN GOTO 3980
3940 TMH!=(((C3%-C3%(B%))*256+(C2%-C2%(B%)))*
256+C1%-C1%(B%))/100
3960 IF QWARN%(B%)<2 AND E%<>7 THEN IF TMH!<MINDT!
THEN GOTO 4840: REM CHECK DT
3980 IF QMODE%=2 THEN GOTO 4260
4000 REM ----- PRACTICE -----
4020 REM ----- PRACTICE - CHECK FOR CORRECT ANSWERS
4040 IF Q%(B%)>QNP%(TNO%) THEN GOTO 5020
4060 IF QPCOR%(TNO%,Q%(B%))=E% AND QWARN%(B%)<2 THEN GOTO 4760
4080 IF QPCOR%(TNO%,Q%(B%))=0 AND QWARN%(B%)<2 THEN GOTO 4760
4100 REM ..... PRACTICE - SOMETHING WRCNG - SET FLAGS AND
CHECK CODE
4120 IF QWARN%(B%)<2 THEN QWARN%(B%)=2:UM%=2:GOSUB 10400:
GOTO 4760
4140 IF QWARN%(B%)=2 AND E%=6 AND TMH!<1 THEN QWARN%(B%)=3:
GOTO 4760
4160 IF QWARN%(B%)=3 AND E%=6 AND TMH!<1 THEN QWARN%(B%)=4:
GOTO 4760
4180 IF QWARN%(B%)=4 AND E%=7 AND TMH!<1 THEN QWARN%(B%)=0:
GOTO 4220
4200 QWARN%(B%)=2: GOTO 4760
4220 REM ..... PRACTICE - SOMETHING WRONG - TAKE ACTION
4240 UM%=0: GOSUB 10400: Q%(B%)=Q%(B%)-1: GOTO 4760
4260 REM ----- MAIN Q. -----
4280 REM ----- CHECK FOR SPECIAL TESTS ++++++++
4300 IF TNO%<>4 AND TNO%<>9 THEN GOTO 4360
4320 IF TNO%= 4 THEN GOTO 4660
4340 IF TNO%= 9 THEN IF TMH!<120 THEN GOTO 4840 ELSE GOTO 4660
4360 REM ----- MAIN Q. - CHECK STEP WARNING
4380 IF E%<>7 AND Q%(B%)<QX%(TNO%,NX%(B%)) AND QWARN%(B%)<2
THEN GOTO 4660
4400 IF E%= 7 AND Q%(B%)=QX%(TNO%,NX%(B%)) AND QWARN%(B%)<2
THEN GOTO 4440
4420 GOTO 4460
4440 NX%(B%)=NX%(B%)+1: GOTO 4660
4460 REM ..... MAIN Q. - SOMETHING WRONG - SET FLAGS+CHECK CODE
4480 TSUM!(B%)=TSUM!(B%)+TMH!

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4500 IF QWARN%(B%)<2 THEN QWARN%(B%)=2:UM%=2:GOSUB 10400:
                                E%=8:GOTO 4660
4520 IF QWARN%(B%)=2 AND E%=6 AND TMH!<1 THEN QWARN%(B%)=3:
                                GOTO 4760
4540 IF QWARN%(B%)=3 AND E%=6 AND TMH!<1 THEN QWARN%(B%)=4:
                                GOTO 4760
4560 IF QWARN%(B%)=4 AND E%=7 AND TMH!<1 THEN QWARN%(B%)=0:
                                GOTO 4600

4580 QWARN%(B%)=2: GOTO 4760
4600 REM ..... MAIN Q. - SOMETHING WRONG - TAKE ACTION
4620 UM%=0: GOSUB 10400
4640 E%=8: TMH!=TSUM!(B%):Q%(B%)=Q%(B%)-1: REM ((0 AS ADDR OK))
4660 REM ----- MEMORISE ACCEPTED BUTTON PRESS IN RESULT MATRIX
4680 TMHE%=VAL(RIGHT$(STR$(TMH!*1E+10),2))-7
4700 TMHV%=TMH!/10^(TMHE%-4)
4720 QANS%(B%,Q%(B%))=1000*E%+10*TMHV%+TMHE%
4740 TSUM!(B%)=TMH!
4760 C1%(B%)=C1%: C2%(B%)=C2%: C3%(B%)=C3%: CMZ%(B%)=CMZ%:
                                REM RESET TM.COUNT

