

https://dspace.org/

Determining Synchrony of Mother-Infant Non-Verbal And Movement Behaviours Using First-Person Observation and Accelerometer Data

Maduna, Dumsile Nontokozo

2025

University of the Witwatersrand, Johannesburg

https://hdl.handle.net/10539/49966

Maduna, Dumsile Nontokozo. (2025). Determining Synchrony of Mother-Infant Non-Verbal And Movement Behaviours Using First-Person Observation and Accelerometer Data [PhD thesis, University of the Witwatersrand, Johannesburg]. WIReDSpace. https://hdl.handle.net/10539/49966

Downloaded from a DSpace repository. https://dspace.org/

Determining Synchrony of Mother-Infant Non-Verbal And Movement Behaviours Using First-Person Observation and Accelerometer Data

By

Dumsile Nontokozo Maduna

A thesis submitted to the Faculty of Health Sciences, University of the Witwatersrand,

in fulfilment of the requirements for the degree of

Doctor of Philosophy

Supervisors: Dr Lukhanyo. H. Nyati

Professor Ian. T. Nabney

Johannesburg, 2025.

Declaration

I declare that this thesis entitled ‘Determining Synchrony of Mother-Infant Non-Verbal and Movement Behaviours Using First-Person Observation and Accelerometer Data, submitted for the degree of Doctor of Philosophy is the result of my own work and that where reference is made to the work of others, due acknowledgement is given.

I also certify that any material in the thesis has not been submitted for degree or for examination purposes to any other university of institution.

Dumsile Maduna

Signed 

23 September 2025

Dedication

This PhD is lovingly dedicated to my mother — a woman of immeasurable strength and sacrifice. You singlehandedly gave us everything you never had, ensuring we received the best you could offer. This achievement is not mine alone; it belongs to both of us. Your unwavering love, hard work, and belief in me carried me through every stage of this journey.

To my siblings — I would do anything to see you thrive. While you've recently earned your diplomas, let this be a reminder that your dreams are valid and entirely within reach. May this serve as inspiration that with faith, hard work, and courage, we can rise beyond every limitation.

To my two beautiful sons, Iviwe and Inamandla — you have a gift for divine timing, arriving just as I chose to walk the path of higher learning. We wrote this thesis together. Your presence in my life gave this work meaning, strength, and heart.

To my husband — **Ginindza lomphomfu, mambalendze lesensokonsokweni!**

Psalm 92: 12-15

"The righteous will flourish like the date palm [long-lived, upright and useful]; They will grow like a cedar in Lebanon [majestic and stable]. Planted in the house of the Lord, they will flourish in the courts of our God. [Growing in grace] they will still thrive and bear fruit and prosper in old age; They will flourish and be [a]vital and fresh [rich in trust and love and contentment]; [They are living memorials] to declare that the Lord is upright and faithful [to His promises]; He is my rock, and there is no unrighteousness in Him."

Abstract

Mother-infant synchrony—the dynamic, coordinated exchange of behaviours and movements between caregivers and their infants—is fundamental for promoting healthy emotional, cognitive, and socio-emotional child development. Despite extensive global research, current evidence remains predominantly derived from Western, Educated, Industrialized, Rich, and Democratic (WEIRD) societies, raising questions about its generalizability to low-resource and culturally diverse contexts such as South Africa. This thesis aimed to address this critical gap by exploring synchrony using innovative multimodal methodologies, specifically first-person observational approaches via head-mounted cameras (headcams) and wrist-worn accelerometer, within a socioeconomically constrained urban South African setting (Soweto).

Three interconnected studies were conducted among mother-infant dyads at critical developmental periods (4 and 8 months postpartum) to assess patterns, determinants, and developmental trajectories of non-verbal behavioural and movement synchrony. Study one employed headcam footage to provide intimate, ecologically valid insights into everyday caregiver-infant interactions, highlighting delays in the emergence and stability of synchronised behaviours compared to high-income contexts. Study two utilised accelerometer data to objectively capture mother-infant movement patterns, revealing detailed temporal synchrony particularly during caregiving routines and demonstrating a developmental shift from mother-led to infant-led coordination. The final study, a longitudinal analysis combining both methodologies, identified maternal employment as a consistent predictor of reduced synchrony, underscoring how structural constraints significantly influence relational caregiving capacities.

Collectively, these findings affirm that synchrony is a dynamic, developmentally evolving process substantially influenced by caregiving context and availability. The integration of first-person observational and accelerometry methods provided robust, objective data, overcoming biases associated with traditional observational techniques. This methodological innovation represents a significant advancement in synchrony research, particularly for low- and middle-income countries. Furthermore, findings hold practical implications for developing culturally sensitive, synchrony-focused early childhood interventions and policy frameworks designed to mitigate developmental risks associated with socioeconomic adversity.

Future research recommendations include extending longitudinal assessments, explicitly incorporating maternal mental health and psychosocial variables, broadening the scope to include multi-caregiver roles, and employing qualitative methodologies to enrich contextual understanding. This thesis thus lays critical groundwork for enhancing early developmental outcomes through evidence-based, culturally responsive synchrony interventions tailored to the South African caregiving landscape.

Keywords: mother infant synchrony, nonverbal behaviour, accelerometry, first person video, caregiving routines, early childhood development, Soweto South Africa, LMICs

Acknowledgements

I am deeply grateful to the many individuals and institutions who made this work possible. First and foremost, I extend my heartfelt thanks to my supervisors and mentors. Dr. Alessandra Prioreschi – thank you for your unwavering support, guidance, and belief in me even when I doubted myself. Your mentorship has had a lasting impact on my growth as a researcher. Dr. Lukhanyo H. Nyati – thank you for the important lessons and challenges that sharpened my thinking and strengthened my academic voice. I am especially thankful to Professor Ian Nabney for your consistent mentorship, intellectual guidance, and encouragement.

To the Head of Department at DPHRU and the Faculty of Health Sciences – thank you for the essential financial assistance that allowed me to carry this work to completion. I am sincerely grateful to Sandra and Charles from HR, and Maria from the Faculty of Health Sciences. Your support, responsiveness, and kindness helped me navigate complex processes at critical points in my academic journey. Sandra, thank you for your incredible generosity in providing accommodation and financial support when I needed it most. It made a world of difference.

Special thanks to my dedicated editors for your precision, patience, and commitment to excellence, which greatly enhanced the quality of this thesis. I would also like to acknowledge the SRC International Office at the University of the Witwatersrand for your continued support and advocacy. To the Faculty of Health Sciences Library at Chris Hani Baragwanath Academic Hospital – thank you for your invaluable assistance during the literature search phase. Your support helped shape the foundation of this research.

To the research participants and the families involved in the PLAY Study – your willingness to share your lives and experiences formed the heart of this work. Thank you.

Finally, I acknowledge the generous funding support from the Wellcome Trust, the National Institute for Health Research (NIHR), and the Centre of Excellence in Human Development (CoE). This study would not have been possible without your investment in research that centres children and families in Africa

Table of Contents

Declaration.....i

Dedication.....ii

Abstract.....iii

Acknowledgements.....v

Table of Contents.....vii

Definition of Key Terms.....xi

List of Abbreviations.....xiv

List of Figures.....xvi

List of tables.....xviii

Preface.....xx

CHAPTER ONE: LITERATURE REVIEW.....1

1.0. Chapter Overview.....1

1.1. General Introduction.....1

1.2. Problem Statement.....4

1.3. Background.....10

1.3.1. Literature Search/ Review Strategy.....10

1.3.2. Early Neurodevelopment and the Role of Caregiver Interaction.....14

1.3.3. Theoretical Foundations of Mother-Infant Synchrony.....15

1.3.4. Importance of Synchrony for Emotional and Cognitive Development.....21

1.3.5. Cross-Cultural and Global Perspectives on Synchrony.....25

1.3.6. The South African Context and Caregiving Practices.....32

1.3.7. Methodological Gaps and Justification for Novel Approaches 37

1.4. Aims, Objectives, and Hypotheses 7

1.5. Chapter Summary 44

CHAPTER TWO: METHODS 45

2.0. Chapter Overview 45

2.1. Study Design and Setting 45

2.2. Participant Recruitment and Eligibility Criteria 47

2.3. Ethical Considerations 50

2.4. Demographic and Background Data Collection 51

2.5. Study 1: Headcam-Based Observation of Non-Verbal Synchrony 52

2.6. Study 2: Movement Synchrony Using Accelerometry 55

2.7. Study 3: Longitudinal Patterns and Predictors of Synchrony 57

2.8. Analytical Strategy 58

2.9. Data Management and Confidentiality 59

2.10. Chapter Summary 60

CHAPTER THREE: RESULTS 61

3.1. Introduction to the Chapter 61

3.2. Study 1 Behavioural synchrony (Headcam) 63

3.3. Study 2: Movement synchrony (Accelerometry) 126

3.4. Study 3: Longitudinal patterns of synchrony and predictors of synchrony (headcam & Accelerometry) 163

3.5. Chapter Summary 186

CHAPTER FOUR: INTEGRATED DISCUSSION AND CONCLUSION 188

4.1. Introduction 188

4.2. Objectives and Summary of Results 190

4.3. Revisiting the Conceptual Framework 192

4.4. Methodological Contributions 193

4.5. Implications for Research, Practice, and Policy 194

4.6. Strengths 196

4.7. Limitations 197

4.8. Conclusions 200

4.9. Knowledge Gaps and Future Priorities 200

4.10. Chapter Summary 204

CHAPTER FIVE: REFERENCES 205

CHAPTER SIX: APPENDICES 223

Appendix 1: PLAY Study CAG – Participant Information Sheet (Mothers) 223

Appendix 2: PLAY Study CAG – Informed Consent Form (Mothers) 228

Appendix 3: PLAY Study – Participant Information Sheet 232

Appendix 4: PLAY Study – Informed Consent Form 239

Appendix 5: Data Collection Questionnaires (Compiled) 241

Appendix 6: PhD Ethics Approval – M220785 Submission 258

Appendix 7: Main Study Ethical Clearance 259

Appendix 8: PhD Study Protocol 261

Appendix 9: Protocol Approval Letter 319

Appendix 10: Author Contributions and Acquiescence 320

Appendix 11: Statistical Methods Applied 321

Definition of Key Terms

Term	Definition
Accelerometry	Objective measurement of movement using wearable sensors that record acceleration, used to derive intensity, timing and patterns of activity.
Affective synchrony	Matching of caregiver and infant emotional states during interaction, for example shared positive affect.
Actor Partner Interdependence Model (APIM)	Dyadic model that estimates how each partner's characteristics or behaviours affect their own outcomes and their partner's outcomes.
Attachment	A stable emotional bond between infant and caregiver that supports regulation, exploration and later social competence.
Attunement	Sensitive, appropriate caregiver response to infant cues, not necessarily simultaneous.
Behavioural synchrony	Time aligned co-occurrence of observable behaviours, for example mutual gaze, touch and coordinated hand movements.
Bidirectionality	Both partners influence the interaction, examined using cross-correlation lags and dyadic models.
Caregiver availability	Time and opportunity for responsive interaction, often constrained by work and household demands.

Term	Definition
Contingency	Predictable response of one partner to the other's signal, can occur with or without exact temporal alignment.
Directionality of synchrony	Which partner tends to lead the aligned behaviour within a window, estimated using cross-correlation lags.
Dynamic Systems Theory	Perspective that views synchrony and development as emergent from continuous interactions among infant, caregiver and context.
Dyad	The mother infant pair analysed as a unit.
Ecological validity	Data collected in natural settings with minimal disruption, so interaction reflects routine caregiving contexts.
First person observation	Method using head mounted cameras to capture the direct perspective of caregiver or infant during interaction.
Headcam	Lightweight head mounted wearable camera used to capture first person video of interactions.
Inter-rater reliability	Agreement among coders for headcam micro coding, reported with kappa or percent agreement.
Joint attention	Simultaneous attention to the same object or activity by caregiver and infant.
Lag structure	The temporal offset at which signals are most aligned, estimated by the cross-correlation function.
Micro coding	Second by second annotation of behaviours from synchronised first-person video streams.

Term	Definition
Movement synchrony	Alignment of mother and infant movement signals derived from accelerometry.
Multimodal assessment	Integration of first-person headcam and accelerometry to capture complementary aspects of interaction.
Physiological synchrony	Alignment of biological signals such as heart rate or hormones.
Responsive caregiving	Prompt, sensitive and appropriate responses to infant cues that promote secure attachment and healthy development.
Rolling correlation	Moving window correlation of ENMO time series to summarise short term fluctuations.
Serve and return	Prompt, contingent, back and forth exchanges between caregiver and infant that scaffold development.
Synchrony	Reciprocal, temporally aligned and affectively matched interaction between mother and infant.
Vector autoregressive modelling	Time series approach used to quantify lagged dependencies between signals.
Wavelet coherence	Time frequency method used to detect synchrony across multiple time scales.
WEIRD contexts	Western, educated, industrialised, rich and democratic societies, used to indicate limited generalisability across cultures.

List of Abbreviations

Abbreviation	Expanded form
APIM	Actor Partner Interdependence Model
CAG	Community Advisory Group
CCF	Cross-correlation function
CHW	Community health worker
DTW	Dynamic time warping
ECD	Early childhood development
EEG	Electroencephalography
ENMO	Euclidean Norm Minus One
fNIRS	Functional near infrared spectroscopy
HDI	Human Development Index
HIC	High income country
HRV	Heart rate variability
ICC	Intraclass correlation coefficient
IQR	Interquartile range
LMIC	Low- and middle-income country
LMM	Linear mixed effects model
NCF	Nurturing Care Framework
NGO	Non-governmental organisation

Abbreviation	Expanded form
PLAY	Play, Love and You Study
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta Analyses
RCT	Randomised controlled trial
SDG	Sustainable Development Goal
SES	Socioeconomic status
VAR	Vector autoregressive model
WEIRD	Western, educated, industrialised, rich, democratic
WHO	World Health Organization

List of Figures

Label	Caption	Page
Figure 1	Literature search flow diagram	13
Figure 2	Dynamic systems model illustrating synchrony as an emergent property of biological, socio cultural, and environmental influences	15
Figure 3	Conceptual framework depicting interconnected dimensions of mother infant synchrony, behavioural, affective, physiological	17
Figure 4	Still image from video recordings depicting behavioural and affective synchrony during naturalistic free play	20
Figure 5	Timeline of major milestones in mother infant synchrony research, from attachment theory to first person observation and accelerometry	26
Figure 6	Comparative analysis of caregiving practices and synchrony indicators in WEIRD vs LMIC contexts, highlighting South African norms	30
Figure 7	Time series graphs showing synchronous vs asynchronous movement patterns from accelerometer data in South African mother infant dyads	39
Figure 8A	Illustration of a lightweight wearable head mounted camera used to capture first person interactions	40
Figure 8B	Correct positioning and secure attachment of the head mounted camera for caregivers and infants	40
Figure 9A	Axivity AX3 wrist worn accelerometer devices used in this study	42
Figure 9B	Adjustable straps designed for securely fitting Axivity AX3 accelerometers on mothers and infants	42

Chapter 2 - Figure 2	Study flow of screening, enrolment, device deployment, quality control, and analytical sample, main PLAY cohort	49
Study 1 - Figure 1	Still image of the first author and infant as an example of a joined mother infant video	70
Study 1 - Figure 2	Observer XT behavioural coding timeline for one infant	73
Study 1 - Figure S1	Paired mother infant gaze behaviours showing less synchrony	119
Study 1 - Figure S2	Paired mother infant gaze behaviours showing more synchrony	120
Study 2 - Figure 1	Temporal dynamics of movement synchrony at 4 months postpartum from continuous accelerometer data over 24 hours	149
Study 2 - Figure 2	Distribution of lead lag in synchrony, best lag in minutes	176
Study 2 - Figure 3	Box plots showing proportion of time in high synchrony, $r \geq 0.50$, at 4 and 8 months	177
Study 2 - Figure 4	Coefficient plot of predictors of mother infant synchrony	179
Study 3 - Figure 1	Change in mother infant synchrony scores within dyads from 4 to 8 months	176
Chapter 4 - Figure 1	Infographic of potential impacts of culturally sensitive, synchrony informed interventions tailored to South African caregiving contexts	201

List of tables

Table No	Description	Page
Table 1	Matching behaviour pairs	75
Table 2	Non-matching behaviour pairs that were not analysed for synchrony	75
Table 3	Description of individual mother and infant behaviours coded	83
Table 4a	Cross-sectional summaries of the frequency of matching behaviours at 4 and 8 months	86
Table 4b	Cross-sectional summaries of the duration of matching behaviours at 4 and 8 months	88
Table 4c	Changes in the frequencies, probabilities, and durations of matching behaviours from 4 to 8 months	90
Table S1	Demographics (Study 1)	105
Table S2:	The Frequencies and mean duration for no behaviour states and not possible to code behaviour states	107
Table S3a.	Cross-sectional summaries of the frequency and probability of mother-infants non-matching behaviour pairs at the 3, 5 and 7 second time windows.	108
Table S3b.	Changes in frequencies, probabilities, and duration of mother-infant non-matching behaviours over time (as a continuous variable), assesses by Multilevel Linear Models (MLMs).	110
Table S4a.	Durations in seconds of mother-infants matching behaviour pairs at each time window, with beta coefficients.	112
Table S4b.	Cross-sectional summaries of the duration of mother-infants non-matching behaviour pairs at the 3, 5 and 7 second time windows.	114

Table S5a.	Kruskal Wallis p-values comparing the frequencies and probabilities of matching behaviour pairs between paired time windows	116
Table S5b.	Kruskal Wallis p-values comparing the frequencies and probabilities of non-matching behaviour pairs between paired time windows	117
Table S6.	Description of mother-infant behaviour codes according to the coding scheme used in this study.	121
Study 2-Table 1	Summary of Rolling Correlation Values	148
Table 2	Summary of Synchrony Measures	151
S2-Table S1.	Participant characteristics of mothers and infant dyads from Soweto, South Africa that participated in the PLAY Love and You randomized trial	161
Study 3-Table 1.	Demographic Characteristics of Participants (N = 63)	174
Table 2	Summary of Mother–Infant Synchrony Metrics	175
Table 3	Multivariable Linear Regression Models for Mother-Infant Synchrony Measures	177
Table 4	Changes in Matching Behaviours Between Mothers and Infants from 4 to 8 months	179
Table 5	Changes in Non-Matching Behaviours Between Mothers and Infants from 4 to 8 months	181
Chapter 4 -Table 14	Objectives of the thesis and corresponding results	190

Preface

This thesis represents the fulfilment of both a personal and academic journey. My interest in mother infant relationships, synchrony, and early development is rooted in my lived experiences as a mother and my professional work in public health. Over the years, I have come to understand that the first few years of life are foundational, not only for physical growth but for emotional, cognitive, and relational wellbeing.

Through this research, I aimed to explore and better understand the non-verbal and movement-based interactions that occur between mothers and their infants. Using first person video and accelerometer data, I investigated the patterns and predictors of synchrony, that is, how mothers and babies move and connect with each other in everyday moments. This work was made possible by the strength of multidisciplinary collaboration and the openness of families who welcomed us into their lives.

The process of conducting this research was not easy. There were moments of intense pressure, personal sacrifice, and emotional strain. Balancing motherhood, research responsibilities, and academic deadlines was overwhelming at times. However, I pushed forward, fuelled by faith, the support of my loved ones, and the desire to contribute to knowledge that can shape better futures for children, especially in under resourced settings.

In this thesis, I examine mother infant synchrony in a South African context using a multimodal approach that integrates first person head mounted cameras and accelerometry. The work characterises behavioural and movement-based synchrony, investigates developmental change, and identifies contextual predictors that shape caregiver infant coordination in everyday life.

The thesis is organised as follows. Chapter One presents the Introduction, literature review, setting out the global and local context for early childhood development, the theoretical foundations of synchrony, cross cultural perspectives, and the South African caregiving context, including methodological gaps that motivate this work. Chapter Two details the methods, including study design and setting, recruitment, ethics, data collection procedures for headcams and accelerometers, and the analytical strategy. Chapter Three reports the results of three interconnected studies, behavioural synchrony from first person video, movement synchrony from accelerometry, and a longitudinal synthesis of both. Chapter Four provides the integrated discussion and conclusions, revisiting the conceptual framework, outlining methodological contributions, and drawing implications for research, practice, and policy, as well as noting strengths, limitations, and future priorities. Chapter Five contains the references. Chapter Six includes the appendices, which provide supporting materials such as ethical approvals, study protocols, and data collection tools.

I am proud to present this thesis, not only as an academic output, but as a testimony of resilience and purpose. My hope is that it inspires further research and contributes to policy and practice that strengthen caregiver infant relationships in the early years of life.

CHAPTER ONE: LITERATURE REVIEW

1.0. Chapter Overview

This chapter provides a comprehensive literature review that sets the foundation for the thesis. It begins with an overview of global and local challenges in early childhood development, followed by theoretical perspectives on mother-infant synchrony. The chapter then explores the importance of synchrony for child outcomes, cross-cultural perspectives, the South African caregiving context, and methodological gaps. It concludes by justifying the novel approaches employed in this study. A consolidated Key Terms table appears after the Contents, and terms are cross referenced at first use in each chapter.

1.1. General Introduction

Early childhood is critically important for shaping lifelong health, learning, and overall well-being. Globally, inadequate caregiving and suboptimal early childhood experiences significantly hinder child development, contributing to poor health, education, and socio-economic outcomes. Approximately 250 million children under five in low- and middle-income countries (LMICs) are at risk of not reaching their developmental potential due to factors such as poverty, undernutrition, and limited cognitive and social stimulation (Black et al., 2016) . In sub-Saharan Africa, this issue is particularly severe, where approximately 66% of children are affected by developmental delays linked to caregiving challenges and resource scarcity (WHO et al., 2018).

South Africa exemplifies these developmental challenges, characterised by stark inequalities, high levels of poverty, and limited access to early childhood services. In settings such as Soweto, socio-economic stressors including high unemployment, overcrowded housing, and inadequate early learning resources reduce caregivers' ability to provide responsive caregiving, contributing to lower Human Development Index (HDI) scores and poorer educational and nutritional outcomes (Ayob et al., 2021). Such conditions represent a critical public health issue and highlight the urgent need for targeted early childhood interventions in LMIC settings.

The Sustainable Development Goals (SDGs) explicitly recognise early childhood development as key to reducing inequalities and promoting health and well-being (SDG 4.2). Global frameworks like the Nurturing Care Framework (WHO, 2018) emphasise that responsive caregiving in the first years of life is essential to achieving these targets. Responsive caregiving – characterized by prompt, contingent, and sensitive interactions between caregivers and infants – provides the “serve-and-return” exchanges that build strong brain architecture and resilience in children (Ilyka et al., 2021). Central to responsive caregiving is mother-infant synchrony, defined as coordinated, reciprocal interaction between caregiver and infant involving matched emotional states, gestures, vocalisations, and even physiological rhythms (Feldman, 2007b, 2012c). This synchronous matching of cues and responses is instrumental in establishing secure attachment and fostering infants’ emotional regulation, social skills, and cognitive development (Ainsworth, 1979; Sroufe & Waters, 1977). Conversely, low synchrony or disrupted early interactions are linked to developmental delays, behavioural problems, and later academic difficulties, thereby perpetuating cycles of disadvantage (Caplan et al., 2015; Woodman et al., 2015).

Despite its critical importance, most research on caregiver-infant synchrony originates from **WEIRD** (Western, Educated, Industrialised, Rich, Democratic) populations (Henrich et al., 2010; Keller, 2018). We therefore position Soweto as a contrasting urban African setting and treat comparisons with high income cohorts as tests of external validity rather than assumptions of equivalence. Much of the existing work is conducted in structured laboratory settings with middle class nuclear families, which may not reflect caregiving in diverse cultural or low resource contexts. In South Africa in 2024, only 31.4 percent of children lived with both biological parents, 45.5 percent lived with mothers only, and 18.8 percent lived with neither parent, with marked urban rural contrasts, 40.2 percent of urban children with both parents compared with 19.3 percent in rural areas, and 50.3 percent of rural children with mothers only (Statistics South Africa, 2024, 2025). Multigenerational living was also common, 13.4 percent of households had three generations, and 4.2 percent were skip generation households, with widespread grandparental care documented nationally (Maluleke, 2025). Together, these patterns indicate that prevailing developmental frameworks risk overlooking the variability of early interactions across cultures. Caregiving practices differ widely: some cultures emphasize continuous physical closeness and tactile stimulation, others prioritize face-to-face vocal engagement, and still others encourage infant autonomy (Keller et al., 2016).

Understanding such cultural variations is essential for designing effective, culturally appropriate interventions. Furthermore, traditional methods for studying synchrony (such as brief clinic observations) may fail to capture the full complexity of everyday caregiver-infant interaction. Emerging methodologies – including first-person head-mounted cameras and wearable accelerometers – now allow researchers to record naturalistic, real-life interactions with greater

objectivity and ecological validity (Hoch et al., 2021). Utilising these innovative tools offers new opportunities to study synchrony as it unfolds in daily routines, as detailed in the methods of Chapters 2 and 3 of this thesis.

Studying synchrony within a community such as Soweto provides a valuable opportunity to examine these principles under real-world conditions. This PhD research investigates both non-verbal behavioural synchrony and movement synchrony in mother-infant dyads using novel multimodal methods. By combining first-person observations and accelerometry in a low-resource setting, the work aims to generate culturally relevant insights. The outcomes will inform interventions and policies to enhance early childhood development in South Africa and similar LMIC contexts, contributing directly toward global SDG targets in health, education, and inequality reduction.

1.2. Problem Statement

Despite extensive global research on mother-infant synchrony, significant gaps remain in our conceptual, methodological, and contextual understanding of this phenomenon – particularly in LMIC settings such as South Africa. Addressing these gaps is crucial for improving early developmental outcomes and reducing global disparities in human capital:

- **Global Early Development Risks:** Millions of children in LMICs fail to reach their developmental potential due to adverse early environments. As noted above, roughly 250 million children under five are at risk of suboptimal development (Black et al., 2016). This represents a massive loss of human potential. While international initiatives (e.g. SDG 4.2) call for all children to have access to quality early development, progress

requires deeper understanding of the specific caregiver-infant interaction deficits contributing to poor outcomes. Early childhood risks, from malnutrition to lack of stimulation, must be addressed through evidence-based strategies targeting the caregiver-infant relationship.

- **Need for Responsive Caregiving and Synchrony:** Responsive, engaged caregiving is a cornerstone of healthy child development. High-quality caregiver-infant interactions, especially synchronous "serve-and-return" exchanges, support the developing brain's architecture and buffer children from stress (Ilyka et al., 2021). Mother-infant synchrony, in particular, appears to be a key mechanism underlying the benefits of responsive caregiving. Synchronous interactions foster infants' emotional security, cognitive engagement, and social competence (Feldman, 2012b, 2017). Therefore, improving synchrony in early life has substantial potential to strengthen developmental trajectories. However, a robust evidence base on synchrony's role in typical and at-risk populations is needed to design effective interventions. The SDGs and Nurturing Care Framework highlight responsive caregiving, but do not yet fully account for how synchrony processes may vary across cultures and contexts.
- **Limited Generalizability of Current Evidence:** A **conceptual gap** exists in whether findings from WEIRD contexts generalize globally. Most empirical knowledge about synchrony (e.g. its positive influence on attachment and self-regulation) comes from Western, middle-class samples. Caregiving practices in places such as Soweto differ substantially – shaped by communal caregiving norms, extended family involvement, and socio-economic adversity (Keller, 2013; Lachman et al., 2022). It is unclear whether the developmental benefits of synchrony observed in Western settings (such as secure

attachment or advanced social skills) manifest similarly in African or other LMIC contexts. There is a need to validate foundational theories of synchrony within diverse cultural settings. Without such evidence, programmes may either overemphasise or overlook aspects of interaction that matter most in non-Western contexts.

- **Methodological Challenges in Naturalistic Settings:** Traditional approaches to measuring synchrony present methodological gaps. Brief laboratory-based observations or global rating scales may not capture the subtle, moment-to-moment coordination that occurs in home environments (Nomikou et al., 2016). Furthermore, they may miss culturally specific expressions of synchrony (e.g. rhythmic body movements, multi-person interactions). Few studies to date have employed advanced, objective recording technologies – such as wearable headcams or accelerometers – to quantify synchrony in everyday settings, especially in low-resource communities. Innovative methodologies are needed to obtain precise, ecologically valid data on caregiver-infant interaction in LMIC contexts (Hoch et al., 2021). Such methods could reveal synchrony patterns and breakdowns that elude traditional observation, thereby informing more effective interventions.
- **Underrepresentation of African Contexts:** A critical contextual gap is the dearth of research on caregiver-infant synchrony in sub-Saharan Africa. Socio-economic stressors prevalent in South African communities (poverty, maternal mental health challenges, etc.) can negatively impact responsive caregiving and potentially disrupt synchrony (Feldman et al., 1999; Tomlinson et al., 2005). At the same time, strong cultural and community supports, such as shared caregiving by relatives, might foster resilient forms of synchrony that are not well documented in the literature. Currently, there is limited local evidence on

how socio-cultural factors influence the development of synchrony in infants. This lack of context-specific knowledge hinders the design of interventions that are attuned to the realities of caregivers in settings such as South Africa.

Addressing these gaps is urgent for both science and policy. Without broader, culturally informed research, our understanding of early relational processes remains incomplete and biased towards Western norms. Generating local evidence on synchrony will directly inform interventions to promote early childhood development in South Africa and similar LMICs. It will also support global initiatives by ensuring that strategies to improve responsive caregiving and early learning (as promoted in the SDGs and WHO's Nurturing Care Framework) are grounded in evidence from diverse contexts. Ultimately, closing these knowledge gaps will help ensure that all children, regardless of where they are born, receive nurturing early care that supports their ability to thrive.

1.3. Aims, Objectives, and Hypotheses

Overall Aim: The overarching aim of this PhD research is to address the identified knowledge gaps by investigating the nature of mother-infant synchrony in a low-resource South African setting, using innovative observational and sensor-based methods. Accordingly, any contrasts with published high-income cohorts are treated as checks of external validity for Soweto, not as assumptions of equivalence. In particular, the study aims to characterize both non-verbal behavioural synchrony and movement synchrony in Sowetan mother-infant dyads, and to determine how these synchronous interactions change over the first year of life. The studies

establish measurement feasibility and generate testable hypotheses for future intervention research.

Research Objectives: To achieve this aim, the study has the following specific objectives:

1. **To determine the synchrony of mother-infant non-verbal behaviours using first-person observation.** This entails quantifying the degree of behavioural and affective synchrony (e.g. joint attention, mutual gaze, shared affect) between mothers and infants during naturalistic interactions, as captured through head-mounted camera footage.
2. **To determine the synchrony of mother-infant diurnal movement patterns using accelerometry.** This involves measuring the coordination of physical activity and movement between the dyad (for example, aligned activity bursts, rest-activity cycles, and movement intensities) over the course of a day, using wearable accelerometer data.
3. **To assess longitudinal patterns of synchrony over the first year and identify predictors of synchrony.** This involves examining how synchrony (both behavioural and movement-based) evolves as the infant ages (e.g. comparing synchrony at ~4 months vs. ~8 months), and evaluating which factors predict higher or lower synchrony. Potential predictors include maternal characteristics (sensitivity, mood, socio-economic status), infant factors (temperament, developmental stage), and contextual factors (social support, household environment).

Hypothesis: It is hypothesized that mother-infant dyads in this South African cohort will exhibit measurable and significant synchrony in both their interactive behaviours and movement

rhythms, and that the novel first-person and accelerometer methods will successfully capture these synchronous patterns. Specifically, we hypothesize that:

- **Existence of Synchrony:** Even in a high-adversity environment, mothers and infants will demonstrate clear instances of synchrony – for example, frequent episodes of matched gaze and affect, and statistically significant correlations in their activity patterns. The level of synchrony may be comparable to that reported in studies from WEIRD contexts, although expressed through culturally relevant forms (e.g. more touch-based coordination).
- **Developmental Progression:** We expect synchrony to show a developmental progression across the first year of life. Early in infancy (~4 months), synchrony might be more heavily driven by caregiver actions (as infants' capacities are limited), but by ~8 months we anticipate more active infant participation and possibly higher synchrony as infants become more socially and motorically skilled. Overall synchrony (especially movement synchrony) may increase with infant age and mobility. We also predict some stability in individual differences – dyads with relatively high synchrony at first assessment will tend to remain higher relative to others later, indicating a trait-like aspect to their interactive style.
- **Influence of Contextual Factors:** We hypothesize that certain factors will be associated with greater synchrony. For instance, mothers with higher responsiveness or lower stress levels will likely achieve more synchrony with their infants. Similarly, infants who are temperamentally easy (adaptable, not overly fussy) are expected to engage in higher synchrony. Conversely, socio-economic strain and maternal psychosocial difficulties (e.g. depressive symptoms) are hypothesized to be linked to reduced synchrony. However,

strong communal support (e.g. presence of helpful co-caregivers) may mitigate some negative effects of adversity on synchrony.

Overall, the hypothesis is that synchrony serves as a resilient feature of mother-infant interaction even in challenging environments, and that by using multimodal assessment we will uncover robust synchronous patterns that have so far been under-recognized in LMIC contexts. Confirming this hypothesis would underscore the universality of synchrony's importance and validate the use of these innovative methods for studying early caregiver-infant relationships in diverse settings.

1.4. Background

1.4.1. Literature Search/ Review Strategy

A rigorous and systematic literature review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines to ensure transparency, methodological rigour and reproducibility (Moher et al., 2009). This approach facilitated the clear documentation of study selection processes and enhanced the reliability of the review findings by minimising potential bias. The strategy included the identification, screening, and synthesis of relevant studies on mother-infant synchrony, with particular focus on its measurement and developmental implications. The review incorporated diverse academic sources including peer-reviewed journal articles, systematic reviews, dissertations, and relevant conference proceedings, ensuring both global relevance and cultural contextualisation,

particularly within sub-Saharan Africa and South Africa (Cote & Bornstein, 2021; Tomlinson et al., 2005).

The literature search was conducted across multiple databases, Google Scholar, ResearchGate, PubMed, PsycINFO, Scopus, and Web of Science, to maximise interdisciplinary coverage of developmental psychology, child health, and behavioural sciences. Search terms included "mother-infant synchrony," "non-verbal synchrony," "parent-infant interaction," "dyadic coordination," "early attachment," "accelerometry in synchrony research," and "video-based synchrony assessment," used individually and in combination with Boolean operators to optimise search outcomes. Studies were included if they were peer-reviewed empirical research focused explicitly on synchrony, used observational or physiological methods relevant to synchrony measurement, and were published in English between January 2000 and March 2024. Special emphasis was placed on studies conducted in South Africa and similar LMIC settings to ensure relevance to the context of this thesis.

Exclusion criteria included studies focusing solely on older children, adults, or non-human subjects, as well as publications lacking methodological clarity or relevance to synchrony assessment via video or accelerometry. In addition to structured database searches, snowballing techniques were employed to identify foundational literature from reference lists, while citation alerts and related article recommendations were systematically reviewed to capture additional high-quality studies. This comprehensive process yielded a diverse yet highly focused body of literature that captures both global advances and local perspectives on synchrony within culturally and socio-economically diverse contexts.

Figure 1 illustrates the comprehensive literature search flow strategy, visually representing the sequential narrowing from broad database queries to the final selection of studies critically synthesised within this review. This transparent outline aligns with PRISMA guidelines, further enhancing methodological clarity and replicability. To improve transparency, we added an exclusion reasons box to Figure 1 and a supplementary table with counts for each reason.

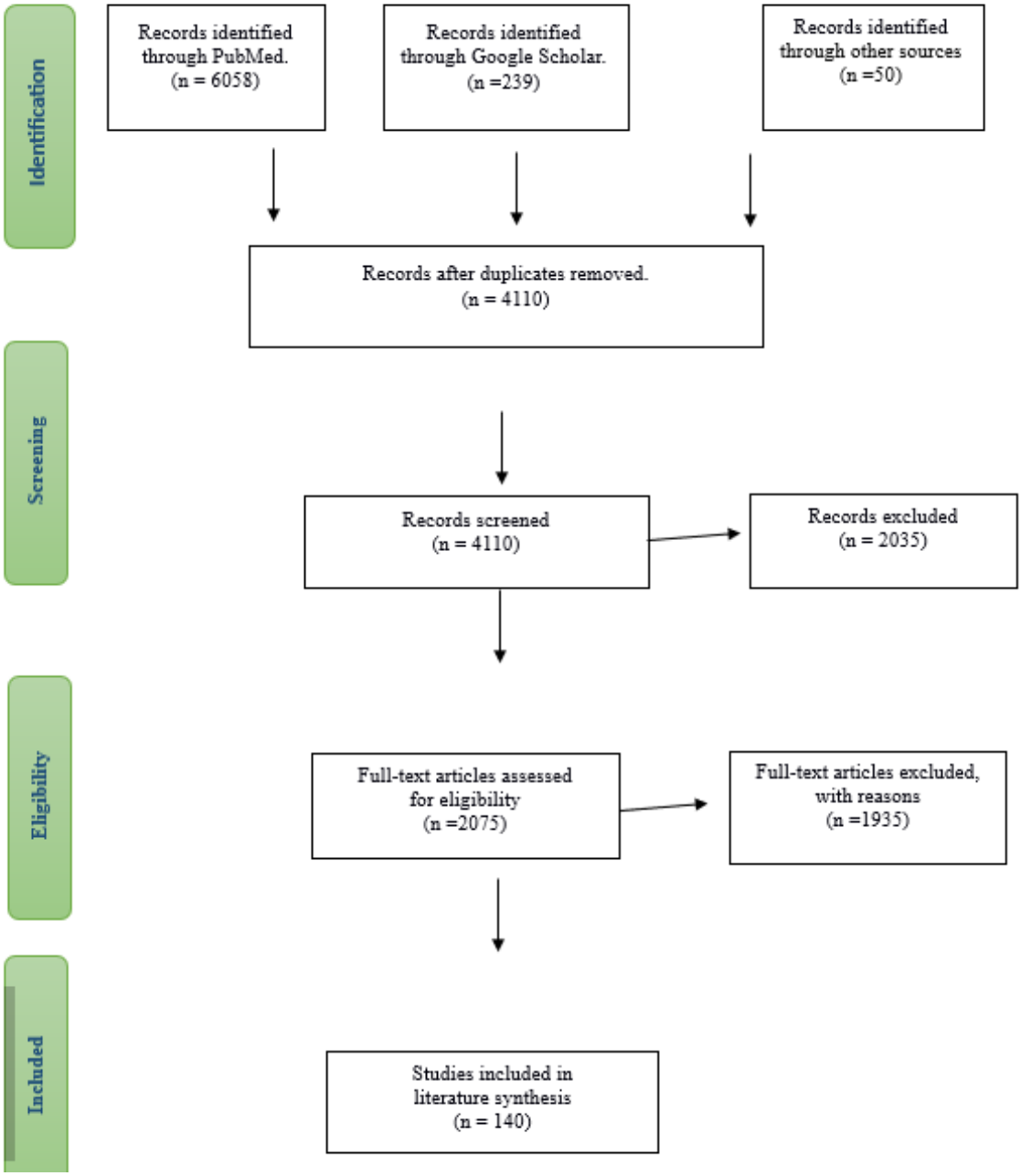


Figure 1 Literature search flow diagram

PRISMA flow of records, identification, screening, eligibility, and inclusion. Full text exclusion reasons included, wrong population, not infant dyads, wrong setting, non LMIC, not synchrony or interaction outcomes, not observational or wearable methods, reviews or abstracts only, and insufficient outcome detail. The reduction from more than 2,000 records to fewer than 150 included items is shown. Counts by exclusion reason are provided in Supplementary Table S1. *From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097**.** For more information, visit www.prisma-statement.org.