4780 REM ----- SET BOX COUNTER
4800 IF QWARN%(B%)<2 THEN Q%(B%)=Q%(B%)+1
4820 IF Q%(B%)>QN% THEN C%=0: GOTO 4860
4840 C%=Q%(B%)+(Q%(B%)\10)*6: REM CONVERTS Q.NO TO HEX OUTPUT
4860 OUT 69,4: CALL DELAY
4880 OUT 68,C%:CALL DELAY
4900 OUT 69,0: CALL DELAY
4920 REM ----- CHECK TIME WARNING
4940 IF (CMZ%-CMZ%(B%))>QTL%(TNO%) THEN GOTO 5000
4960 IF QWARN%(B%)=1 THEN IF QMODE%=2 THEN QWARN%(B%)=0: UM%=0:
                                GOSUB 10400

4980 GOTO 5020
5000 IF QWARN%(B%)=0 THEN IF QMODE%=2 THEN QWARN%(B%)=1: UM%=1:
                                GOSUB 10400

5020 NEXT B%
5040 REM ===== END LOOP TO SCAN ALL BOXES ONCE -----
5060 REM ----- CHECK SELECTION MENUE (WARN,STOP,END)
5080 TSTOP%=TIME%: REM SET MZ80B TIME MEMORY IN CASE OF STOP
5100 KEY$="": KEY$=INKEY$
5120 IF WORK%=0 AND QMODE%=2 THEN KEY$="7": REM AUTOSAVE
5140 IF KEY$="1" THEN GOTO 5160 ELSE GOTO 5200
5160 GOSUB 11020: IF X$<>"Y" THEN GOTO 5200
5180 QSTOP%=0: TPC%=0: TPSCAN%=-999: TNO%=0: GOTO 5460
5200 IF KEY$="2" THEN IF QMODE%=1 THEN GOTO 2720
5220 IF KEY$="3" THEN QSTOP%=1:OUT 71,4:CALL DELAY:OUT 71,0:
                                GOTO 5460

5240 IF KEY$="5" THEN FTP%=3: GOSUB 7260
5260 IF KEY$="7" THEN GOTO 5280 ELSE GOTO 5340
5280 IF QMODE%<>2 THEN GOTO 5340
5300 PRINT CHR$(27);";";"WAIT !": FTP%=1: GOSUB 7260
5320 GOSUB 8620: QSTOP%=0: GOTO 5460
5340 REM ----- CHECK TIME FOR TEMPERATURE SCAN
5360 IF (TIME%-TPSCAN%) < TPDT% THEN GOTO 5400:
                                REM (TIME TAKEN BEFORE SCAN)

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5380 TPSCAN%=TIME%: FTP%=1: GOSUB 7260
5400 REM ----- UPDATE BUSY
5420 IF WORK%<>WORKO% THEN WORKO%=WORK%: UM%=12: GOSUB 10400
5440 GOTO 3220: REM END QUESTIONNAIRE SCAN LOOP =====
5460 RETURN
5480 REM ***** SUBROUTINE FOR UNPREPARED REACTION TIME *****
5500 SM%=5: GOSUB 9940
5520 INPUT "TEST-TYPE (11 OR 55): ";RTNR%
5540 IF RTNR%<>11 AND RTNR%<>55 THEN GOTO 5520
5560 IF RTNR%=11 THEN ITER%=3 ELSE ITER%=2
5580 REM =====
5600 FOR LP%=1 TO ITER%
5620 INIT%=0: GOSUB 9440: REM INITIALISE BOXES TO "00"
5640 GOSUB 8440: REM READ TIME
5660 FOR Z%=1 TO BN%: RQUES%(Z%)=0: RANS%(Z%)=0: RTT%(Z%)=0
5680 RSEQ%(Z%)=0: NEXT Z%
5700 REM ----- DEFINE PSEUDORANDOM BOX SEQUENCE
5720 H1%=VAL(RIGHT$(STR$(TIME%),2)): HBN%=0
5740 FOR I%=1 TO BN%
5760 H1%=(H1%+16) MOD 40)+1
5780 IF H1%>BN% THEN GOTO 5760
5800 IF MISS%(H1%)=1 THEN GOTO 5840
5820 HBN%=HBN%+1: RSEQ%(HBN%)=H1%
5840 NEXT I%
5860 REM ----- IDLE 5 SEC
5880 IF LP%>1 THEN GOTO 5920
5900 FOR I%=1 TO 500: H=9: H=H^H: NEXT I%
5920 REM =====
5940 SHIFT%=5: H2%=HBN%+SHIFT%: REM SHIFT BETWEEN 33 AND 11 (22...)
5960 FOR H1%=1 TO H2%
5980 REM ----- WRITE 33
6000 IF H1%>HBN% THEN GOTO 6140
6020 H3%=RSEQ%(H1%)
6040 OUT 68,H3%:CALL DELAY
6060 OUT 69,1: CALL DELAY: OUT 69,0: CALL DELAY
6080 OUT 69,4: CALL DELAY
6100 OUT 68,51:CALL DELAY
6120 OUT 69,0: CALL DELAY
6140 REM ----- IDLE 1 SEC
6160 IF H1%>SHIFT% THEN GOTO 6200
6180 FOR I%=1 TO 50: H=9: H=H^H: NEXT I%: GOTO 6820
6200 REM ----- EMERGENCY EXIT
6220 KEY$="": KEY$=INKEY$: IF KEY$="7" THEN GOTO 7240
6240 REM ----- CHOSE BOX, ADDRESS IT, RESET IT
6260 B%=RSEQ%(H1%-SHIFT%)
6280 OUT 68,B%:CALL DELAY: REM SEND ADRESS
6300 OUT 69,1: CALL DELAY: OUT 69,0: CALL DELAY: REM SEND ADDR LATCH PLSE
6320 OUT 71,3: CALL DELAY: OUT 71,35: CALL DELAY: OUT 71,3: REM RESET COUNT
6340 REM ----- WRITE NUMBER TO DISPLAY AND START COUNTER
6360 IF RTNR%=11 THEN H%=17: GOTO 6420