1.4.2. Early Neurodevelopment and the Role of Caregiver Interaction

The first years of life represent a period of unparalleled brain development and plasticity. During infancy, millions of neural connections are formed or pruned in response to early experiences. Caregiver-infant interactions play a decisive role in shaping this emerging brain architecture (Ilyka et al., 2021). Indeed, social exchanges in infancy are thought to be *critical for optimal brain development*, as they provide essential input for neural circuitry related to emotion and cognition (Ilyka *et al.*, 2021). Research indicates that aspects of caregiver behaviour during early interactions are associated with infants' brain structure and function, with measurable effects as early as 3 months of age and lasting impacts observed into adolescence (Ilyka et al., 2021). In other words, the quality of an infant's early social environment can have both immediate and long-term influences on neurodevelopmental outcomes. Sensitive, engaging interactions – including eye contact, affectionate touch, and prompt responsiveness – support healthy brain maturation, whereas chronically unresponsive or stressful interactions may disrupt neural and behavioural development (Cekaite & Bergnehr, 2018; Smith & Pollak, 2020). This evidence underscores why nurturing caregiver engagement (and synchrony in particular) is a focus of early intervention efforts.

1.4.3. Theoretical Foundations of Mother-Infant Synchrony

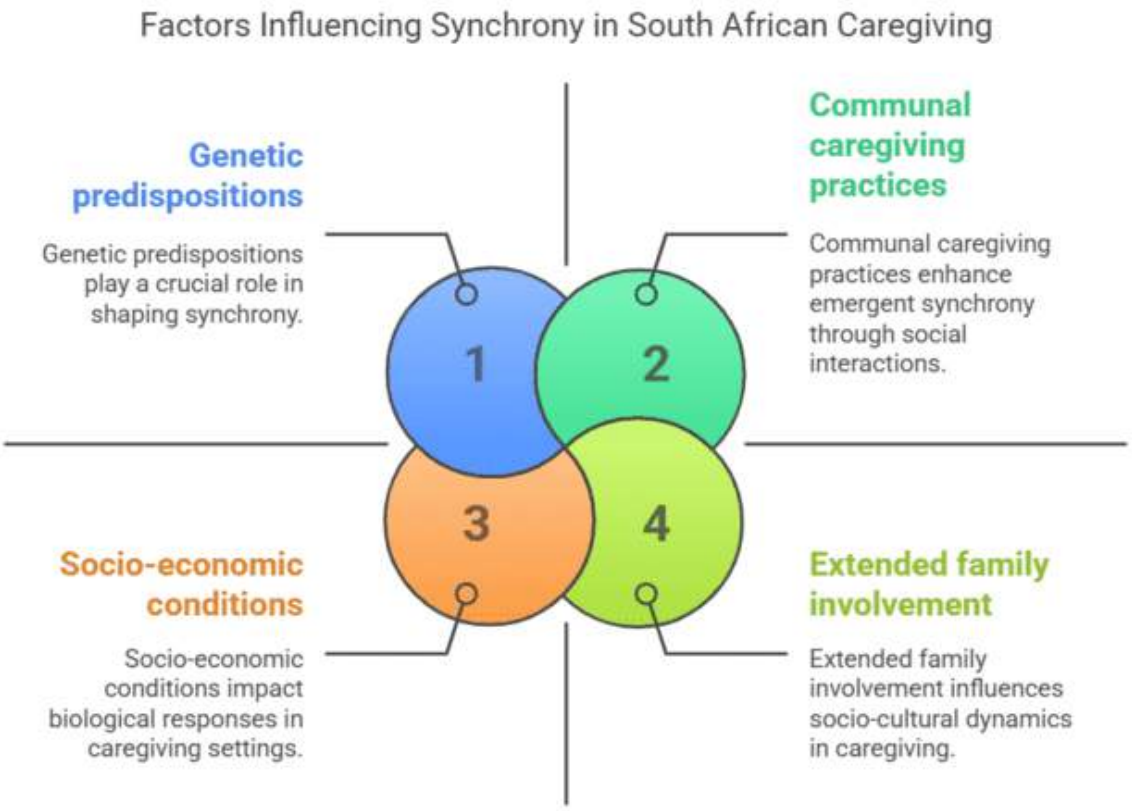


Figure 2 Dynamic systems model illustrating synchrony as an emergent property shaped by ongoing interactions among biological factors (e.g., genetic, neural), socio-cultural contexts (communal caregiving and extended family involvement), and environmental influences prevalent in South African caregiving settings.

Mother-infant synchrony represents a complex, dynamic process of mutual regulation in which caregiver and infant coordinate their behaviour, affect, and physiology in time. It has been examined through multiple theoretical lenses, each offering insights into how synchrony originates and why it matters. Classic attachment theory provided an early framework, positing that an infant's experiences of caregiver responsiveness in the first year form the basis for secure

or insecure attachment bonds (Ainsworth, 1979; Bowlby, 1969). In this view, episodes of synchrony – for example, an infant's smile met by the mother's warm vocal response – help build the infant's sense of security and trust. Consistent synchronous interactions are thought to underlie secure attachments that predict positive emotional outcomes.

Subsequent models, such as Tronick's mutual regulation model and dynamic systems theory, emphasize the bidirectional, emergent nature of synchrony. Dynamic systems theory conceptualizes synchrony as an *emergent property* of continuous caregiver–infant interactions embedded in context. Rather than a fixed trait, synchrony is seen as arising from moment-to-moment adjustments by both partners in response to each other's cues. The caregiver and infant form a coupled system, co-regulating each other's behaviour and physiological states in real time. From this perspective, patterns of synchrony are adaptive and fluid, shaped by factors like infant temperament, caregiver characteristics, and the surrounding environment (Thelen & Smith, 1994; E. Z. Tronick & Cohn, 1989a).

A related framework, bio-behavioural synchrony (Feldman, 2012b, 2017), integrates biological processes into our understanding of synchrony. Feldman's model proposes that caregiver-infant attunement operates on multiple levels simultaneously, behavioural (e.g. gaze, vocalisation, touch), affective (emotion matching), and physiological (heart rate, hormones, neural activation). Studies have shown, for instance, that during synchronous interactions caregivers and infants can exhibit coordinated heart rate patterns or cortisol levels and even synchronised brain activity measured by EEG or fNIRS (Feldman, 2012a; Leong et al., 2017). These findings highlight that synchrony is deeply grounded in biology: hormonal systems like oxytocin are engaged to

promote sensitive caregiving, and reward-related neural circuits in the adult brain (e.g. orbitofrontal cortex and amygdala) are activated during positive parent-infant exchanges (Atzil et al., 2011; Feldman, 2017). Thus, multiple theoretical perspectives, attachment, dynamic systems, and bio-behavioural, collectively portray synchrony as a multidimensional, context-sensitive process that is central to early development.

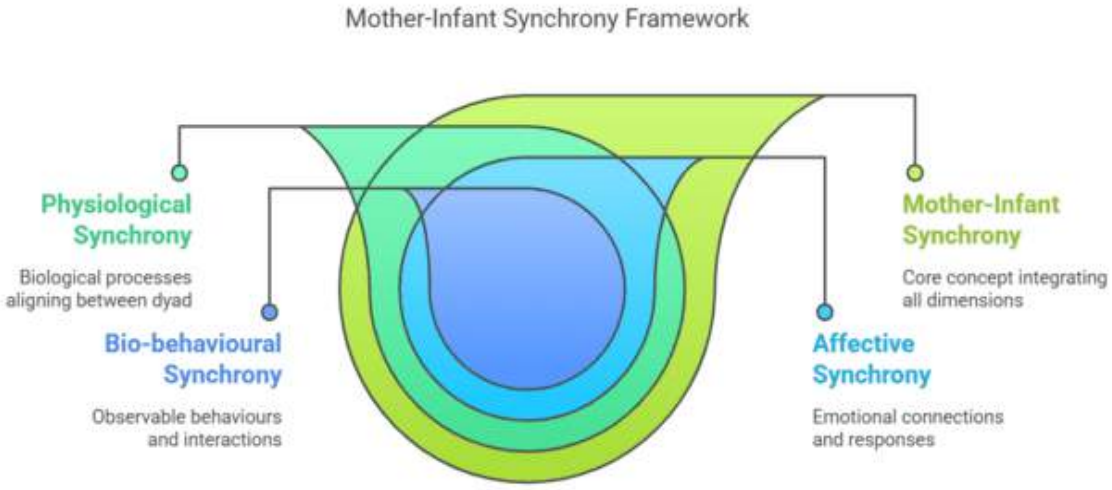


Figure 3 Conceptual framework depicting the interconnected dimensions of mother-infant synchrony (behavioural, affective, and physiological). This diagram illustrates culturally relevant interaction features observed among Black South African mother-infant dyads, highlighting key synchronous behaviours such as gaze coordination, emotional attunement, and responsive touch.

In understanding synchrony, it is important to distinguish it from related concepts like attunement, reciprocity, and contingency. While these terms are sometimes used interchangeably in developmental literature, they have distinct meanings (Stern, 2018). **Attunement** refers to the

caregiver's sensitivity and appropriate responsiveness to an infant's signals, especially emotional cues. A mother who is *attuned* will notice her baby's distress and soothe the infant appropriately. Attunement does **not** require an immediate simultaneous response; it can occur even if the caregiver's reaction is slightly delayed, if it is fitting to the infant's need (Stern, 2018). Synchrony, in contrast, implies a tighter *temporal alignment* of behaviours or affect – a near-simultaneous matching that attunement alone does not demand.

Reciprocity describes the mutual give-and-take nature of interactions in which partners alternate roles (e.g. one initiates, the other responds, then vice versa). Reciprocal interactions can include both synchronous moments and asynchronous turn-taking; for example, a back-and-forth game of peekaboo is reciprocal, but each partner acts in succession rather than exactly at the same time (Bullowa, 1979). Finally, contingency refers to the degree to which one partner's behaviour is a predictable response to the other's signal. An interaction is contingent if the caregiver's action depends on the infant's preceding behaviour (such as smiling when the infant smiles). Not all contingent responses are synchronous, a response can be appropriate yet not instantaneous (Beebe et al., 2016).

Clearly delineating these terms enhances precision in research and intervention. **Synchrony** in the strict sense implies a subset of interactions that are *temporally coordinated and mutually absorbing*, whereas attunement, reciprocity, and contingency describe broader qualities of caregiver-infant engagement. For this thesis, synchrony is defined as reciprocal, temporally aligned, and affectively matched interaction between mother and infant, a definition that

inherently includes elements of attunement and reciprocity, but with an added emphasis on timing.

Another key concept is that synchrony involves multiple interrelated components or dimensions. Research has identified at least three core components of mother-infant synchrony: behavioural, affective, and physiological synchrony. *Behavioural synchrony* includes the coordination of overt actions, such as a mother and infant making eye contact and vocalizing in a coordinated turn-taking pattern, or a baby reaching for a toy just as the mother moves it, in a smoothly timed way. High behavioural synchrony (captured through micro-coding of interactions) has been linked to secure attachment and later social competence (Beebe, 2010; Feldman, 2007). *Affective synchrony* refers to the matching of emotional states between caregiver and infant – for example, shared positive affect during play, or the mother mirroring the infant's excitement or distress appropriately. When affective synchrony is strong (e.g. both partners are joyfully engaged), it supports the infant's emotion regulation and is associated with the development of empathy and emotional understanding (Feldman, 2012b; E. Tronick & Beeghly, 2011). Conversely, mismatches in emotional tone (the caregiver is anxious while the infant is calm, or vice versa) can signal or induce stress in the infant (Beebe *et al.*, 2010). *Physiological synchrony* involves the coordination of biological signals, such as heart rate or hormonal levels, between the dyad.



Figure 4 A still image extracted from video recordings depicting behavioural and affective synchrony between the first author and her infant during a naturalistic free-play session. The image captures distinct synchrony indicators, including mutual gaze, coordinated hand movements, shared attention, and positive affect, exemplifying the synchrony dimensions (behavioural and affective) detailed in section 1.3.3.

Studies show that engaged mother-infant pairs can exhibit synchronised heart rate variability and cortisol patterns, reflecting a coupling of their arousal and regulatory systems (Feldman, 2017; Leong *et al.*, 2017). This physiological coupling is thought to indicate a deep level of connection and is linked to the infant's capacity to manage stress and emotions (Feldman, 2017). These three components often occur together during moments of full synchrony, for instance, during a warm

face-to-face play interaction, mother and infant may exchange smiles and vocalisations (behavioural), share a joyful mood (affective), and have coordinated calm physiology (low stress hormones, stable heart rhythms). Understanding each dimension of synchrony is important because any one dimension alone does not capture the richness of the interaction. A dyad might be behaviourally in sync (coordinating actions) but not affectively in sync (one is frustrated, the other happy), or vice versa. The conceptual framework for this research (Figure 3) emphasizes these interlinked dimensions and acknowledges that synchrony is a *multifaceted construct*. Appreciating this complexity is crucial for measurement and for designing interventions that target the specific interaction processes needing support.

Collectively, the theoretical and conceptual foundations highlight that mother-infant synchrony is a dynamic, co-created experience. It emerges from the interplay of sensitive caregiving, infant cues, and contextual factors. When present, synchrony provides a vital context for numerous developmental processes, as discussed next. When absent or disrupted, it can be a key mechanism by which adversity undermines child outcomes. These insights set the stage for examining why synchrony matters for infant development and how it may vary across different cultural contexts. For clarity, throughout the thesis synchrony refers to reciprocal, time aligned and affectively matched interaction, attunement to appropriate but not necessarily simultaneous responsiveness, reciprocity to turn taking, and contingency to predictable responses that may be delayed, see Key Terms.

1.4.4. Importance of Synchrony for Emotional and Cognitive Development

A growing body of empirical evidence indicates that early synchrony – and the related construct of caregiver attunement – has profound effects on infants' emotional, cognitive, and social development. In terms of emotional development, synchronous interactions serve as a training ground for infants' emotion regulation. When a caregiver and infant achieve synchrony, the infant experiences periods of smoothly modulated arousal: for example, the caregiver's gentle rocking and soothing vocalisations can bring a distressed infant back to calm, synchronising the infant's affect with a more regulated state. Such experiences, repeated over time, help the infant learn to manage emotions and stress. Emotionally synchronous exchanges (especially those characterized by shared positive affect) promote the infant's developing ability to cope with challenges and are associated with greater emotional resilience (Beebe *et al.*, 2016b; Tronick & Beeghly, 2011). On the other hand, frequent mismatches – the caregiver and infant being out of sync emotionally – can contribute to an infant's heightened stress reactivity or difficulties with self-soothing. Longitudinal studies have linked disrupted synchrony in infancy to later risk of emotional disorders such as anxiety and poorer socio-emotional adjustment (Feldman, 2012c; Beebe *et al.*, 2010). Thus, synchrony appears to function as an early protective mechanism for mental health, buffering infants against the effects of stress and helping them develop healthy emotion regulation capacities.

In the cognitive domain, synchrony likewise plays a facilitative role. Synchronous interactions often involve episodes of intense joint engagement and attention, which are thought to support early learning. For instance, when a mother and infant are jointly attending to a toy in a synchronised way – the infant babbles while looking at the toy, and the mother immediately labels it or imitates the babble – this coordinated attention can enhance the infant's information

processing and language exposure. Research suggests that infants who experience higher levels of synchrony demonstrate stronger joint attention skills, earlier language acquisition, and better problem-solving abilities (Feldman, 2012a; Leong *et al.*, 2017). During synchronous play, caregivers naturally scaffold infant cognitive experiences (e.g. timing their actions to maintain the infant's interest), which may lead to improvements in infants' attentional control and memory. Over the long term, a history of rich synchronous engagement is associated with improved executive functioning and even higher academic readiness in preschool (Davis et al., 2017). The cognitive stimulation provided within synchronous interactions – such as contingent responses and prompt feedback – aligns well with how infants learn, thereby accelerating cognitive development.

Perhaps the most extensively studied outcome of early synchrony is its link to attachment security. Consistent caregiver-infant synchrony, especially when it encompasses emotional attunement, contributes directly to the formation of a secure attachment relationship (Ainsworth, 1979; Isabella & Belsky, 1991). When a caregiver regularly participates in synchronous routines with an infant (for example, a predictable bedtime song and cuddle that calms the baby each night), the infant learns to expect that the caregiver will be available and responsive. This builds a sense of security. Securely attached infants, in turn, tend to have better emotional and social outcomes later in childhood – they are more empathetic, more confident exploring their environment, and more resilient to stress. Studies have found that infants who experienced greater synchrony in early infancy were more likely to be securely attached at one year, which then predicted positive social-emotional functioning in adolescence (Sroufe, 2005). In contrast, chronically low synchrony or erratic synchrony (e.g. a caregiver who is sometimes in tune but

often disengaged) can contribute to insecure attachment patterns (avoidant, ambivalent, or disorganized), with cascading effects on the child's emotional health and relationships. In sum, synchrony and attunement are foundational to healthy socio-emotional development: they nurture the infant's capacity to form secure relationships, regulate feelings, and confidently engage with the world (Sroufe & Waters, 1977; Tabachnick et al., 2021).

Importantly, the impact of early synchrony is not fleeting, it has long-term implications for health and well-being. Longitudinal research indicates that infants who experience higher levels of synchrony go on to exhibit better outcomes well beyond the infant-toddler period. For example, one long-term study showed that qualities of mother-infant interaction at 3 months (such as mutual responsiveness and synchrony) predicted the child's social competence and emotion regulation abilities in adolescence and even into adulthood (Davis et al., 2017; Moore et al., 2015). High synchrony in infancy has been associated with lower incidence of behavioural problems and psychopathology in later life, suggesting a lasting protective effect. Conversely, early disruptions in synchrony (for instance, due to maternal postnatal depression or other adversities) have been linked to elevated risk of anxiety, attachment disturbances, and difficulties in peer relationships in later childhood (Feldman, 2017; Beebe *et al.*, 2010). In South Africa and other high-adversity contexts, there is emerging evidence that strong mother-infant synchrony can serve as a buffer against socio-economic risks. For instance, recent local studies suggest that synchrony may mitigate some negative effects of poverty and maternal stress on child development, by providing the infant with a stable, enriching relational environment (Prioreschi et al., 2023a; Tomaz et al., 2019). These findings underscore that fostering synchrony is a promising target for interventions aiming to promote resilience in vulnerable populations. By

enhancing synchrony and caregiver attunement, it may be possible to improve not only immediate developmental outcomes but also the child's longer-term trajectory in health, education, and well-being.

1.4.5. Cross-Cultural and Global Perspectives on Synchrony

While caregiver-infant synchrony appears to be a universal phenomenon, its expression and normative patterns can vary widely across cultures. Understanding cross-cultural variations is crucial for accurately assessing synchrony and for designing culturally appropriate interventions. Historically, much of the synchrony research was rooted in Euro-American contexts influenced by attachment theory, which emphasized the dyadic mother-infant bond in a nuclear family (Ainsworth, 1979; Tronick & Cohn, 1989). These early studies, including Tronick's famous Still-Face Paradigm experiments, underscored how disruptions in face-to-face synchrony (e.g. a mother suddenly becoming unresponsive) upset infants' emotional regulation. However, as the field progressed, researchers like Heidi Keller drew attention to the *WEIRD bias* in developmental science and questioned the universality of these patterns (Henrich et al., 2010; Keller, 2013). A significant limitation of the existing literature has been its predominant focus on Western middle-class samples, which may constrain generalizability (Mesman *et al.*, 2016). In fact, a review noted that until the 2010s, the vast majority of empirical studies on infant-caregiver interaction were conducted in North America or Western Europe (Keller, 2018). Figure 5 summarises this trajectory, and we interpret subsequent cross-cultural contrasts through three parameters from our synchrony model, reciprocity, temporal alignment, and affective matching.

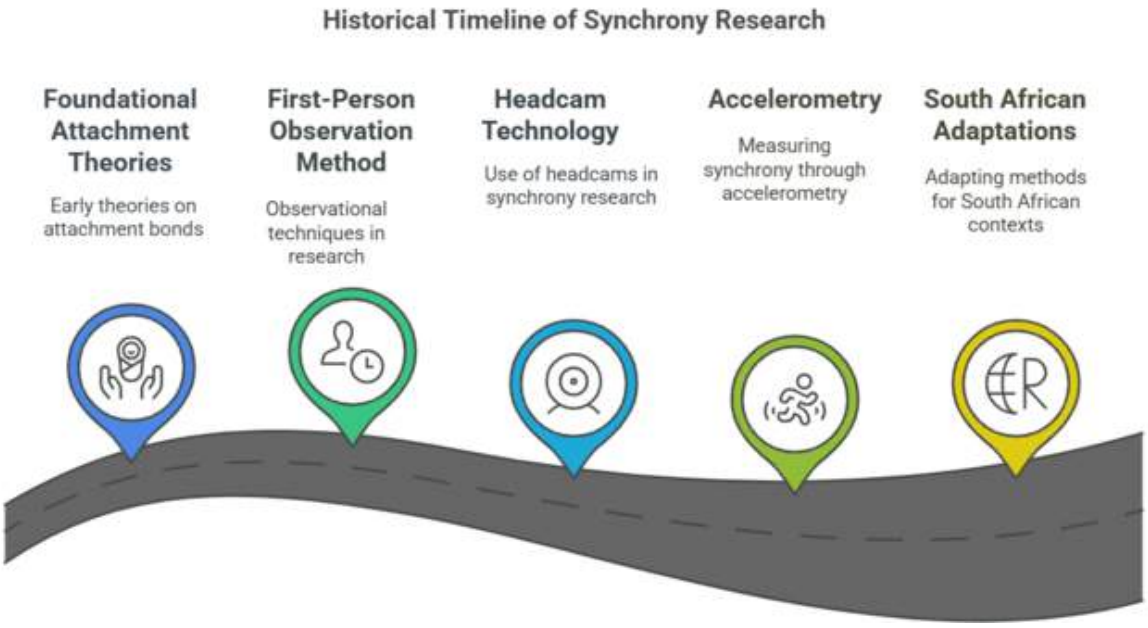


Figure 5 Timeline depicting major historical milestones in mother-infant synchrony research, tracing foundational attachment theories through contemporary methodological innovations (first-person observation, headcams, accelerometry). Special emphasis is given to advancements and adaptations within the South African research context, as discussed in Section 1.3.5.

To align cross-cultural observations with our theoretical model of synchrony, we read differences between WEIRD settings and Soweto through three parameters, reciprocity, temporal alignment, and affective matching. For reciprocity, WEIRD laboratory studies often foreground brief face to face turn taking and vocal exchange, whereas Soweto caregiving commonly involves proximal care and shared object handling in everyday tasks, which yields longer tactile, or activity based reciprocal bouts. For temporal alignment, daily routines and multi caregiver involvement in Soweto can shift the lag structure of matched behaviours, for example more mother led regulation during transport or queuing, and more infant led bids during quiet play. For affective

matching, matched affect is frequently expressed through touch and co vocalisation rather than face to face smiling alone, which has implications for coding schemes derived from WEIRD samples. This framework is used in later chapters to interpret where patterns converge with, and diverge from, reports from high income cohorts.

In many WEIRD contexts, synchrony is often conceptualized around behaviours like direct eye contact, exaggerated infant-directed speech (e.g. "motherese"), and turn-taking in vocalisations or play. These interactions usually occur in one-on-one settings with the mother as primary caregiver. For example, American and Western European parents commonly engage their infants in face-to-face play on the floor or a playmat, emphasizing *dyadic* exchange – the infant and parent focus solely on each other (Keller, 2013; Leclère et al., 2014). In such contexts, studies find a high premium on contingent responsiveness: a mother is expected to promptly respond to an infant's fuss or vocalisation with eye contact, speech or a smile, which facilitates synchrony (Beebe *et al.*, 2016a). The typical laboratory assessments (like free-play or feeding observations) in Western samples have indeed documented rich synchrony, but within a narrow cultural script. Moreover, these studies often take place in controlled environments that may not reflect the natural distractions and multi-tasking a caregiver experiences at home. Thus, although they provide detailed information on synchrony (including physiological measures in some cases), their ecological validity can be limited.

By contrast, in many LMIC and non-Western cultures, infant caregiving is embedded in broader social networks and daily routines that differ markedly from Western norms. Caregiving tends to be more communal or distributed among multiple people, including relatives and siblings

(Nsamenang, 2006; Tomlinson et al., 2005). Infants might be held or carried for much of the day, often experiencing continuous physical proximity to caregivers. For instance, in many African and South Asian settings, practices like baby-wearing, co-sleeping, and constant bodily contact are common (Barry, 2019; Keller et al., 2005.; Little et al., 2019). These contexts may foster synchrony through subtler channels – e.g. rhythmic movement or touch – rather than through face-to-face exchange. Caregivers in communal cultures might not maintain prolonged eye contact or conversation with infants as is done in the West; instead, synchrony might occur through bodily entrainment (rocking, bouncing to a rhythm, infants strapped on the caregiver's back moving together during daily chores). Even vocal interactions can differ in some communities, caregivers speak less directly to infants, but infants hear responsive *humming, clicking sounds, or songs* that align with their mood (Keller, 2013). It is important to note that these interactions are not less synchronous or responsive – they are simply expressed differently. For example, a Cameroonian Nso mother may achieve synchrony by intuitively adjusting her carrying rhythm to her infant's state, rather than by exchanging facial expressions as a Western mother might (Keller et al., 2005).

Comparative studies underscore these cultural differences in interaction style. Keller et al. (2005) famously compared German middle-class mothers (representing Western dyadic style) with rural Nso mothers in Cameroon. The German mothers showed more face-to-face gazing and object-focused play, whereas Nso mothers showed more body contact, warmth, and rhythmic soothing. Both groups of infants formed attachments, but the *pathways* to synchrony and attachment were different. Another cross-cultural study by Bornstein *et al.* (2012) observed mother-infant dyads in five countries (Argentina, Belgium, Israel, Italy, and the United States) and found variations in

how much mothers stimulated or responded to infants, corresponding to cultural values of independence vs. interdependence (Bornstein & Gov, 2012). Notably, cultures prioritizing interdependence (e.g. Kenya or rural communities) tend to engage infants in group settings with multiple caregivers and emphasize compliance and calmness, whereas individualistic cultures prioritize one-on-one engagement and infant autonomy (Bornstein & Putnick, 2012). These orientations influence synchrony – in interdependent contexts, an infant might be passed between caregivers smoothly (maintaining overall synchrony in the group), while in individualistic contexts synchrony is tightly concentrated in the mother-infant pair. Neither approach is inherently better; they are adaptive to cultural goals. What is common is that infants everywhere benefit from some form of predictable, contingent interaction, but the modalities of those interactions differ.

South Africa provides an interesting case as a country with diverse cultural groups and a mix of traditional and modern caregiving practices. Within South African communities (especially in African cultures), caregiving often involves extended family members actively participating in raising the child (Tomlinson et al., 2005; Nsamenang, 2006). A young infant might have an older sibling, aunt, or grandmother frequently in synchronous interaction with them in addition to the mother. This shared caregiving can lead to instances of "triadic" or group synchrony (e.g. mother and grandmother jointly calming a crying baby in a coordinated way). It also means that infants may experience synchrony in more varied contexts – not just quiet play time with mom, but also on the caregiver's back while she works, or during community gatherings with constant social input. Such patterns challenge Western-centric models that assume synchrony is mainly a dyadic, private phenomenon. In South Africa's communal settings, synchrony may be more about an

infant being integrated into ongoing social rhythms. For example, research in a peri-urban Xhosa community found that infants often engaged in rhythmic vocal interactions with multiple adults in social settings, suggesting a broader arena of synchronous stimulation (Nomikou et al., 2016).

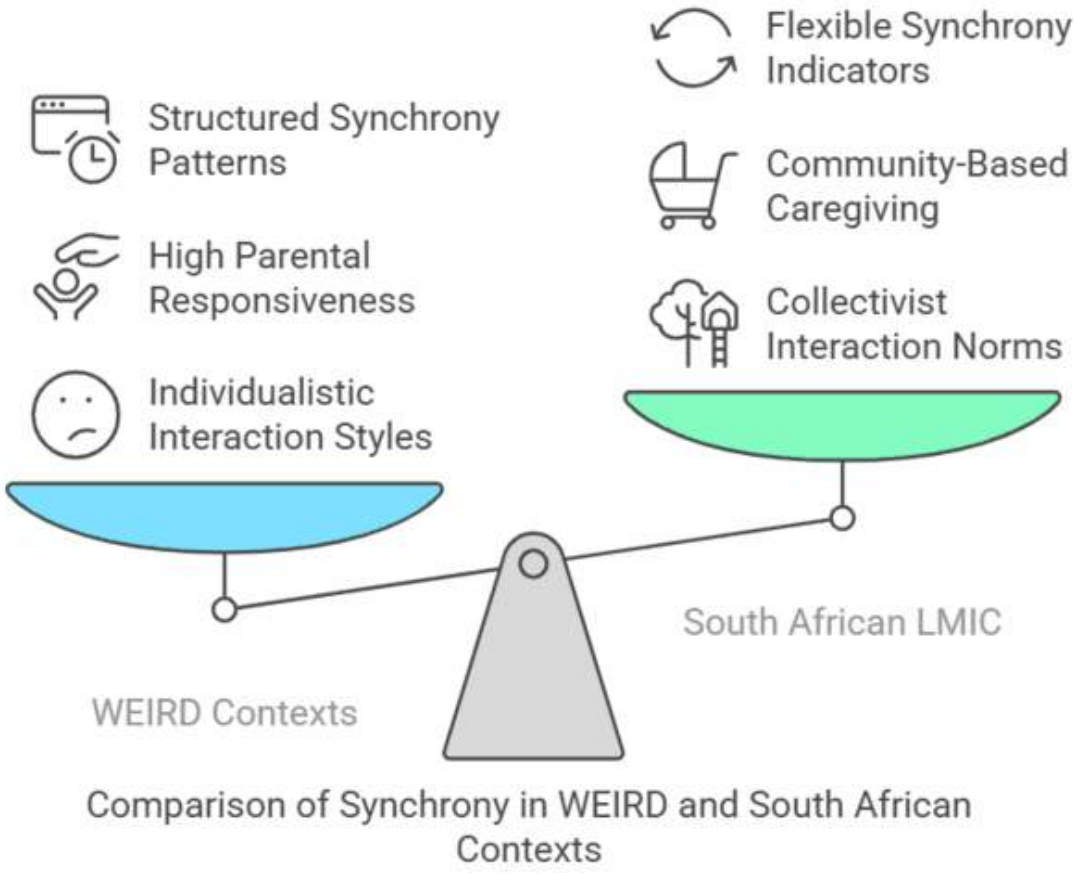


Figure 6 Comparative analysis of caregiving practices and synchrony indicators in WEIRD (Western, Educated, Industrialized, Rich, Democratic) contexts versus Low- and Middle-Income Countries (LMICs), specifically highlighting South African caregiving norms. The table emphasizes differences in interaction styles, parental responsiveness, and synchrony patterns discussed in detail in Section 1.3.5.

From a global perspective, these subtle cultural differences have methodological and practical implications. Measuring synchrony requires tools that can capture culture-specific expressions. A structured coding scheme developed in the U.S. may overlook synchrony cues important in another culture (e.g. the significance of a grandmother's clapping in time to an infant's movements). Culturally relevant studies are increasingly calling for expanding our definitions of synchrony. Mesman et al. (2016) argue that concepts like sensitivity and synchrony need to be redefined for cultures where direct parent-infant interaction is less emphasized. They advocate including behaviours like instrumental caregiving (feeding, cleaning) done in a coordinated way, or community engagement, as part of what constitutes synchrony in those contexts. Cross-cultural research also informs interventions: if we know, for instance, that in some culture's synchrony is more physical than verbal, parenting programs can encourage responsive carrying, massage, or other tactile games rather than focusing only on talking or singing.

In summary, cross-cultural evidence highlights that the essence of synchrony, timely, appropriate responses between caregiver and infant, is universal and beneficial, but the form it takes is shaped by cultural norms and caregiving ecologies. There is no one size fits all profile of 'ideal' synchrony, rather, each culture provides a range of pathways to achieve the caregiver-infant coordination that supports development. Recognising this diversity broadens our theoretical models and ensures that assessments and interventions are culturally valid. It also reinforces the notion that findings from WEIRD samples must be tested, and sometimes recalibrated, in other populations. Future research is encouraged to prioritise cross-cultural and international studies on synchrony, using ecologically valid methods (Nomikou et al., 2016; Tomaz et al., 2019). By doing so, the field can build a more inclusive science of early interactions, one that truly reflects

both universal and culture specific aspects of human development. For clarity, we operationalise reciprocity as matched mother-infant behaviours within a 3 second window using headcam codes in Study 1 (Section 2.5.2), temporal alignment as lagged associations estimated with cross-correlation in Section 2.6, and affective matching as modality specific concordance, for example touch and gaze, coded in Study 1 (Section 2.5.2).

1.4.6. The South African Context and Caregiving Practices

South Africa's socio-cultural landscape provides a unique and important context for studying mother-infant synchrony. The country faces significant socio-economic inequalities and stressors which can affect early caregiving, yet it also has rich traditions of communal childcare and resilience. Understanding synchrony here is essential for developing locally relevant early interventions.

Socioeconomic and environmental influences: Many South African families, particularly in historically disadvantaged communities (townships, rural areas), experience high rates of poverty, unemployment, and overcrowded living conditions. These factors can directly and indirectly impact caregiver-infant interactions. Economic hardship is associated with caregiver stress, depression, and fewer resources or time for stimulating play (Cooper et al., 2009; Tomlinson et al., 2005). A caregiver juggling work or household chores without support may have less capacity to engage in sustained synchronous play. Research in South Africa has documented that maternal stress and mental health issues (often tied to poverty or trauma) correlate with less responsive and more inconsistent parenting, which likely disrupts synchrony (Field, 2010); Ramokgopa et al., 2021). Moreover, issues like malnutrition or ill health can make

infants more lethargic or irritable, affecting their ability to participate in synchronous exchanges (Feldman et al., 1999).

One South African study noted that among high-risk mother-infant pairs (e.g. maternal HIV or perinatal depression), interactions were often characterized by flatter affect and less turn-taking, indicating challenges in achieving synchrony (Tomlinson et al., 2005). These findings align with global evidence that adversity can undermine the delicate *dance* of interaction. However, South African caregivers also exhibit remarkable strengths in the face of adversity – many provide warm, affectionate care and creatively include infants in daily life activities, which can promote synchrony in subtle ways (Sherr *et al.*, 2022).

Communal and cultural caregiving patterns: A defining feature of many South African communities (particularly Black African cultures) is communal caregiving. It is common for infants to be cared for by an extended network – grandmothers, aunts, neighbours, older siblings – rather than exclusively by the biological mother (Nsamenang, 2006; Madhavan & Gross, 2013). This communal approach stems from cultural values emphasizing family and community interconnectedness (*Ubuntu* philosophy). It has several implications for synchrony. First, infants often receive responsive attention from multiple sources. For example, if a mother is busy, an aunt may bounce and soothe the fussy infant, ensuring the infant's cues are not ignored. This can maintain a level of synchrony even when the mother herself is occupied. Second, infants grow accustomed to interacting with more than one partner, which might make dyadic synchrony with one specific person less pronounced at any given time – but the infant may still be experiencing a continuous responsive environment. Third, certain synchronous activities are done in group

settings: *infant playgroups* or clinic gatherings where mothers collectively sing to babies are quite common in some areas. These create opportunities for synchrony in a social setting (e.g., babies and mothers rhythmically clapping together). Traditional practices also influence synchrony.

In many South African cultures, caregivers use a lot of tactile and vestibular stimulation (like bouncing, piggy-back carrying, swaddling) to calm and engage infants (Keller, 2013; van der Walt *et al.*, 2019). These practices can generate synchrony through movement and touch. For instance, a mother carrying her baby on her back while working will naturally synchronise her steps and motions to the infant's state (adjusting her pace if the baby is sleeping vs. awake). Such interactions might not involve face-to-face contact or talking, but they reflect an attuned coordination. Additionally, culturally transmitted games (like call-and-response songs, peekaboo variants, or lap games) provide structured moments of synchrony that are passed down through generations (Ward, 1978). In Zulu and Xhosa traditions, for example, there are bouncing knee games that grandmothers play with infants, timing the bounce to the infant's laughter – a clear instance of synchrony and joy.