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6380 H%=(MI%+B%)*11: H%=(H% MOD 44)+11: IF H%>22 THEN H%=H%+11
6400 RQUES%(B%)=H%: H%=H%+(H%\10)*6
6420 OUT 69,4: CALL DELAY
6440 OUT 68,H%:CALL DELAY
6460 OUT 69,0: CALL DELAY
6480 REM -----
6500 OUT 69,8: CALL DELAY: OUT 71,11: CALL DELAY:
                                REM DISABLE BUFFER
6520 OUT 71,3: REM START COUNTER
6540 REM ----- READ DATA AND BRANCH
6560 OUT 69,10:CALL DELAY: REM READ PULSE
6580 ZA%=INP(68):ZD%=ZA% AND 1
6600 IF ZD%>0 THEN OUT 71,7:CALL DELAY:OUT 71,3:GOTO 6720
6620 OUT 69,8: CALL DELAY
6640 REM ----- NO BUTTON PRESSED
6660 OUT 71,19: CALL DELAY: RTT%=INP(71): REM READ COUNTER
6680 IF RTT%>200 THEN GOTO 6780
6700 OUT 71,3:GOTO 6560
6720 REM ----- ANSWER BUTTON PRESSED
6740 OUT 71,19: CALL DELAY: RTT%=INP(71): REM READ COUNTER
6760 H%=ZA% AND 30: RANS%(B%)=H%/2+1
6780 RTT%(B%)=RTT%: UM%=3: GOSUB 10400
6800 OUT 71,3
6820 NEXT H1%
6840 INIT%=0: GOSUB 9440: REM SET BOXES TO "00"
6860 REM ===== STORE REACTION TIME VALUES ON DISK
6880 GOSUB 9720: REM OPEN DATA FILES
6900 FOR Y%=2 TO 3
6920 PRINT#Y%,"***** UNPRP RT (DSPL:ANS:IT:
                                MT(SEC)) *** ";EXCODE$
6940 PRINT#Y%,"FTYP FNO DATE      TMNOW BN  ENT - - - -"
6960 PRINT#Y%,"2      ";FILNR$;"      ";DATE$;"      ";NOW$;"      "BN$;
                                "      1      0      0      0"

6980 FOR R%=1 TO BN%
7000 PRINT#Y%,USING"##";RQUES%(R%);
7020 PRINT#Y%,USING" #";RANS%(R%);
7040 PRINT#Y%,USING" #.##";RTT%(R%)/100!;
7060 IF (R% MOD 5)<>0 THEN PRINT#Y%,"      "; ELSE PRINT#Y%,""
7080 NEXT R%
7100 IF (BN% MOD 5) <> 0 THEN PRINT#Y%,""
7120 PRINT#Y%,"*****"
7140 CLOSE #Y%
7160 NEXT Y%
7180 IF LP%<>ITER% THEN SM%=5: GOSUB 9940: PRINT "WAIT !"
7200 NEXT LP%
7220 ITER%=1: GOSUB 9440: REM INITIALISE BOXES TO "01"
7240 RETURN
7260 REM ***** SUBROUTINE FOR TEMPERATURE SCAN *****
7280 REM (FTP%: 0=FINGER 1=AUTOSCAN 2=MANUAL-SCAN 3=ROOMMEAN)
7300 IF FTP%=0 OR FTP%=2 THEN SM%=6+FTP%/2: GOSUB 9940
7320 GOSUB 8440: REM READ TIME
7340 REM ===== TEMPERATURE SCAN LOOP
7360 FOR B%= 1 TO BN%

```