Existing studies in South Africa: Empirical research specifically on mother-infant synchrony in South Africa has been relatively limited, but a few studies shed light on local interaction patterns. Tomlinson et al. (2005) conducted one of the seminal studies, observing mother-infant dyads in a peri-urban South African settlement. They found that despite economic hardships, many mothers were able to engage in positive synchronous interactions with their infants, often facilitated by support from family members. The study highlighted the role of grandmothers in maintaining

interaction quality; infants whose mothers and grandmothers both participated actively in care showed more stable interaction rhythms and positive affect.

Another line of research has examined physical activity synchrony in South African mother-infant pairs. Prioreschi et al. (2018a) used accelerometers to measure how mothers' and infants' movement patterns correlated in Soweto. Interestingly, they found significant synchronisation in diurnal movement – when mothers were more active (walking, doing chores), their infants tended to be more active around the same periods, indicating a coupling of routines. This movement synchrony is a more implicit form of interaction, but it suggests that caregivers and babies in these communities fall into shared daily rhythms (perhaps because infants accompany caregivers in many activities). Additionally, Wrottesley et al. (2021a) reported that South African mothers who engaged in responsive play (even in short bursts amid other tasks) had infants with better motor and cognitive scores, implying that even moderate synchrony embedded in daily life can benefit development.

South African research also underscores the influence of factors like maternal mental health and HIV status on synchrony. Feldman et al. (1999) in a rural KwaZulu-Natal sample found that maternal depression was associated with lower levels of attunement and more disengaged infant behaviour. However, when depressed mothers had strong social support, their interactions were notably better – again pointing to communal buffering effects. In contexts of maternal HIV, some studies have observed that anxiety about the infant's health can alter interaction patterns, but interventions (like parenting workshops) have been effective in improving responsiveness (Rotheram-Borus et al., 2011). These differences highlight the need for context-specific

knowledge: factors like illness, stigma, and social support networks all intersect with how synchrony unfolds in South Africa.

Research gaps: Despite these insights, there remain critical gaps in our understanding of synchrony in the South African context. First, much of the local research to date has relied on Western-derived frameworks and observational tools, which may not fully capture indigenous interaction styles (Mesman et al., 2016). There is a need to develop or adapt measurement approaches that recognize communal caregiving dynamics – for example, coding schemes that allow for multiple caregivers, or that count rhythmic body interactions as part of synchrony.

Second, there have been few longitudinal studies following South African infants over time to see how early synchrony relates to later outcomes. Such studies would clarify the long-term impact of synchronous vs. asynchronous early relationships in this context, and whether it parallels findings elsewhere. Third, almost no research has explicitly examined paternal or other caregiver-infant synchrony (beyond mothers) in South Africa. Given the prevalence of non-maternal caregivers, understanding father-infant or grandmother-infant synchrony is an important extension. Lastly, socio-economic diversity within South Africa means that synchrony might look different in an urban middle-class family (where global media and parenting trends have influence) versus a rural village. These variations are worth exploring to inform specific intervention strategies.

In summary, South Africa's context is characterized by high adversity that can threaten caregiver-infant synchrony, but also by strong family networks and cultural practices that can

support it. The communal nature of caregiving and the integration of infants into daily life are salient features. These can be applied in interventions – for instance, involving grandmothers in programs to improve synchrony, or teaching play activities that fit into daily routines. The existing evidence, though limited, suggests that synchrony is as beneficial for South African infants as for any others, correlating with better regulation and development (Tomlinson et al., 2005; Prioreschi et al., 2023a). Therefore, fostering synchrony in this context holds promise for improving early childhood outcomes. The current research (in this thesis) directly addresses some of the gaps noted, by using innovative methods to measure synchrony in naturalistic settings and by focusing on a South African sample to generate contextually relevant data.

1.4.7. Methodological Gaps and Justification for Novel Approaches

Studying mother-infant synchrony in everyday environments poses several methodological challenges. Traditional observational methods – such as coding interactions from a corner of a room or using one stationary video camera – may not capture the full richness of natural, unstructured interactions. This is especially true in busy home settings or outdoor environments typical of many LMIC contexts, where interactions are fluid and multi-contextual. Key limitations of prior approaches include:

- **Limited observation windows:** Many classic studies rely on short observations (5–20 minutes) in lab or clinic settings. These snapshots might miss infrequent but important synchronous moments that occur throughout the day. In a home setting, a mother and infant might share a beautifully synchronous interaction during bathing or feeding which would be overlooked if the observation occurred only during playtime. There is a need

for methods that can record interactions continuously or at multiple time points to truly gauge the frequency and patterns of synchrony over a day.

- **Observer effect and context stripping:** The presence of a researcher or camera can alter caregiver behaviour (e.g. mothers may become self-conscious or try to perform "better"), potentially skewing the natural interaction. Moreover, when an interaction is pulled into a lab, it loses context – a mother in a lab might focus wholly on the infant because she's instructed to, whereas at home she would be multi-tasking. This can inflate synchrony measures in lab studies relative to real life. Methods that are more *obtrusive* or seamlessly integrated into daily life can reduce these observer effects (Nomikou et al., 2016).
- **Coarse measurement tools:** Some earlier work used global rating scales for synchrony (e.g. rating an interaction on a 1–5 scale of "sensitivity/synchrony"). While useful for broad assessments, these scales can gloss over micro-dynamics of synchrony. Two dyads might score "4" on sensitivity for very different interaction patterns. To advance understanding, more fine-grained and objective measures are needed. For example, micro-coding every instance of mutual eye gaze, or using second-by-second time-series analysis, can quantify synchrony with greater precision (Feldman, 2012a; Chetouani et al., 2017).

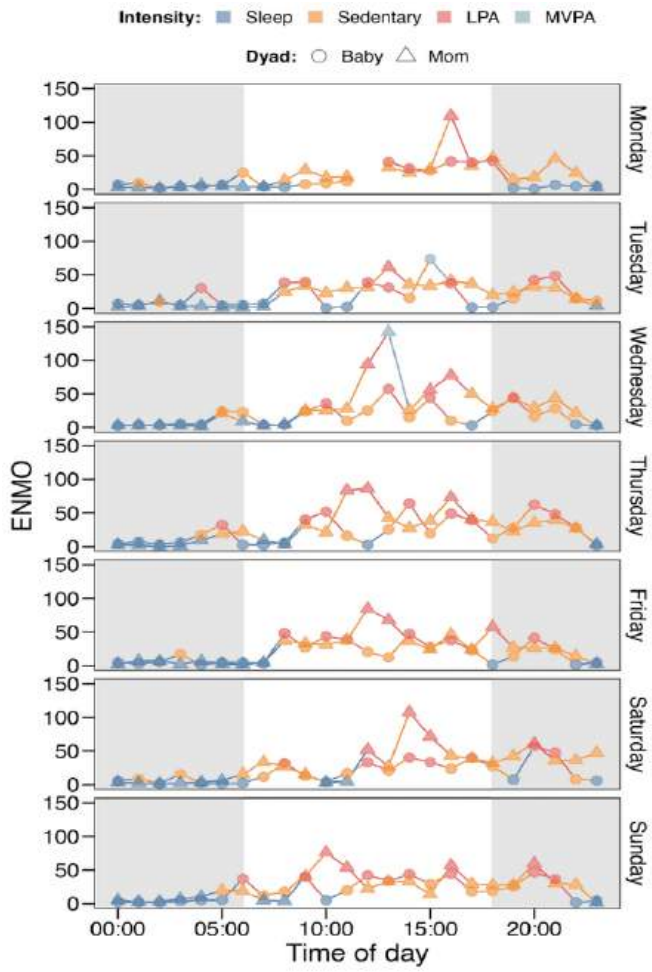


Figure 7: Time-series graphs depicting clear distinctions between synchronous and asynchronous movement patterns derived from accelerometer data in South African mother-infant dyads. Annotated examples highlight specific synchrony indicators, complementing analytical techniques discussed in detail within Section 1.3.7.

Recent technological innovations offer powerful tools to address these gaps. One approach is using first-person wearable cameras (headcams) to record exactly what the mother and infant are seeing and doing from their own perspectives. By equipping both the mother and the infant with lightweight head-mounted cameras, researchers can capture an immersive, infant's-eye and mother's-eye view of interactions throughout daily activities. This method greatly enhances

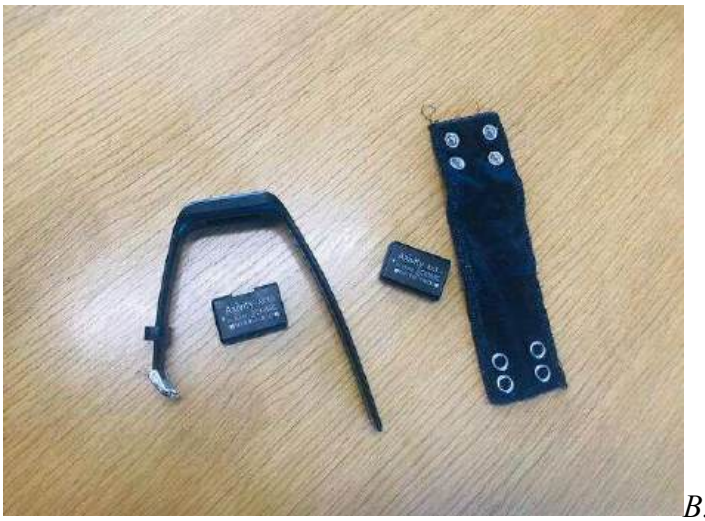
ecological validity – the dyad can be recorded in their natural setting (at home, in the yard, at the market) without a researcher present, and over longer periods. A low-cost headcam system has been evaluated for mother-infant interaction assessment in Soweto, proving acceptable and feasible for families to use (Lachman et al., 2022).

A.  *B.* 

Figure 8A: Illustration of a lightweight, wearable head-mounted camera device used to capture first-person observational data of mother-infant interactions. This device facilitates detailed recording of real-time interactive behaviours and enhances ecological validity in synchrony research, as described in section 6.0. Figure 8B: Visual demonstration of correct positioning and secure attachment of the head-mounted camera for both caregivers and infants. Proper placement ensures optimal recording angles, enabling accurate and detailed behavioural analyses of mother-infant synchrony.

By analysing synchronised first-person videos from mother and baby, one can objectively code moments of joint attention (when their gaze aligns on the same object), matching emotional expressions, or contingent actions from each partner. This provides a much more granular view of synchrony than third-person observations. Additionally, first-person video allows capture of subtle cues (slight smiles, pointing from the infant's vantage) that a fixed external camera might miss.

Another complementary innovation is the use of wearable accelerometers to measure movement synchrony. Accelerometers are small sensors (often wristwatch or pebble-sized) that continuously record movement along multiple axes. When attached to both mother and infant, they produce time-series data that can be analysed for coordinated activity bursts or rhythms. For example, a cross-correlation analysis of mother vs. infant activity signals can reveal to what extent their movements are aligned in time (Prioreschi et al., 2018b). These devices are objective and unobtrusive – a mother can wear one on her wrist and an infant on an ankle or wrist, and they simply go about their day. They are particularly useful for capturing synchrony in physical activities (walking, feeding, playing) and daily routines that might not be video recorded at all times (e.g. while the infant is in a carrier and the camera view is limited). Figure 9A below shows the Axivity AX3 accelerometer device used in this study, and Figure 9B shows the adjustable soft strap that secures the accelerometer on an infant's wrist or ankle. When properly placed, as in Figure 8B, the device comfortably measures the acceleration of the limb, allowing precise quantification of movement intensity, frequency, and timing for both partners.



B.



Figure 9A: An illustrative image of the Axivity AX3 wrist-worn accelerometer devices used in this study. These devices objectively quantify movement behaviours, enabling precise measurement of intensity, frequency, duration, and synchrony of movements between mothers and infants, as discussed in Section 6. Figure 9B: Demonstration of the adjustable straps specifically designed for securely and comfortably fitting Axivity AX3 accelerometers on mothers and infants. Proper placement of these devices ensures accurate, consistent, and high-quality data collection during naturalistic daily interactions.

By integrating first-person observation and accelerometry, the present research employs a novel multimodal approach. Each method compensates for the other's limitations: headcam video excels at capturing social and emotional cues but might not quantify subtle movement synchrony, while accelerometers quantitatively capture movement coordination even when video is not clear (Nomikou et al., 2016; Leclère et al., 2014). Together, they provide a robust picture of synchrony across both behavioural (visual, social) and physical domains. This kind of data integration is at the cutting edge of synchrony research. Recent international studies have begun to combine wearable sensors and video to examine parent-infant interaction in real-life settings, finding that

such multimodal data significantly enhance the detection of synchrony compared to single-mode data (Bruijns et al., 2020; Lee et al., 2017). In LMIC contexts, these technologies have been shown to be feasible and acceptable when adapted appropriately. For instance, a study in Uganda successfully used headcams with mothers in a rural village and found that community engagement and clear communication about the device were key to acceptance (Kohrt et al., 2019). In South Africa, Wrottesley et al. (2021a) reported that mothers were generally willing to use wearable devices for research when the purpose was explained, and they often became interested in the feedback about their infant's activity patterns.

Of course, introducing technology into homes is not without challenges. Potential issues include device affordability, data storage and management (hours of video generate huge amounts of data), and ensuring participant privacy (Nomikou et al., 2016). Ethical protocols must be in place, for example to manage video that incidentally captures other people or sensitive situations. In this study, we addressed these by using encrypted devices, obtaining extensive informed consent (and assent from any others in the home on video), and allowing participants to review or delete any recordings they were not comfortable sharing. The benefits of using these tools, however, are considerable. They enable quantitative analysis of synchrony with high temporal resolution. For example, we can calculate the percentage of time a mother-infant pair is in synchrony over an hour or examine whether synchrony tends to occur during certain routines (feeding vs play) more than others. We can also explore micro-patterns, such as typical lag times between a mother's action and the infant's reaction, across many interactions. Such detailed analyses were not feasible with older methods.

In sum, the use of first-person head-mounted cameras and accelerometers represents a methodological advancement that is well-justified to fill the gaps identified. These approaches allow us to overcome previous limitations by capturing naturalistic, continuous, and fine-grained data on mother-infant synchrony in a South African setting. The conceptual framework of this thesis (Figure 3 in Section 1.4.3) illustrates how these methods come together: headcam and accelerometer data streams are synchronised and analysed to give a multidimensional assessment of interaction. Embracing these novel tools positions this research at the forefront of a more ecologically valid and culturally sensitive study of synchrony, generating insights that would be inaccessible through traditional techniques.

1.5. Chapter Summary

In summary, the literature highlights that while synchrony is a central mechanism supporting infant development, most existing evidence comes from WEIRD contexts, limiting generalisability. Furthermore, traditional methods may not capture synchrony as it naturally unfolds in daily life. This chapter therefore establishes the conceptual and methodological gaps that the current thesis addresses through multimodal approaches in a South African context.

CHAPTER TWO: METHODS

2.0. Chapter Overview

This chapter outlines the methods used to investigate mother-infant synchrony. It begins by describing the study design, setting, and participant recruitment, followed by ethical considerations. Detailed procedures for each of the three component studies are presented, including headcam-based behavioural observation, accelerometry, and longitudinal analyses. The chapter concludes with a description of the analytical strategies and data management processes applied.

2.1. Study Design and Setting

This research is embedded within the Play Love and You (PLAY) Study, a randomised controlled trial (RCT) conducted in Soweto, Johannesburg, South Africa. Soweto, located in Region D of the City of Johannesburg, is a large urban township shaped by apartheid-era spatial planning, and today comprises densely settled neighbourhoods with a strong civic identity (Encyclopaedia Britannica, 2025; Ngalokhulu, 2018). Primary care is delivered through a network of municipal clinics, and the area is served by Chris Hani Baragwanath Academic Hospital, one of the largest public hospitals in the world (The Chris Hani Baragwanath Hospital, 2025)Households are linguistically diverse, with isiZulu the most common home language in the province (Khanyile & Ballard, 2022). Many families face persistent socioeconomic challenges, including high

unemployment and concentrated disadvantage in township and informal settlement areas (Worku, 2023).

The PLAY Study aimed to strengthen early child development by promoting responsive caregiving and enhancing maternal self-efficacy through structured behavioural feedback and play-based sessions with mothers (Prioreschi et al., 2023). It enrolled a longitudinal cohort of mother–infant dyads and applied both quantitative and qualitative methods to evaluate early caregiving practices. Recruitment was conducted through public community clinics in Soweto. Given the predominance of WEIRD samples in the synchrony literature, we interpret contrasts with high-income cohorts as external validity checks rather than assumptions of equivalence. A strength of the PLAY Study is its ecological validity, as observations and sensor-based measures were collected in routine home and clinic settings with minimal disruption to caregiving routines. This ensured synchrony was measured as it occurred naturally in Soweto, rather than in laboratory simulations. In this context, synchrony typically took the form of responsive touch, shared object handling, carrying, and short play bouts, which were effectively captured by in situ observation.

The present thesis draws on two complementary datasets from the PLAY Study: a formative pilot conducted through a Community Advisory Group (CAG) and the main RCT. The CAG, established at study inception, guided protocol development, ensured cultural acceptability, and strengthened local engagement (Wrottesley et al., 2021). It also served as a pilot platform to test novel tools such as head-mounted video cameras (headcams) and accelerometry for capturing naturalistic mother–infant interactions at home. Data from this pilot (n = 14 dyads) were

analysed independently and form the basis of Study 1, which examined behavioural synchrony at a single time point. The main RCT dataset followed dyads longitudinally at 4 and 8 months postpartum, incorporating both headcam and accelerometry measures. While the pilot and main datasets were interpreted separately, the use of harmonised protocols across both enhanced methodological consistency and strengthened external validity.

Data from both the pilot (CAG) and main trial were used to inform the three integrated sub-studies comprising this PhD research:

- **Study 1:** A cross-sectional behavioural study using first-person headcam footage to quantify micro-level synchrony.
- **Study 2:** An observational study using wrist-worn accelerometers to assess movement synchrony over a full 7-day period.
- **Study 3:** A longitudinal study evaluating developmental changes in synchrony and their predictors, combining both data modalities at two timepoints (4 and 8 months postpartum).

All research activities were carried out in participants' homes, reflecting real-world caregiving contexts in a historically disadvantaged, low-resource urban township.

2.2.Participant Recruitment and Eligibility Criteria

Participants were recruited from two sources. The population of reference was mothers and infants attending public primary healthcare services in Soweto. First, the Community Advisory Group (CAG) pilot, May to July 2022, purposively recruited dyads to reflect a range of caregiving contexts, contact was made in clinic waiting areas, via community noticeboards, and

by word of mouth, with screening by trained research assistants. Secondly, the main PLAY Study RCT, May to October 2023, enrolled dyads at public community clinics during routine postnatal visits, where research assistants verified eligibility from the Road to Health booklet, confirmed Soweto residency, and invited consent. CAG pilot participants formed a separate, non-overlapping cohort. No CAG dyads enrolled in the main PLAY RCT. Participant flow, including numbers screened, ineligible with reasons, declined, enrolled, device refusals, and losses to follow-up at 4 and 8 months, is shown in Figure 2.1 (main PLAY cohort). Figure 2.1 provides the counts needed to understand rejections and losses to follow up for the main study and is used when discussing external validity.