```

7380 IF MISS%(B%)=1 THEN GOTO 7740
7400 OUT 68,B%: CALL DELAY: REM SEND ADDRESS
7420 REM ----- SEND ADDRESS LATCH PULSE
7440 OUT 69,0: CALL DELAY: OUT 69,1: CALL DELAY:
                                OUT 69,0: CALL DELAY
7460 OUT 69,8: CALL DELAY: REM DISABLE BUFFER
7480 OUT 69,10: CALL DELAY: REM SEND READ PULSE
7500 REM ===== A/D CONVERSION
7520 OUT 70,0: CALL DELAY: REM ADDRESS CHANNEL 0
7540 OUT 70,16: CALL DELAY: REM ADDRESS LATCH
7560 OUT 70,48: CALL DELAY: REM START CONVERSION
7580 OUT 70,0: CALL DELAY
7600 CALL DELAY:CALL DELAY: CALL DELAY
7620 OUT 70,64: CALL DELAY :REM OUTPUT ENABLE
7640 H!=0
7660 REM INPUT A/D DATA
7680 H!=INP(70)
7700 TP!(B%)=TPCAL!(B%,1)+TPCAL!(B%,2)*H!:
                                REM CONVERTS A/D READING TO TEMP
7720 OUT 69,8: CALL DELAY: REM READ PULSE LOW
7740 NEXT B%
7760 REM ===== SHOW RESULTS ON SCREEN
7780 IF FTP%=1 OR FTP%=3 THEN GOTO 7820
7800 UM%=4: FOR B%=1 TO BN%: TP!=TP!(B%): GOSUB 10400: NEXT B%
7820 REM ===== CALCULATE AND SHOW ROOM TEMP MEAN
7840 IF FTP%=0 THEN GOTO 8140
7860 H!=0: NUM%=0
7880 FOR IT%=1 TO BN%
7900 IF TP!(IT%)<5.1 OR TP!(IT%)>45 OR MISS%(IT%)=1 THEN
                                GOTO 7940
7920 H!=H!+TP!(IT%): NUM%=NUM%+1
7940 NEXT IT%
7960 TPMEAN!=H!/NUM%: UM%=13: GOSUB 10400
7980 IF NOT(FTP%=1) THEN GOTO 8420
8000 REM ===== MEMORISE ROOM TEMP VALUES IN RESULT MATRIX
8020 IF TPC%=50 THEN GOSUB 9040
8040 TPC%=TPC%+1: TPTM$(TPC%)=NOW$
8060 FOR IT%=1 TO BN%
8080 TPROOM%(IT%,TPC%)=TP!(IT%)*10
8100 NEXT IT%
8120 GOTO 8420
8140 REM ===== STORE FINGER TEMPERATURE VALUES ON DISK
8160 GOSUB 9720: REM OPEN DATA FILES
8180 FOR Y%=2 TO 3
8200 PRINT#Y%,"***** FING TEMPERATURES (DEG.CELS) *** ";
                                EXCODE$
8220 PRINT#Y%,"FTYP FNO DATE TMNOW BN ENT - - - "
8240 PRINT#Y%,"3 ";FILNR$;" ";DATE$;" ";NOW$;" "BN%;
                                " 1 0 0 0"
8260 FOR I%=1 TO BN%
8280 PRINT#Y%,USING"##.##";TP!(I%);
8300 IF (I% MOD 10)<>0 THEN PRINT#Y%," "; ELSE PRINT#Y%,""
8320 NEXT I%

```

```

8340 IF (BN% MOD 10) <> 0 THEN PRINT#Y%,""
8360 PRINT#Y%,"*****"
8380 CLOSE #Y%
8400 NEXT Y%
8420 RETURN
8440 REM ***** SUBROUTINE TO READ MZ80B TIME *****
8460 CALL GETCLK(DA%,TIME%)
8480 MI%=MIN%+(TIME%/60)MOD 60
8500 IF MI%<60 THEN HR%=HOUR%+TIME%\3600: GOTO 8540
8520 HR%=HOUR%+TIME%\3600+1: MI%=MI%-60
8540 HR$=STR$(HR%): IF HR%<10 THEN HR$="0"+RIGHT$(HR$,1) ELSE
                                         HR$=RIGHT$(HR$,2)
8560 MI$=STR$(MI%): IF MI%<10 THEN MI$="0"+RIGHT$(MI$,1) ELSE
                                         MI$=RIGHT$(MI$,2)
8580 NOW$=HR$+MI$
8600 RETURN
8620 REM ***** SUBROUTINE TO STORE TESTRESULTS (AND ROOMTEMP) *
8640 GOSUB 8440: REM READ TIME
8660 IF TPC%>0 THEN GOSUB 9040
8680 GOSUB 9720: REM OPEN DATA FILES
8700 FOR Y%=2 TO 3
8720 PRINT#Y%,"***** QUESTIONS (ANS:2.3*10**4 MSEC) *** ";
                                         EXCODE$
8740 PRINT#Y%,"FTYP FNO DATE      TMNOW BN  ENT TNO TMGO  TMRUN"
8760 PRINT#Y%,"1      ";FILNR$;"      ";DATE$;"      ";NOW$;"      ";BN$;"
                                         "      ";QN$;"      ";
8780 PRINT#Y%,"TNO%;" " ";QSTART$;USING"###.##";QRUN!
8800 FOR I%=1 TO QN%: REM RESULTS SORTED BY QUESTIONNUMBER
8820 FOR J%=1 TO BN%
8840 PRINT#Y%,USING"###.##";QANS%(J%,I%);
8860 IF (J% MOD 10) <> 0 THEN PRINT#Y%," "; ELSE PRINT#Y%,""
8880 NEXT J%
8900 IF (BN% MOD 10) <> 0 THEN PRINT#Y%,""
8920 NEXT I%
8940 PRINT#Y%,"*****"
8960 CLOSE #Y%
8980 NEXT Y%
9000 TNO%=0
9020 RETURN
9040 REM ***** SUBROUTINE TO STORE ROOMTEMPERATURES *****
9060 GOSUB 9720: REM OPEN DATA FILES
9080 FOR Y%=2 TO 3
9100 PRINT#Y%,"***** ROOM TEMPERATURES (DEG.CELS) *** ";
                                         EXCODE$
9120 PRINT#Y%,"FTYP FNO DATE      TMNOW BN  ENT TNO TMGO  TMRUN"
9140 PRINT#Y%,"4      ";FILNR$;"      ";DATE$;"      ";NOW$;"      ";BN$;"
                                         TPC$;"      ";
9160 PRINT#Y%,"TNO%;" " ";QSTART$;USING"###.##";QRUN!
9180 FOR I%=1 TO TPC%
9200 PRINT#Y%,TPTM$(I%)
9220 FOR J%=1 TO BN%
9240 PRINT#Y%,USING"###.##";TPROOM%(J%,I%)/10!;
9260 IF (J% MOD 10) <> 0 THEN PRINT#Y%," "; ELSE PRINT#Y%,""

```