2.2.1. Study flow and sample derivation, main PLAY cohort

The PLAY Study recruited 150 mother infant dyads at the 4-month visit. For the accelerometry sub study, 20 Axivity AX3 devices were prepared, 8 failed pre deployment quality control, leaving 12 functional units. These were rotated across participants and deployed to 78 dyads. Of these, 66 dyads, 85 percent, returned usable paired mother infant files. After file level quality control, paired files, at least 5 full wear days, stable timestamps, successful download and calibration, no major artefacts, 5 dyads were excluded for missing data, mother n = 2, infant n = 3, and 1 dyad for insufficient wear, fewer than 4 days. The final synchrony analytical sample was 62 dyads. The headcam pilot subsample, Study 1, comprised 14 dyads at 4 months. Headcam footage in Study 3 was used only for contextual illustration and was not pooled with accelerometry.

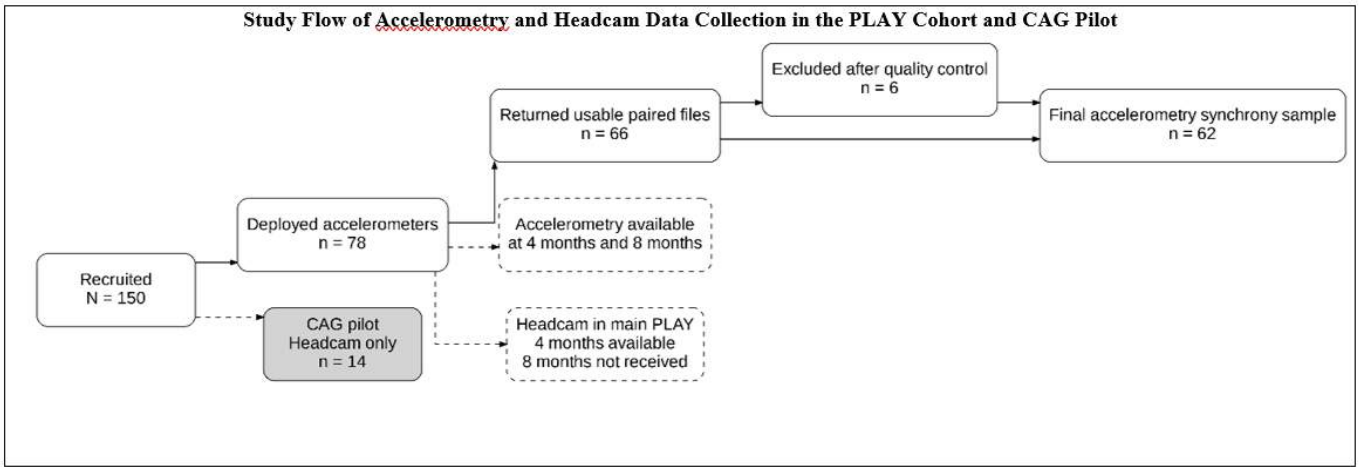


Figure 2.1. Study flow of screening, enrolment, device deployment, quality control, and analytical sample, main PLAY cohort.

2.2.2. Sampling frame and external validity

The analytical sample is not a random population sample. Enrolment occurred among clinic attending dyads at the 4 month visit and device wear required caregiver acceptance. As a result, the analytical sample likely over represents families who attend routine care and who tolerate wearable use and underrepresents non-attenders and households with unstable schedules. Findings are therefore most generalisable to similar urban, clinic attending LMIC settings. Attrition and exclusions are detailed in Figure 2.1B and are used to assess and explain differences between the analytical sample and the source population when discussing external validity.

Population of reference and recruitment procedures. The reference population comprised mothers and infants attending public primary healthcare services in Soweto. In the CAG pilot (May to July 2022), mothers were approached in clinic waiting areas and by word of mouth, with

in person screening by trained research assistants. In the main PLAY RCT (May to October 2023), mothers were approached during routine postnatal visits at public community clinics; eligibility was verified from the Road to Health booklet and Soweto residency, and consent was taken on site.

Eligibility criteria were identical for both cohorts and comprised: mothers aged 18 years or older; residency in Soweto; and infants aged between 0 and 5 months at baseline. Dyads were excluded if the infant had been born preterm (<37 weeks gestation), had any congenital anomaly or developmental disability, or if the mother had a serious mental health condition requiring inpatient care. Only mothers who consented to both behavioural video recording and movement tracking were enrolled for the PhD sub-studies.

Participants provided written informed consent for each component of data collection. In the case of headcam recordings, additional consent was obtained for the use of visual data in scientific presentations or publications.

2.3.Ethical Considerations

Ethical approval for all procedures was granted by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand. The CAG pilot was approved under protocol number M210846. The main PLAY Study RCT received approval under protocol M220217, while the PhD-specific(Harris et al., 2009, 2019) longitudinal sub-studies were approved under protocol M220785.

All procedures adhered to the ethical principles of the Declaration of Helsinki. Participants were informed of the voluntary nature of the study and their right to withdraw at any point without consequence. Video footage was anonymised through careful de-identification, and all raw files were stored on secure university servers with restricted access. Ethical protocols also ensured that no third parties, such as household members or other children, were visible in the final analysed video frames. Participants could pause or stop recording at any time, review their footage, and request deletion of any segment, although no deletion requests were made, and any such requests would have been honoured and logged prior to analysis, with no identifiable images reproduced in this thesis.

2.4.Demographic and Background Data Collection

Upon enrolment, detailed demographic information was collected from each mother using structured questionnaires administered by trained research assistants in the participant's preferred language. Variables included maternal age, highest education level, employment status, marital status, household size and composition, and access to basic amenities such as electricity, water, and child support grants.

Infant data were also collected, including age in weeks, sex, birth weight, immunisation status, and feeding practices. Maternal reports of antenatal care attendance and postpartum support were included as contextual variables. All data were entered directly into REDCap®, a secure electronic data capture tool hosted by the University of the Witwatersrand (Harris et al., 2009, 2019), with regular checks conducted for missing or inconsistent data.

Variable operationalisation, overview. All variables were pre specified with explicit coding rules to support reproducible derivations and merges across studies. Time varying measures, headcam events and accelerometry epochs, were stored with harmonised timestamps to allow join by time operations. Static covariates, demographics and background, were stored as labelled factors or numeric values with a documented value map.

Demographic variables, coding. Maternal age, years, numeric. Education, primary, secondary, tertiary. Employment, employed, unemployed, informal, student. Marital status, single, married, cohabiting, separated or divorced. Household size, integer, count of usual residents. Household composition, number of adults, number of children. Basic amenities, electricity yes or no, piped water yes or no, flush toilet yes or no. Child support grant, receives yes or no. Infant age, weeks, numeric. Infant sex, male or female. Birth weight, grams, numeric. These variables were used for descriptive profiling and as covariates in regression models as relevant to each study.

2.5. Study 1: Headcam-Based Observation of Non-Verbal Synchrony

To measure behavioural synchrony in ecologically valid settings, mother infant dyads wore head mounted video cameras, headcams, during naturalistic free play, Wrottesley et al., 2021. Devices were lightweight and unobtrusive, secured with adjustable fabric headbands. Mothers and infants recorded concurrently, which enabled dual perspective footage that was later synchronised for analysis.

Headcam hardware and limitations. We used lightweight head mounted micro cameras on soft elastic headbands. Devices recorded colour video with audio at standard definition or higher,

720p or higher, 30 frames per second or higher, with onboard storage. Common limitations included occlusion from caregiver movement or infant proximity, low light noise, motion blur during fast movements, and finite battery life. These constraints motivated short clips of about 5 minutes. We mitigated issues through positioning guidance, brief practice clips, and routine quality checks, although ambient lighting and visibility gaps sometimes reduced the proportion of scorable frames.

Mothers were instructed to conduct three unstructured free-play sessions, each lasting approximately 5 minutes, over a 3-day period. Free play was not scripted or directed by the researchers; rather, mothers were encouraged to interact with their infants as they normally would during daily caregiving routines. Fieldworkers demonstrated camera usage, provided hands-on guidance, and answered any questions during home visits. Written pictorial instructions were also provided.

Video recordings were reviewed for quality and content. Videos were excluded if they were less than 2 minutes in length, lacked visibility of the infant's face, or had excessive background interference. All acceptable videos were synchronised using Adobe Premiere Pro based on audio waveforms and visual cues. Each synchronised video was rendered in a split-screen format to facilitate side-by-side coding of mother and infant behaviours.

Behavioural micro coding, definitions and modifiers. Unit of analysis, event-based codes with onset and offset timestamps at 1 second resolution in Observer XT 16.0. Core behaviours and states, Touch, any visible manual contact by the coded actor with infant, mother, or object, touch

yes or no. Modifiers, initiator mother or infant, target partner or object, hand left or right. Gaze, eyes oriented to the partner's face, states gaze partner, gaze away, occluded, modifier, direction to partner or away. Hand movement, reaching without contact toward partner or object, reach yes or no, modifier, target partner or object. Play, object or social play marked by active manipulation or a shared routine, for example peek a boo or rhythmic rocking, states play evident or not evident, modifier, object involvement recorded when visible. When the relevant body part or face was not visible, not possible to code was assigned.

Derived variables and time alignment. Frequency equals count of events per behaviour. Duration equals sum of event durations; mean duration equals duration divided by frequency. Leader or follower equals initiator of the initial event in a behaviour pair. Behavioural synchrony equals a response event by the partner within 3, 5, or 7 seconds of an initial event. Synchronous duration equals the overlap, the minimum of paired durations. Probability of response equals transitions from an initial behaviour to a specified response divided by all transitions from that initial behaviour. For synchrony, event tables were rendered to a second-by-second raster and initial, response pairs were matched within the specified windows. Inter rater reliability after drift checks and reconciliation, kappa at least 0.80.

A detailed behavioural coding scheme was developed based on existing frameworks and tailored to this specific population (Beebe et al., 2010; Costantini et al., 2021). Five core behaviours were identified: gaze, touch, hand movement, and play. Each behaviour was defined with operational criteria and time-stamped using Observer XT 16.0 (Noldus Information Technology, 2020). Behaviours were categorised as mother-initiated, infant-initiated, or simultaneous, and synchrony

was defined based on co-occurrence within 3, 5, or 7 second windows (Chorney et al., 2010). Coding reliability was confirmed through double coding of 20% of videos, with inter-rater agreement above 0.85 (Cohen, 2012). Terminology note, synchrony denotes reciprocal, time aligned and affectively matched interaction, attunement denotes appropriate but not necessarily simultaneous responsiveness, reciprocity denotes turn taking, and contingency denotes predictable responses that may be delayed. Physiological synchrony is discussed conceptually only in this thesis, see Key Terms.

2.6. Study 2: Movement Synchrony Using Accelerometry

To objectively quantify mother-infant movement synchrony, Axivity AX3 tri-axial accelerometers were used. These devices are compact, waterproof, and validated for capturing physical activity in both infants and adults (Doherty et al., 2017). Each device was configured using OMGUI software to record continuously at 100 Hz and timestamped to ensure data alignment.

Devices were placed on the non-dominant wrist of the mother and the left wrist of the infant using adjustable wristbands. Participants were asked to wear the device continuously for seven days, including during sleep, removing only for bathing or where safety was a concern. Fieldworkers provided verbal demonstrations and written guides with illustrations.

Upon retrieval, raw data files were converted to .wav format and processed using the GGIR package in R (van Hees et al., 2013). Processing steps included auto-calibration, non-wear time detection, epoch generation, and derivation of ENMO (Euclidean Norm Minus One) which is an

accepted metric of raw acceleration (van Hees et al., 2013). Valid data were defined as having at least five days of recordings with a minimum of 13 hours of wear per day.

What the data look like. Each device produced a continuous time series of raw triaxial acceleration at 100 Hz, dynamic range ±8 g, which was processed in GGIR to ENMO in mg, 5 second epochs, with non-wear masked. Daily ENMO profiles show low amplitude segments, quiet holding or sleep, and higher amplitude bursts, play or caregiving transitions.

Operational indices. High activity thresholds were set per participant at the 75th percentile of ENMO, mother and infant separately. Co active windows were epochs where both partners exceeded these thresholds. Movement synchrony was summarised using, Rolling correlation, 10-minute window, short term Pearson r over time. Cross correlation, lags within ±5 minutes, recording peak r and best lag, negative lag indicates mother leads, positive lag indicates infant leads. Summary indices, mean synchrony score, average r, proportion of time with high synchrony, r greater than 0.50, and directionality, the distribution of best lags. Analytic tables contained aligned timestamps with derived fields for high activity and synchrony indices for both partners.

Movement synchrony was assessed using time-series techniques such as cross-correlation functions (CCF), dynamic time warping (DTW), and wavelet coherence (Chetouani et al., 2017; Ramseyer & Tschacher, 2011). These methods evaluated the strength and timing of alignment between mother and infant activity throughout the day, including circadian synchrony across sleep and wake cycles.

2.7.Study 3: Longitudinal Patterns and Predictors of Synchrony

This study integrated data from dyads who participated in both time points of the main trial, with synchrony data collected at 4 and 8 months postnatally. The objective was to evaluate changes in synchrony over time and identify predictors such as maternal employment, infant sex, and caregiving context.

Synchrony trajectories were examined using multilevel models that accounted for within-dyad clustering (Chow et al., 2010; Yu & Smith, 2013). The analysis explored whether synchrony remained stable over time and whether external factors influenced synchrony levels or leader-follower dynamics. Data were summarised using descriptive statistics, intraclass correlation coefficients (ICCs), and regression estimates from timepoint comparisons. Where headcam and accelerometry suggested different patterns, we inspected short windows around salient events and applied windowed cross correlation with lag scanning, with manual checks of coding onsets and offsets to ensure temporal alignment, and we interpreted results from signal dynamics and coded behaviours because activity type was not coded.

It is important to note that these longitudinal analyses were conducted within the context of a randomized controlled trial. While the intervention arm was not analysed separately in this thesis, exposure to an early caregiving programme may have influenced synchrony outcomes, particularly by enhancing maternal responsiveness. This potential influence is acknowledged as a contextual factor when interpreting the results.

2.8.Analytical Strategy

Behavioural synchrony data from headcam footage were analysed using descriptive and inferential statistics. Synchrony was operationalised as the frequency and duration of matched or complementary behaviours within pre-defined time windows. Directional synchrony (e.g., maternal leading or infant responding) was calculated using lag-lead sequencing and transition probabilities. For regression analyses we assumed linearity and homoscedasticity of residuals, normally distributed random effects, and conditional independence within dyads, which we checked using residual plots and QQ inspection. Missing observations were handled by analysing all available episodes with listwise exclusion at the observation level under a missing at random assumption, no imputation was used.

Accelerometer data were processed using dynamic time warping, cross-correlation, and multiscale entropy analysis to characterise movement synchrony. Time series were aligned to evaluate moment-to-moment matching of activity levels. Wavelet coherence was used to detect synchrony across multiple timescales (Chetouani et al., 2017). When integrating modalities, discrepancies were resolved by aligning event windows and interpreting lead lag structure using windowed cross correlation after manual checks of coding boundaries, without reference to activity labels. Signals were resampled to 1 second epochs and z scored within dyad before analysis to enable partner comparison, and segments identified as non-wear or missing were masked and excluded from pairwise computations. Although devices recorded continuously, analyses in this thesis focused on diurnal synchrony, nocturnal periods were available but were not modelled. Leader follower directionality was defined from the sign and lag of the cross-correlation peak, with positive lag indicating maternal lead and negative lag indicating infant

lead, and stability was examined by summarising lag signs across contiguous 5-minute segments at each timepoint.

All regression modelling was conducted in R using the lme4 package (Bates et al., 2015; R Core Team, 2016). Fixed effects included contextual predictors, while random intercepts were included to account for clustering within dyads. Significance was set at $p < 0.05$, and model diagnostics included checks for residual normality and multicollinearity. Software versions and full model formulae are listed in Appendix A, Statistical Methods and Reproducibility Notes, together with brief, line referenced pointers to the analysis scripts.

2.9.Data Management and Confidentiality

All data were stored on encrypted servers maintained by the University of the Witwatersrand. Participants' data were identified using unique ID codes, and all visual files were de-identified prior to analysis. Access to identifiable information was restricted to approved personnel. Video and accelerometry files were stored separately from participant information. Ethical protocols ensured full compliance with national data protection guidelines, and all analysis outputs were shared in aggregate form without reference to individual identities. Data access and sharing, De identified accelerometry time series at 1 second epochs with non-wear masked, headcam annotation files with event codes and timings, codebooks, and the analysis scripts will be made available under controlled access after a short publishing embargo. Requests will be submitted via the project and University Library websites and reviewed by the study leadership, with release subject to ethics approval and a data use agreement. Raw headcam video cannot be fully anonymised and will not be shared publicly; it will be archived on secure university servers

with staged access to protect participants. Shared resources will support replication and secondary analysis and can inform intervention design by identifying daily windows when synchrony is more likely and by providing simple monitoring indicators for programme evaluation. Headcam event logs and accelerometry epochs were stored in long format with harmonised timestamps to permit join by time operations for synchrony derivations.

2.10. Chapter Summary

In conclusion, the methodological approach combined naturalistic first-person observation with objective accelerometry, supported by robust statistical analysis. This design ensured both ecological validity and analytical precision, providing a strong basis for addressing the thesis objectives.

CHAPTER THREE: RESULTS

3.1. Introduction to the Chapter

This chapter presents the core empirical findings of the thesis in the form of three standalone manuscripts. Each paper addresses a distinct but complementary objective aligned with the overarching aim of this PhD: to examine mother-infant behavioural and movement synchrony in the first year of life using novel, multimodal methods within a South African context.

The three manuscripts reflect a staged research process, drawing on data collected through the pilot Community Advisory Group (CAG) study and the main Play Love And You (PLAY) Study randomized controlled trial:

- **Manuscript 1** explores micro-level non-verbal synchrony between mothers and their infants using first-person head-mounted camera footage captured during free-play interactions
- **Manuscript 2** investigates diurnal movement synchrony in mother-infant dyads using wrist-worn accelerometers, with attention to temporal dynamics and patterns of alignment.
- **Manuscript 3** provides a longitudinal analysis of synchrony at two key developmental timepoints (4 and 8 months postpartum), focusing on predictors of synchrony trajectories over time.

Each manuscript is written in a format suitable for peer-reviewed publication and includes its own introduction, methods summary, results, and discussion sections. Methodological detail common to all three studies has been presented in Chapter 2 and is therefore only briefly summarised within each paper.

At the time of submission of this thesis:

- **Manuscript 1** was rejected from the Journal of Non-verbal behaviours and is currently being prepared for resubmitted in the journal of Infant and Child Development.
- **Manuscripts 2 and 3** are ready for submission manuscripts and will be submitted to relevant peer-reviewed journals in the fields of developmental science, behavioural medicine, or maternal and child health.

Below are the three interconnected studies. Section 3.2 reports behavioural synchrony findings from headcam footage, Section 3.3 describes movement synchrony derived from accelerometry, and Section 3.4 integrates longitudinal analyses combining both modalities. Each section includes descriptive summaries, statistical outputs, and key patterns of synchrony.