```

9280 NEXT J%
9300 IF (BN% MOD 10) <> 0 THEN PRINT#Y%,""
9320 NEXT I%
9340 PRINT#Y%,"*****"
9360 CLOSE #Y%
9380 NEXT Y%
9400 TPC%=0: TPSCAN%=-999
9420 RETURN
9440 REM ***** SUBROUTINE TO INITIALISE/UPDATE BOXES *****
9460 FOR B%=1 TO BN%
9480 IF INIT%=1 THEN C%=1: GOTO 9560: REM TO INITIALISE TO "01"
9500 IF INIT%=0 THEN C%=0: GOTO 9560: REM TO INITIALISE TO "00"
9520 C%=Q%(B%)+(Q%(B%)\10)*6: REM CONVERTS Q.NO TO HEX OUTPUT
9540 IF Q%(B%)>QN% THEN C%=0
9560 OUT 68,B%:CALL DELAY: REM ADDRESS BOX
9580 OUT 69,1: CALL DELAY: REM ADDRESS LATCH PULSE
9600 OUT 69,0: CALL DELAY
9620 OUT 69,4: CALL DELAY: REM WRITE PULSE
9640 OUT 68,C%:CALL DELAY: REM UPDATE BOX
9660 OUT 69,0: CALL DELAY: REM WRITE PULSE LOW
9680 NEXT B%
9700 RETURN
9720 REM ***** SUBROUTINE TO SET FILNAME INDEX *****
9740 FILNR%=FILNR%+1
9760 OPEN "O",#4,"A:FLMEMO.DAT": PRINT#4,FILNR%: CLOSE #4
9780 OPEN "O",#5,"B:FLMEMO.DAT": PRINT#5,FILNR%: CLOSE #5
9800 FILNR$=STR$(FILNR%)
9820 IF LEN(FILNR$)=2 THEN FILNR$="00"+RIGHT$(FILNR$,1)
9840 IF LEN(FILNR$)=3 THEN FILNR$="0" +RIGHT$(FILNR$,2)
9860 IF LEN(FILNR$)=4 THEN FILNR$="" +RIGHT$(FILNR$,3)
9880 OPEN "O",#2,"A:XOUT."+FILNR$
9900 OPEN "O",#3,"B:XOUT."+FILNR$
9920 RETURN
9940 REM ***** INFORMATION SHEET STRUCTURE *****
9960 PRINT " ": REM CLEAR GRAPHIC BUFFER OF MZ80B
9980 PRINT CHR$(27);";":CHR$(27);"C";
10000 PRINT " SCHOOL PROJECT *** MODE= ";SM$(SM%);
10020 PRINT " ": PRINT
10040 FOR I%=1 TO 4: UM%=I%+10: GOSUB 10400: PRINT " ";:
NEXT I%
10060 PRINT: PRINT
10080 FOR K%=1 TO 4
10100 FOR I%=1 TO 71: PRINT CHR$(155);: NEXT I%: PRINT
10120 FOR I%=1 TO 10: PRINT CHR$(128);" ";:NEXT I%:
PRINT CHR$(128)
10140 NEXT K%
10160 FOR I%=1 TO 71: PRINT CHR$(155);: NEXT I%: PRINT
10180 IF SM%=1 THEN GOTO 10380: REM NO MENUE
10200 IF SM%=4 THEN FOR B%=1 TO 40: UM%=QWARN%(B%):
GOSUB 10400: NEXT B%
10220 PRINT CHR$(27);CHR$(61);CHR$(31+22);CHR$(31+1);
CHR$(27);"C";

```

```

10240 PRINT
      "
10260 IF SM%<>2 AND SM%<>5 AND SM%<>6 AND SM%<>7 THEN
      GOTO 10300: REM MAIN MENUE
10280 PRINT
      " F1=QUEST F4=FINGT F5=ROOMT F6=RTIME F7=ENDALL ":
      GOTO 10320
10300 PRINT
      " F1=KILLQ F2=MAINQ F3=INTERQ F5=ROOMT F7=STOREQ "
10320 PRINT
      "
10340 PRINT CHR$(27);"D"
10360 UM%=16: GOSUB 10400
10380 RETURN
10400 REM ***** SUBROUTINE TO UPDATE SCREEN *****
10420 IF UM%>10 THEN GOTO 10640
10440 REM -----
10460 H%=(B%-1)\10: PL%=31+H%*2+7: PC%=31+(B%-10*H%-1)*7+2
10480 PRINT CHR$(27);CHR$(61);CHR$(PL%);CHR$(PC%);
10500 ON UM%+1 GOTO 10520,10540,10560,10600,10620
10520 PRINT " ": GOTO 11000
10540 PRINT USING" ## ";B%: GOTO 11000
10560 PRINT CHR$(27);"C";: PRINT USING" ## ";B%;
10580 PRINT CHR$(27);"D": GOTO 11000
10600 PRINT USING" #.## ";RTT%/100!: GOTO 11000
10620 PRINT USING" ##.## ";TP!: GOTO 11000
10640 REM -----
10660 IF UM%>14 THEN GOTO 10840
10680 PL%=31+3: PC%=31+1+(UM%-11)*18
10700 PRINT CHR$(27);CHR$(61);CHR$(PL%);CHR$(PC%);CHR$(27);"C";
10720 ON UM%-10 GOTO 10740,10760,10780,10800
10740 PRINT " TEST: ";: PRINT TNAME$(TNO%);" ": GOTO 10820
10760 PRINT " WORKING: ";: PRINT USING" ## ";WORK%: GOTO 10820
10780 PRINT " ROOMTEM: ";: PRINT USING" ##.## ";TPMEAN!:
      GOTO 10820
10800 PRINT " RUNTIME: ";: PRINT USING" ##.## ";QRUN!:
10820 PRINT CHR$(27);"D";: GOTO 11000
10840 REM -----
10860 REM FOR UM%=15 PL% AND PC% HAVE BEEN DEFINED
10880 IF UM%<>16 AND UM%<>17 THEN GOTO 10960
10900 PL%=31+17: PC%=31+1
10920 PRINT CHR$(27);CHR$(61);CHR$(PL%);CHR$(PC%);
10940 PRINT
      "
10960 PRINT CHR$(27);CHR$(61);CHR$(PL%);CHR$(PC%);
10980 IF UM%=17 THEN PRINT "DONE !"
11000 RETURN
11020 REM ***** SUBROUTINE CHECK *****
11040 UM%=16: GOSUB 10400
11060 INPUT "ARE YOU SHURE? Y/N ";XS
11080 RETURN
11100 END

```

APPENDIX B: CONTROL DATA FILE FOR ADCS