3.2. Study 1 Behavioural synchrony (Headcam)

Determining synchrony of mother-infant non-verbal behaviours using first-person observation

Dumsile Maduna[1*], Lukhanyo H. Nyati[1,2], Alessandra Prioreschi[1], Rebecca M Pearson[3], Ansuyah Magan[1], Ian Nabney[4]

Author affiliations

[1]SAMRC/Wits Developmental Pathways for Health Research Unit, Department of Paediatrics and Child Health, Faculty of Health Sciences, School of Clinical Medicine, University of the Witwatersrand, Johannesburg, South Africa. [2]Interprofessional Education Unit, Faculty of Health Sciences, University of the Western Cape, South Africa. [3]Department of Psychology, Manchester Metropolitan University. United Kingdom. [4]School of Engineering Mathematics and Technology, University of Bristol. United Kingdom.

Correspondence to Dumsile Maduna; dumsilesdmaduna@gmail.com

Abstract

Non-verbal synchrony, including shared gaze, coordinated touch, facial mirroring, and play, shapes early development in everyday caregiving contexts.

Aim: To explore patterns of expression, frequency, and synchrony of mother-infant non-verbal behaviours using first-person observation and accelerometry in Soweto, South Africa.

Methods: Fourteen mother-infant dyads, infants aged 1 to 5 months, were recruited via a Community Advisory Group. Recordings took place at home during free play or routine care without prompts. Each dyad captured three five-minute segments across three days between May and July 2022. Videos were coded second by second in The Observer XT 16.0 for gaze, touch, reaching, and play, with inter-rater reliability above 0.80. Synchrony was defined a priori as co-occurrence within 3, 5, and 7 second windows. We observed 26 behaviour pairs, 10 matching and 16 non-matching, and used multilevel linear regression to explore leader-follower dynamics, with full outputs reported elsewhere.

Key findings: Gaze was the most frequent individual behaviour, while play had the longest duration. Gaze synchrony was most frequent for mother-initiated (median 7, IQR 2 -19) and infant-initiated (median 6, IQR 3 -16). Infant play with mother play showed higher probability at 3 and 5 seconds than at 7 seconds (conditional probabilities 0.14, 0.10, and 0.10). For gaze, frequencies increased from 3 to 7 seconds, and conditional probability rose from 0.20 to 0.25. Most pairs were positively correlated.

Conclusion: Frequent gaze synchrony, long play durations, and greater coordination at wider windows characterise early interactions in this pilot.

Keywords: synchrony, mother-infant interactions, non-verbal, behaviours, headcam, South Africa.

Introduction

The risk of poor child development remains a major health challenge in low- and middle-income countries (LMICs) such as South Africa. It is estimated that approximately 40% of the world's children below the age of five will reside in Africa by 2050 (Guerrera, 2015). However, more than half of the children in these LMICs are currently exposed to adverse environmental factors, from conception to early childhood, which may compromise their developmental trajectories (Jamieson et al., 2017; Martin, 2020). Consequently, mothers as primary caregivers play a crucial role in mitigating these effects by providing stimulation and serving as models for emotional and cognitive learning (Mackay et al., 2022; Pedersen et al., 2019). Responsive caregiving and non-verbal synchrony are crucial aspects of parent-child relationships that contribute to the optimal emotional, behavioural, psychological, and social development of the child learning (Mackay et al., 2022; Pedersen et al., 2019). Specifically, non-verbal synchrony plays a key role in shaping the quality of mother-infant interactions and fostering secure attachment (Cohen, 2012; Feldman, 2016).

Frequent synchronous interactions are critical for the infant's psycho-social development, and these short episodes of face-to-face play allow infants to co-construct positive arousal with their parents (Feldman, 2007). This environment accelerates the development of relational skills and fosters self-regulation and social fittedness (Feldman, 2003), through the development of co-regulatory experiences and achievement of mutual synchrony (Feldman, 2007). Free play is unstructured, child led interaction within everyday routines, it is commonly used to index caregiver responsiveness and early coordination, and it is associated with socio emotional,

language, and attentional development (Ginsburg et al., 2007; Lillard et al., 2013; Tamis-LeMonda & Bornstein, 2002)

Synchrony involves more than just simultaneous behaviour—it reflects a caregiver's ability to attune and respond to their infant's cues in real-time. For example, a mother gently rocking her infant in response to fussing represents an adaptive, synchronised interaction grounded in everyday experience.

Historically, methods of measuring mother-infant have often relied on third-person observation techniques (Albinali et al., 2009). In the third-person point of view, the mother-infant interactions are observed or filmed by an external observer such as a trained researcher in a clinical, research, or home setting (Lee et al., 2017). These methods can sometimes lack precision due to observer bias or limited viewpoints. More recently, the use of first-person observation has been investigated using small cameras attached to specially designed headbands worn by both mothers and infants during their interaction (Lee et al., 2017; Prioreschi et al., 2023; Wrottesley et al., 2021). Given that definitions of synchrony are based on high-income countries (Abu Salih et al., 2023; Giusti et al., 2018; Rocha et al., 2020), there is a need for data using newer methods in LMICs. Therefore, the aims of this study from a middle-income country perspective were: 1) to conduct a second-by-second coding of specific mother-infant micro-behaviours, specifically touch as touch, hand movement, gaze and play using an event-based coding framework specifically developed for mother-infant interactions; 2) to identify and characterize the synchrony of touch, gaze and play for mother-infant dyads: 3) To analyse the dynamics of

synchrony by determining the timing, frequency, probability, duration, strength, and the leader-follower relationship of these mother-infant interactions.

Methods

Study setting and participants.

This study involved quantitative analysis of video data from a pilot study that established and developed a Community Advisory Group (CAG) in Soweto, Johannesburg, South Africa. The purpose of the CAG was to inform the development of the PLAY Study trial, which aimed to promote infant development through increasing maternal self-efficacy using behavioural feedback, and supportive interventions (Prioreschi et al., 2023). The CAG was developed to collect quantitative and qualitative data in order to provide insight into the drivers, barriers, and facilitators of responsive caregiving in the sampled community. In this regard, specific focus was accorded to mother-infant interactions, developmentally and contextually appropriate play, as well as breastfeeding. The participant inclusion criteria were women older than 18 years of age who had a child aged between 0 and 4 months and resided in the Soweto area. For this study, headcam data were collected from fourteen (14) mother-infant dyads from the CAG. For the present analysis we use only the headcam pilot dataset generated within the CAG, which served to test procedures and describe patterns, the CAG was a standalone sample that informed Study 1 only. Participants agreed to be involved in the study, and that their headcam video footage could be collected and shared with colleagues for analysis by signing a written consent form (Wrottesley et al., 2021). This study was approved by the University of the Witwatersrand's

Human Research Ethics Committee (M210846). Given the pilot nature and n = 14, external validity is limited, and findings are interpreted descriptively. Details of recording protocol, coding procedures, reliability checks, and synchrony definitions are provided in the subsequent Data Collection, Video processing, Micro Analysis of Behaviours, Reliability Analysis, and Synchrony measures subsections to avoid overlap across subsections .

Data Collection

Demographic data

Demographic factors such as the age and sex of the child, maternal age, marital status, employment status, and education were collected using a questionnaire administered at recruitment. All the questionnaire data were stored in the Research Electronic Data Capture (REDCap) application hosted by the University of Witwatersrand (Harris et al. 2009; Harris et al. 2019). The mothers self-reported their date of birth and that of their infant, which were then used to calculate their age.

Primary observational data: Headcam

Headcam data were collected between May and July 2022. Headcams are small video devices attached to a soft fabric headband which are worn by mothers and infants to capture their moments of interaction at home. Mothers were given headcams to take home and asked to record at least three 5-minute interactions over a period of three days, as proposed by Mother-infant

dyads were requested to wear headcams during free play in order to record first-person observations (see Figure 1). Free play refers to a period of unstructured and spontaneous play between a mother and an infant. This means that they engage in activities without any specific rules or objectives. During free play, infants are encouraged to freely explore their surroundings, interact with toys, and engage in playful activities at their own pace. The mother, in return, responds to the infant's cues and behaviours. The research assistant provided instructions, demonstrated the use of the headcams during home visits, and collected the devices after three days. Recordings were completed during the infant's waking hours in the usual caregiving space at home, mothers were asked to interact as they normally would without prompts, and each dyad completed three five-minute episodes across three days following the brief in home orientation.

Video processing

Video footage was downloaded from the headcam for each mother-infant dyad. Videos were screened to ensure they fulfilled the basic quality standards stipulated in the literature (Prioreschi et al., 2023; Wrottesley et al., 2021) and the Observer XT coding scheme (Costantini et al., 2021). The video quality was assessed through scene analysis, with the first author watching each video to identify and track features such as the mother's face, the infant's body, and the surrounding environment. Video quality was evaluated based on three criteria, namely: 1) camera position, 2) image quality/definition, and 3) footage luminosity. Videos were considered to be of good or sufficient quality if subtle behaviours could be identified, i.e., 1) videos filmed in an adequately lit space or room; 2) cameras positioned to capture the mother and infant facing each other directly to see each other's faces; 3) videos containing at least a 3–5-minute continuous

mother-infant interaction; and 4) videos that only had the mother and baby, and no other person.

Due to time constraints, standardization of analysis, and data quality considerations, only the first matching mother and infant videos of acceptable quality were used for coding and analysis purposes (see Figure 1). Mother and infant video sequences were aligned side-by-side and automatically synchronised on sound through the Adobe Premiere Pro software (Adobe Systems Incorporated, 2023). The non-synchronous portions of the videos were trimmed, resulting in 14 synchronised mother-infant videos in a split-screen view. Where raw footage exceeded five minutes, only the first five minutes of acceptable quality were coded to standardise observation windows across dyads.



Figure 1. A still image from a video of the first author and her infant child as an example of a joined mother-infant video

Micro-Analysis of Behaviours

Mother-infant videos were micro-coded using behavioural coding software (The Observer XT 16.0, Noldus Information Technology, Wageningen, Netherlands). A second-by-second manual coding of specific mother-infant behaviours, including touch, hand movement, gaze and play, was performed using an event-based coding scheme accessible online and explicitly developed for mother-infant interactions (Costantini et al., 2021; Northrup & Iverson, 2019). This coding scheme included codes for each behaviour and each behaviour modifier for each participant (Burgess et al., 2023; Costantini et al., 2021). A summary of the coding scheme used in this study, which included five key codes, is shown in Supplementary Table 6. The participant code referred to either the mother or the infant, and the behaviour code referred to the specific behaviours of interest (i.e., touch with the right hand, touch with the left hand, gaze/visual attention, hand movement or play).

Modifier codes were assigned as additional labels or qualifiers to provide more specific information about each behaviour (Montague et al., 2011). For example, modifiers for *touch* specified whether the touch was initiated by the mother or the infant, regardless of which hand was used. This classification indicated that the touch was directed toward either the mother or the infant. Similarly, the gaze was directed at either the mother or the infant. Hand movement was either reaching the mother, infant, or object, while play was either evident or inconspicuous.

Procedures applied during the coding of behaviours.

A two-pass method was applied, with only the mother's behaviour coded for completion during the first video viewing, and the infant's behaviour coded during the second viewing (Montague et al., 2011). A timestamp was allocated to mark the beginning and end of each behaviour in the video. Coders began at the zero-time stamp of the synchronised split screen rather than selecting a subjective onset of free play, and each coded sequence was capped at five minutes to standardise observation windows across dyads. No time weighting was applied because all coded sequences were of equal length. For example, "mother touch with the right hand" was time-stamped when the mother put her right hand on any object and stopped when her right hand was removed from the object it touched (Montague et al., 2011). Modifiers were then selected to describe the person or situation to which the behaviour was directed. For example, if the behaviour regarding "mother touch with the right hand" was directed towards the infant, the modifier described the behaviour as "mother touching infant with the right hand". When the mother's right hand was visible to the coder but not touching anything, this was coded as "no mother touch right hand".

Similarly, in the event that the mother's right hand was not visible to the coder due to poor video quality or the mother's positioning prevented the coder from determining whether or not touch was occurring, this was coded as "not possible to code the mother touch right hand". The same coding process was applied to all mother-infants' behaviours. The entire duration of the mother-infant interaction was coded, and time-stamped behaviours and modifiers for each participant were stored by the Observer XT software. Coders began at the zero-time stamp of the

synchronised split screen rather than selecting a subjective onset of free play, and each coded sequence was capped at five minutes, therefore no time weighting was required.

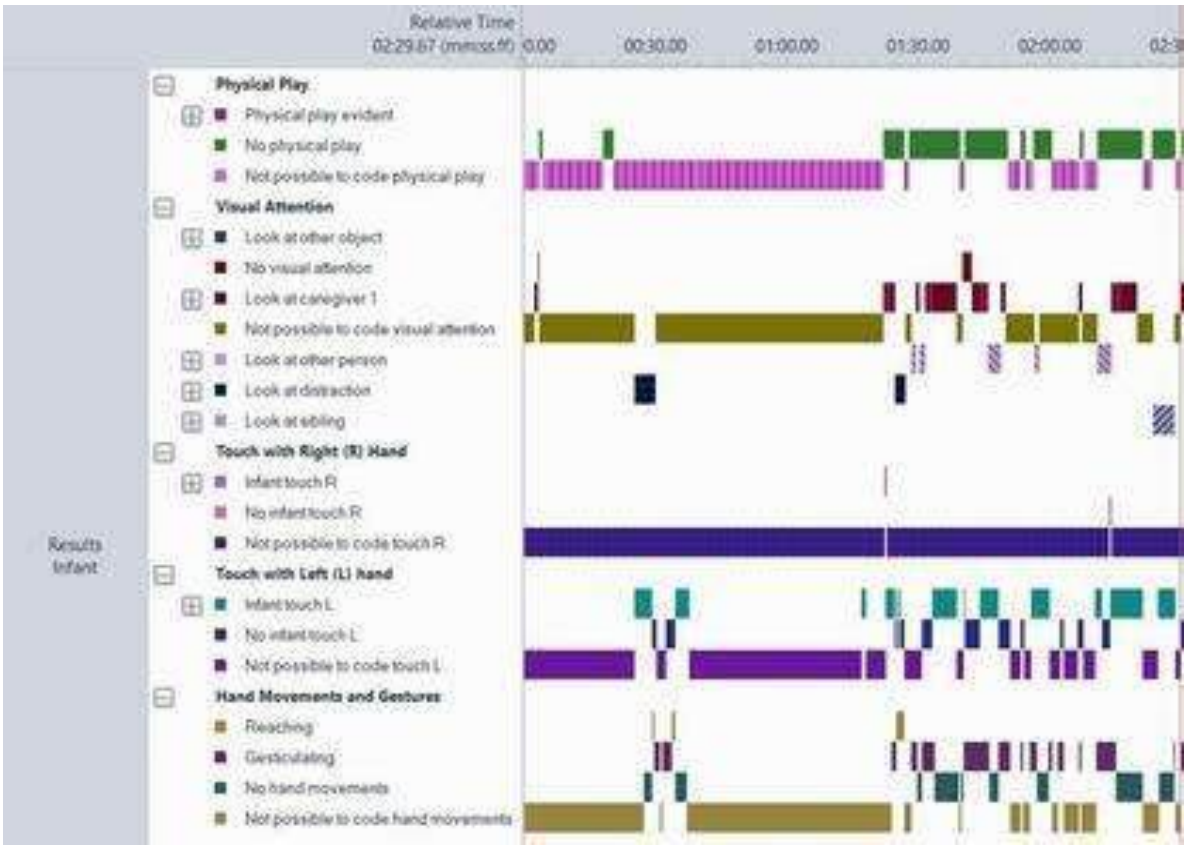


Figure 2. An example of the visual output from the Observer XT software for coded behaviours for one infant.

Reliability Analysis

Coding reliability was ensured with thorough training of the coders before the commencement of the coding process. Boundary disagreements were more likely for very brief gaze shifts and shorthand movements during partial occlusion, rather than for sustained behaviours. Despite these challenges, all codes remained above $\kappa = 0.80$. To maintain consistency during long coding

runs, we scheduled periodic drift checks, held short recalibration meetings, applied targeted double coding of rotating subsets, and used a written reconciliation rule that prioritised agreement on onsets and offsets when behaviours overlapped. Initial coding was performed by the first author while a second coder, PLAY Study Principal Investigator, performed an independent and blinded coding of 4, 30%, of the paired videos to test their reliability. The Observer XT software was used for conducting inter observer reliability analysis between pairs of observations to determine the extent to which the two coders scored the same behaviours with the same durations. The reliability analysis enabled a comparison of the paired behaviours and their durations with the utilisation of the duration and sequence comparison method. Synchrony of videos was undertaken with the alignment of the video start time in cases where coder 1 started coding at a different time in the video to coder 2. Cohen's kappa coefficients and the proportion agreement were used to assess the synchrony reliability in this regard. All reliability procedures applied to the fixed five-minute coded segments specified above.

Behaviour pairs

Data profiles for all behaviour pairs were created to determine mother- vs infant-initiated behaviours. Initiating behaviours were matched with response behaviours to form behaviour pairs. Behaviour pairs were further categorised as pairs containing matching behaviours or non-matching behaviours. Matching behaviours refer to the correlation of mother-infant responses to each other's behaviour with the same behaviour, such as an infant responding to a mother's touch with a touch. In contrast, non-matching behaviour refers to a different behavioural response to

the initial behaviour. The initial and response behaviour pairs are shown in Table 1 and Table 2.

Table 1. Matching behaviour pairs

Patterns	**Behaviours**	**Matching Behaviour Pairs**	
		Initial Behaviours	**Response Behaviours**
Mother-Initiated Behaviours	Touch	Mother Touch Right Hand	Infant Touch Right Hand
		Mother Touch Left Hand	Infant Touch Left Hand
	Gaze	Mother Gaze Infant	Infant Gaze mother
	Hand movement	Mother Reaching	Infant Reaching
	Play	Mother Play	Infant Play
Infant-Initiated Behaviours	Touch	Infant Touch Right Hand	Mother Touch Right Hand
		Infant touch Left hand	Mother Touch Left Hand
	Gaze	Infant Gaze Mother	Mother Gaze Infant
	Hand movement	Infant Reaching	Mother Reaching
	Play	Infant Play	Mother Play

Table 2. Non-matching behaviour pairs that were investigated

Patterns	**Behaviours**	**Matching Behaviour Pairs**	
		Initial Behaviours	**Response Behaviours**
Mother-Initiated Behaviours	Touch	Mother Touch Right Hand	Infant Gaze Mother
		Mother Touch Right Hand	Infant Play

		Mother Touch Left Hand	Infant Gaze Mother
		Mother Touch Left Hand	Infant Play
	Gaze	Mother Gaze Infant	Infant Reaching
		Mother Gaze Infant	Infant Play
	Hand movement	Mother Reaching	Infant Gaze Mother
	Play	Mother Play	Infant Gaze Mother
Infant-Initiated Behaviours	Touch	Infant Touch Right Hand	Mother Gaze Infant
		Infant Touch Right Hand	Mother Play
		Infant Touch Left Hand	Mother Gaze Infant
		Infant Touch Left Hand	Mother Play
	Gaze	Infant Gaze Mother	Mother Reaching
		Infant Gaze Mother	Mother Play Evident
	Hand movement	Infant Reaching	Mother Gaze Infant
	Play	Infant Play	Mother Gaze Infant

Synchrony measures

The mother-infant non-verbal behaviour pairs were quantified based on the occurrence of each behaviour and its temporal immediacy (Montague et al.,2011). Thus, we defined synchrony as mother-infant behaviours occurring within a specified window of 3, 5 or 7 seconds (Leclere, 2014; Bell, 2020). Window selection was based on previous studies that suggested the likelihood

of a response behaviour following an initial behaviour within these time windows (Burgess et al., 2023; Northrup & Iverson, 2019; Yu & Smith, 2013).