```

=====STD6W=====
TIME-BETWEEN-TPSCANS(SEC), 600      MIN-TM-BETWEEN-B.PRESS(SEC), 0.3
=====
TESTNAMES=,      CLASS,      COMPA,      MATHE,      WRITI,      MEMOR
                NUMBE,      FIGUR,      PATTE,      OCONN,      MOODT
                .....,      .....,      .....,      FORWA,      PERSO
-----PERSONAL QUESTIONS-----
---TESTNO, 15      ---PRACTQN, 6      ---MAINQN, 57      ---WARNTIME(SEC), 90
---RUNTIM(MIN), 30.0 ---PRACT.ANS,  0 0 0 4 1 7 0 0
 6 12 18 24 30 36 42 48 54 57 00 00 00 00 00 00 00 00 00
-----CLASSIFICATION-----
---TESTNO, 01      ---PRACTQN, 5      ---MAINQN, 84      ---WARNTIME(SEC), 90
---RUNTIM(MIN),  8.0 ---PRACT.ANS,  1 3 5 2 7 0 0 0
 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 84 00 00 00
-----COMPARISON-----
---TESTNO, 02      ---PRACTQN, 5      ---MAINQN, 60      ---WARNTIME(SEC), 90
---RUNTIM(MIN), 10.0 ---PRACT.ANS,  3 4 4 2 7 0 0 0
 6 12 18 24 30 36 42 48 54 60 00 00 00 00 00 00 00 00 00
-----MATHEMATICS-----
---TESTNO, 03      ---PRACTQN, 5      ---MAINQN, 47      ---WARNTIME(SEC), 90
---RUNTIM(MIN), 15.0 ---PRACT.ANS,  1 2 5 5 7 0 0 0
 7 14 21 28 35 42 47 00 00 00 00 00 00 00 00 00 00 00 00
-----WRITING SPEED-----
---TESTNO, 04      ---PRACTQN, 4      ---MAINQN, 99      ---WARNTIME(SEC), 90
---RUNTIM(MIN), 10.0 ---PRACT.ANS,  0 0 0 0 0 0 0 0
99 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
-----MEMORY-----
---TESTNO, 05      ---PRACTQN, 0      ---MAINQN, 32      ---WARNTIME(SEC), 90
---RUNTIM(MIN),  5.0 ---PRACT.ANS,  0 0 0 0 0 0 0 0
 5 10 15 20 25 30 32 00 00 00 00 00 00 00 00 00 00 00 00
-----NUMBER SERIES-----
---TESTNO, 06      ---PRACTQN, 5      ---MAINQN, 77      ---WARNTIME(SEC), 90
---RUNTIM(MIN), 15.0 ---PRACT.ANS,  1 5 4 5 7 0 0 0
07 14 21 28 35 42 49 56 63 70 77 00 00 00 00 00 00 00 00
-----FIGURE ANALOGIES-----
---TESTNO, 07      ---PRACTQN, 5      ---MAINQN, 85      ---WARNTIME(SEC), 90
---RUNTIM(MIN), 10.0 ---PRACT.ANS,  2 5 2 2 7 0 0 0
 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 00 00 00
-----PATTERN COMPLETION-----
---TESTNO, 08      ---PRACTQN, 5      ---MAINQN, 89      ---WARNTIME(SEC), 90
---RUNTIM(MIN), 15.0 ---PRACT.ANS,  5 3 2 1 7 0 0 0
 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 89 00 00
-----OCONNOR PEG TEST-----
---TESTNO, 09      ---PRACTQN, 0      ---MAINQN, 01      ---WARNTIME(SEC), 300
---RUNTIM(MIN), 10.0 ---PRACT.ANS,  0 0 0 0 0 0 0 0
99 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
-----NO SCORE TEST FOR TRYING OUT-----
---TESTNO, 14      ---PRACTQN, 5      ---MAINQN, 50      ---WARNTIME(SEC), 90
---RUNTIM(MIN), 60.0 ---PRACT.ANS,  0 0 0 0 0 0 0 0
 5 10 15 20 25 30 35 40 45 50 00 00 00 00 00 00 00 00 00

```

APPENDIX C: PERSONAL QUESTIONNAIRE

01

What did you have for breakfast this morning?

Nothing	A drink	Something to eat	Something to eat and drink

A	E	I	O

02

Did you eat bread or toast at breakfast this morning?

Yes	No

A	E

03

Did you eat pap (mealie meal porridge) at breakfast this morning?

Yes	No

A	E

04

Did you eat cereal (for example, cornflakes) at breakfast this morning?

Yes	No

A	E

05

Did you eat fruit at breakfast this morning?

Yes	No

A	E

06

Computer check: Press button X.

07

Did you drink milk at breakfast this morning or have milk on your cereal or porridge?

Yes No

A E

08

Did you eat enough at breakfast this morning or were you still hungry afterwards?

Enough Still hungry Ate nothing

A E I

09

Did you bring something to eat or drink to school today?

Something to eat Something to drink Something to eat and drink Nothing

A E I 0

10

Are you going to buy something to eat during your break today?

Yes No

A E

11

Did you bring bread or sandwiches to school today?

Yes No

A E

12

Computer check: Press button X.

13 Did you bring fruit to school today?

Yes No

A E

14 Did you bring sweets to school today?

Yes No

A E

15 Did you bring milk to school today?

Yes No

A E

16 Do you often feel hungry at school?

Yes No

A E

17 What time did you get out of bed today?

Before	06:00 to	07:00 to	After	Don't
06:00	06:55	08:00	08:00	know

A	E	I	O	U

18 Computer check: Press button X

19

What time did you leave the house today to come to school?

Before	06:00 to	07:00 to	After	Don't
06:00	06:55	08:00	08:00	know

A	E	I	O	U

20

What time did you go to bed last night?

Before	07:00 to	08:00 to	After	Don't
07:00	07:55	09:00	09:00	know

A	E	I	O	U

21

Did you walk all of the way to school today?

Yes	No

A	E

22

Did you travel by bus on your way to school today?

Yes	No

A	E

23

Did you travel by car on your way to school today?

Yes	No

A	E

24

Computer check: Press button X

25

Did you travel by bicycle on your way to school today?

Yes No

A E

26

Does the teacher give you homework?

Yes, most Only Never
days sometimes

A E I

27

Do your parents help you with your school work at home?

Yes No

A E

28

Do you have a quiet place at home where you can do your homework?

Yes No Don't have homework

A E I

29

Do your parents read to you or tell you stories?

Yes No

A E

30

Computer check: Press button X

31

Do your parents listen to you when you talk about what happened at school during the day?

Yes

No

A

E

32

Do you read things like books and comics at your own home?

Yes

No

A

E

33

Do you help your mother at home with her housework?

Yes

No

A

E

34

Do you prefer to be at school or at home?

At school

At home

A

E

35

Do you think it is better to be a girl or a boy?

Girl

Boy

A

E

36

Computer check: Press button X.

37

When you are in school during winter do you sometimes feel cold?

Never

Sometimes

Often

A

E

I

38

When you are in school during summer do you sometimes feel hot?

Never

Sometimes

Often

A

E

I

39

How do you feel in the classroom today?

Too cold

Too hot

Just right

A

E

I

40

What hand do you write with?

Left

Right

A

E

41

What would you most like to be? You can choose only one of them.

Cleverest
in the
class

Most liked
in the
class

Strongest
in the
class

Prettiest
in the
class

A

E

I

O

42

Computer check: Press button X.

43

How many adults (this includes your parents, grandmother, grandfather, aunts and uncles) live in your house?

1	2	3	4	More than 4
A	E	I	0	U

44

How many brothers live in your house?

0	1	2	3	More than 3
A	E	I	0	U

45

How many sisters live in your house?

0	1	2	3	More than 3
A	E	I	0	U

46

How many people, including yourself, slept in your bedroom last night?

1	2	3	4	More than 4
A	E	I	0	U

47

Did your father sleep at home last night?

Yes	No	I have no father
A	E	I

48

Computer check: Press button X.

49

Did your mother sleep at home last night?

Yes

No

I have no mother

A

E

I

50

Does your mother go out to work

Yes

No

I have no mother

A

E

I

51

Does your father go out to work?

Yes

No

I have no father

A

E

I

52

Do you have a television in your home?

Yes

No

A

E

53

Do your parents have a car?

Yes

No

A

E

54

Computer check: Press button X.

55

Do you have a telephone in your home?

Yes

No

A

E

56

Do you have a fridge in your home?

Yes

No

A

E

57

Computer check: Press button X.

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