We identified several synchrony variables: the timing of synchrony occurrence, the duration of synchrony, and the leader-follower relationships (i.e., who initiated a behaviour sequence during free play). We also examined the frequency of synchrony, the strength of the association, and maximum synchrony. The timing of synchrony occurrence referred to the specific moment during the interaction when synchronous behaviours were observed, specifically the first instance of a response following an initial behaviour. We compared three-time windows to determine which behaviours demonstrated greater synchrony. The duration of synchrony indicated how long synchronous behaviours were maintained, measuring the time a behaviour pair lasted within a specified period. Leader-follower relationships described the sequence of observed behaviours by identifying whether the mother or the infant initiated a behaviour during free play. For example, if a mother-initiated gaze toward her infant and the infant responded by gazing back within the defined time window, the mother was classified as the leader and the infant as the follower. Conversely, if the infant-initiated play by reaching for a toy and the mother responded by engaging in play, the infant was considered the leader in that interaction

The strength of association measured the level of similarity in frequency, probabilities, and duration across the selected time windows, providing a statistical assessment of the consistency or robustness of synchrony between mother-infant behaviours. This was assessed using multilevel regression models to account for the nested nature of the data (e.g., multiple observations within dyads). Maximum synchrony referred to the highest frequency or probability

of a behaviour occurring within the selected windows and the longest duration of continuous synchrony observed during the interaction session. The frequency of synchrony indicated the number of transitions from the initial behaviour to the response behaviour, specifically the number of times synchronous behaviours occurred during the observation period. We determined these synchrony variables for each behaviour pair investigated.

Statistical Analysis

Demographic Analysis

We summarised the variables as categories, including infant gender, maternal marital status, educational attainment, and employment status as percentages. Marital status was classified as single, married, engaged, or in a relationship. Employment status was categorised as employed or unemployed. Additionally, educational status was categorised into three levels: secondary (Grade 8-11), Matric (Grade 12), and tertiary education. These categorical variables were subsequently summarised as frequencies and percentages. Continuous and discrete variables, such as infant age, maternal age, and the number of other children in the household, were summarised through the median and interquartile range (IQR).

Behaviour analysis

The behaviour analysis module within Observer XT software was utilised for summarising the individual behaviours with respect to their frequency, duration, and rate per minute. The average

duration was calculated as the total duration (the sum of the duration of all events of a specific behaviour) divided by the number of times the behaviour occurred. The average rate per minute was calculated as (Total number of occurrences/ Duration in seconds) * 60. The duration, frequency, and rate per minute were summarised as median and inter-quartile range (IQR). In addition, the frequencies, durations, and rate per minute of the "no behaviour" and "not possible to code behaviour" states were also assessed (Supplementary Table 2).

Sequential analysis to characterise the mother-infant behaviour pairs

The Observer XT software was utilised for the calculation of the time-window sequential analysis and subsequent summarising of the frequency and probability of mother-infant behaviour pairs to identify the synchrony of touch, gaze, and play for mother-infant dyads at 3, 5, and 7s (Chorney et al., 2010). We summarised the frequency of each behaviour, as well as the probability that a specific response behaviour followed an initial behaviour within each time window (e.g., the probability that within 3 seconds of the infant playing, the mother also engaged in play). These probabilities, along with the duration of behaviours, were reported as median and inter-quartile range (IQR). Frequency was calculated as the number of transitions from the initial to the response behaviour. Probability was calculated as the number of transitions for each combination of initial and response behaviour (behaviour pair) divided by the total number of transitions from that initial behaviour. The sum of the transition probabilities for each initial behaviour is equal to 1 (Costantini et al., 2021). Differences in frequency, probability and duration between the 3-, 5- and 7-sec time points were determined using the Friedman test

(Pereira et al., 2015).

Regarding the durations of mother-infant behaviours, all behaviour pairs had two values which represented the duration of each behaviour involved in that pair. We used the lowest value of duration in the pair to determine the duration of synchrony, representing the length of time shared between these behaviours. For example, in the behaviour pair "infant play – mother play", the durations were 2.62 (2.41-2.82) and 2.66 (2.25-3.00) seconds, respectively. Then, in this case, 2.6 (2.4-2.8) was used as the correct duration for synchrony. Differences in frequency, probability and duration between the 3-, 5- and 7-sec time points were determined using the Friedman test.

Multilevel linear regression modelling (MLMs) with random effects for dyads was used to explore the relationship between the frequencies, probabilities, and durations of mother-infant matching and non-matching behaviour pairs and to account for variability between dyads. Given the small sample size, a simple model was fitted with time (measured as a continuous variable) as the only independent variable. To limit overfitting, no additional covariates were included, and models were therefore specified as time only with random intercepts for dyad. As a sensitivity check, we ran exploratory single covariate additions, which did not change the direction of effects but widened uncertainty, so the parsimonious specification is retained and flagged as pilot. Models were fitted individually for each behaviour pair's frequency, probability, and duration for matching and non-matching, mother-initiated and infant-initiated behaviours. To minimise any influence of clip length, descriptive results are reported as both counts and rates per minute, and sequential probabilities are normalised within each initial behaviour, so row

sums equal 1. Data were analysed in STATA 17.0), and significance was determined at the 5% level of significance.

Results

This study included a sample of 14 mother-infant pairs. The average age of the mothers was 27.9 (SD = 8.9), ranging from 18 to 43 years, while infants ranged from 1 to 5 months (mean, 2.3 (SD = 1.7)). The sample consisted of 6 (42.9%) male and 8 (57.1%) female infants. Mothers were predominantly single 10 (71.4%), with a smaller proportion of 2 (14.3%) who were in a relationship, engaged 1 (7.1%), or married 1 (7.1%). Most mothers (9; 64.3%) had completed Grade 12, followed by those with secondary education (Grade 9 to Grade 11) (4; 28.6%) and tertiary education (1; 7.1%). Additionally, most (11; 78.6%) mothers were employed. The mean number of additional children in the household was 2, ranging from 0 to 5 (Supplementary Table 1). Because recordings were made in routine home settings, we interpret the findings with ecological validity in view and note that observed patterns reflect caregiving as practised in Soweto. In the videos, synchrony typically appeared as brief bouts of mutual gaze, mirrored touch, and joint handling of toys during free play.

Reliability of coding

A Cohen's kappa coefficient of 0.90 was obtained for the inter-observer agreement for scoring the same behaviours. For the non-verbal behaviours, which were the primary focus of this study, the coders' average reliability was 0.78 for touch with the right hand, 0.81 for touch with the left

hand, 0.75 for visual attention/gaze, and 0.79 for play. Kappa values for inter-coder reliability between 0.60 and 0.75 are considered good, while scores above 0.75 are considered exceptional (Bakeman, 2000), which validates the coding quality.

Characterisation of individual mother and infant behaviours

The mean length of videos included in this study was 3.2 (SD =1.6) minutes. Although mothers were asked to record at least 5-minute interactions, some videos were shorter due to factors such as interruptions, technical issues, or incomplete recordings. Because recordings were made in routine home settings, we interpret the findings with ecological validity in view and note that observed patterns reflect caregiving as practised in Soweto. In the videos, synchrony typically appeared as brief bouts of mutual gaze, mirrored touch, and joint handling of toys during free play. Across clips, the median coded length was 225.4 seconds, IQR 121.2 to 273.4, which equates to approximately one time stamp per second and 2,662 coded seconds in total, thereby providing a substantial first level of observation despite the small N. The frequency, duration, and rate per minute for each of the five individual mother and infant behaviours, touch with the left hand, touch with the right hand, gaze, reaching, and play, are presented in Table 3 below.

Table 3. Description of individual mother and infant behaviours in relation to the length of the video

	Behaviours	**Frequencies**	**Rate Per Minute**	**Duration**
		Median (IQR)	**Median (IQR)**	**Median (IQR)**
Mother's Behaviours	Mother Touch Right hand	17 (12-25)	6.42 (5.12-8.18)	1.67 (0.87-4.00)
	Mother Touch Left hand	9 (4-10)	3.48 (1.63-4.82)	2.02 (1.15-6.35)
	Mother Gaze Infant	20 (7-36)	9.55 (5.18-10.95)	1.20 (0.57-2.83)
	Mother Reaching	6 (5-13)	3.12 (1.33-3.46)	1.20 (0.70-2.30)
	Mother Play	11 (2-17)	3.59 (1.00-4.10)	3.67 (1.57-6.93)
Infant's Behaviours	Infant Touch Right hand	6 (2-12)	1.28 (0.99-3.07)	1.88 (0.93-4.40)
	Infant Touch Left hand	7 (4-16)	1.99 (0.82-4.72)	2.27 (1.27-5.07)
	Infant Gaze Mother	19 (12-26)	6.66 (4.90-9.82)	1.40 (0.67-3.07)
	Infant Reaching	5 (2-7)	1.44 (0.53-1.86)	1.44 (0.97-3.43)
	Infant Play	3 (1-6)	1.04 (0.65-2.43)	5.03 (2.40-10.73)

Characterisation of matching mother-infant behaviour pairs

i) Cross-sectional comparisons at 3, 5, and 7seconds

Differences in frequencies, probabilities, and durations of matching mother-infant behaviour pairs at 3, 5, and 7 seconds are shown in Tables 4a, and 4b. For both mother-initiated and infant-initiated behaviour pairs, the frequency of rhythmic touch and play showed a significant increase from 3 to 7 s. Rhythmic gazes had the highest frequency of all behaviour pairs, which doubled from 7 (IQR = 2-19) within 3 s to 16 (IQR = 5-35) within 7 s for mother-initiated behaviour pairs, and from 6 (IQR =3-16) within 3 s to 12 (IQR = 8-30) within 7 s for infant-initiated behaviour pairs. Probabilities for sequential transitions were normalised within each initial behaviour; therefore, row sums equal 1, which reduces any influence of clip length on estimated transition likelihoods.

The duration of all behaviour pairs increased significantly as time progressed from within 3 seconds to within 7 seconds, especially for infant responses.

ii) Changes across the three-time points

Findings for the association of frequency, probability and duration with time (measured continuously) are presented in Table 4c. Among mother-initiated behaviour pairs, the frequency of "*mother gaze infant – infant gaze mother*" had a significant positive association with time (b=2.18; 95% CI: 1.31, 3.06). Similarly, the frequency of "*infant gaze infant – mother gaze infant*" had a significant positive association across the three-time points (b=2.81; 95% CI: 0.57,

5.05) among infant-initiated behaviour pairs. In contrast with the frequency, a significant change in the probabilities of infant-initiated behaviour pairs was only observed for "*infant gaze-mother gaze*" (b= 0.01; 95% CI: 0.005, 0.01). Given the pilot sample, models were deliberately parsimonious with time as the sole predictor and random intercepts for dyad. Exploratory single covariate checks produced the same directions of effect with wider uncertainty, therefore the time only specification is retained, and full outputs are provided in the Supplementary materials.

Characterisation of non-matching behaviours

i) Cross-sectional comparisons at 3, 5, and 7s

Among mother-initiated behaviour pairs, "*touch with the right hand-infant gaze mother*" was recorded more frequently within 3, 5 and 7 seconds than any other behaviour pair (Supplementary Table 3a). Significant differences in frequency were observed for *"Mother touch right hand – Infant play", "Mother touch left hand – Infant play", "Mother gaze infant – Infant reaching", "Mother reaching – Infant gaze mother"*, between 3 and 7 s. Among infant-initiated behaviours, significant increases in frequency were observed for all behaviour pairs between 3 and 7 s, except for *"Infant gaze mother – Mother play*".

Table 4a. Cross-sectional summaries of the frequency and probability of matching mother-infant behaviour pairs at the 3, 5 and 7-second time windows. Differences in medians between the time points assessed using Friedman's test

Behaviour pairs	**3 seconds**		**5 seconds**		**7 seconds**	
Mother-Initiated Behaviours	**Freq**	**Prob**	**Freq**	**Prob**	**Freq**	**Prob**
Mother touch right hand– Infant touch right hand	1 (0-5) b***	0.05 (0.0-0.19)	2 (1-8)	0.07 (0.03-0.16)	2 (1-8)	0.09 (0.03-0.14)
Mother touch left hand - Infant touch left hand	1 (0-2) b**	0.06 (0-0.15)	2 (0-4)	0.11 (0.0-0.02)	2(0-4)	0.12 (0.00-0.19)
Mother gaze infant – Infant gaze mother	7 (2-19)	0.15 (0.04-0.26) b*	12 (2-25)	0.18 (0.09-0.27)	16 (5-35)	0.23 (0.16-0.31)
Mother reaching – Infant reaching	1 (0-2) b***	0.23 (0.17-0.29)	1 (0-3)	0.21 (0.17-0.31)	2 (1-4)	0.27 (0.16-0.33)
Mother play – Infant play	1 (1-2)	0.13 (0.06-0.22)	1 (1-3)	0.12 (0.05-0.16)	1 (1-3)	0.11 (0.04-0.17)
Infant-Initiated Behaviours						

Infant touch right hand– Mother touch right hand	2 (1-3) b**	0.30 (0.18- 0.33)	3 (1-6)	0.25 (0.21-0.33)	3(1-7)	0.23 (0.18-0.35)
Infant touch left hand – Mother touch left hand	1 (1-2) b**	0.10 (0.03-0.20)	2 (1-3)	0.10 (0.3-0.22)	2 (1-3)	0.20 (0.5-0.25)
Infant gaze infant – Mother gaze infant	6 (3-16)	0.20 (0.12-0.24) b**	9 (6-24)	0.24 (0.14-0.25)	12 (8-30)	0.25 (0.13-0.27)
Infant reaching – Mother reaching	1 (0-3) b*	0.12 (0.05-0.29)	1 (0-4)	0.23 (0.11-0.33)	1 (0-5)	0.23 (0.12-0.31)
Infant play – Mother play	1 (0-2)	0.14 (0.0-0.25)	1 (0-3)	0.10 (0.0-0.25)	1 (0-3)	0.10 (0.00-0.23)

Median (IQR) frequencies and probabilities are presented at 3, 5 and 7 seconds. Freq = frequencies, and prob = probabilities.

Differences: a=3s vs 5s vs 7s; *p<0,05; **p<0,01; ***p<0,001.

Table 4b. Cross-sectional summaries of the duration of matching mother-infant behaviour pairs at the 3, 5 and 7-second time windows. Differences in medians between the time points assessed using Friedman's test

Behaviour pairs	**3s**		**5s**		**7s**	
Mother- Initiated Behaviours	**Mother**	**Infant**	**Mother**	**Infant**	**Mother**	**Infant**
Mother touch right hand– Infant touch right hand	1.59 (1.28-2.26)	0.94 (0.63-1.47)	1.81 (1.55-2.24)	1.21 (0.85-2.06)	2.12 (1.77-2.74)	1.45 (0.7-2.85)
Mother touch left hand – Infant touch left hand	1.95 (1.57-2.32)	1.45 (0.75-2.17) [b*]	2.61 (1.72-3.16)	2.04 (0.82-2.43)	2.74 (2.40-4.04)	2.09 (1.4-3.41)
Mother gaze infant – Infant gaze mother	1.33 (1.17-1.47) [b***]	1.28 (1.08-1.74) [b**]	1.41 (1.23-1.89)	1.49 (1.29-2.14)	1.59 (1.35-2.17)	1.77 (1.65-2.25)
Mother reaching – Infant reaching	1.46 (1.02-2.13)	1.07 (1.03-2.28) [b**]	1.44 (1.10-2.53)	1.87 (1.77-2.80)	1.41 (1.14-2.65)	1.87 (1.55-3.75)
Mother play – Infant play	2.31 (1.92-2.89)	1.86 (1.13-2.40) [b***]	2.97 (2.58-4.13)	3.13 (2.67-3.52)	3.41 (3.17-4.24)	5.13 (3.58-6.73)
Infant-Initiated Behaviours	**Infant**	**Mother**	**Infant**	**Mother**	**Infant**	**Mother**

Infant touch right hand– Mother touch right hand	1.97 (1.22-2.16)	1.66 (1.36-1.93) [b**]	1.80 (0.7-2.54)	2.07 (1.69-3.10)	2.00 (0.77-2.71)	2.53 (1.79-3.43)
Infant touch left hand – Mother touch left hand	1.98 (1.86-2.30) [b***]	1.92 (1.22-2.75) [b*]	2.47 (2.14-2.87)	2.63 (1.45-4.00)	2.60 (2.01-3.13)	2.44 (1.57-4.22)
Infant gaze infant – Mother gaze infant	1.39 (1.26-1.75)	1.32 (0.76-1.86) [b**]	1.78 (1.44-2.20)	1.94 (1.01-2.25)	2.12 (1.66-2.43)	2.06 (1.09-2.49)
Infant reaching – Mother reaching	1.91 (1.41-2.55) [b***]	0.88 (0.65-1.49)	1.94 (1.71-2.55)	1.00 (0.69-1.90)	2.07 (1.55-2.68)	1.36 (0.69-1.89)
Infant play – Mother play	2.62 (2.41-2.82) [b***]	2.66 (2.25-3.00) [b***]	3.54 (3.29-4.32)	4.12 (2.89-5.00)	4.54 (3.75-5.82)	5.41 (3.57-6.92)

Differences: a=3s vs 5s vs 7s; *p<0,05; **p<0,01; ***p<0,001.

Table 4c. Changes in the frequencies, probabilities, and duration over time (as a continuous variable), assessed by Multilevel Linear Models (MLMs). Data presented as beta coefficient (β) and confidence interval (CI)

Behaviour pairs	**Freq**		**Prob**		**Mother**	**Duration**		**Infant**
Mother-Initiated Behaviours	**β**	**CI**	**β**	**CI**	**β**	**CI**	**β**	**CI**
Mother touch right hand– Infant touch right hand	0.57*	[0.14, 0.99]	0.003	[-0.04, 0.01]	0.18***	[0.10, 0.27]	0.16**	[0.04,0.27]
Mother touch left hand - Infant touch left hand	0.34*	[0.10, 0.57]	0.01*	[0.0004, -0.02]	0.28***	[0.16, 0.41]	0.24*	[0.04, 0.43]
Mother gaze infant – Infant gaze mother	2.18*	[1.31, 3.06]	0.02*	[0.01, 0.03]	0.17**	[0.05, 0.28]	0.17**	[0.06, 0.27]

Mother reaching – Infant reaching	0.27*	[0.13, 0.41]	0.01	[-0.003, 0.01]	0.05*	[0.01, 0.10]	0.27**	[0.07, 0.47]
Mother play – Infant play	0.13	[-0.03, 0.29]	-0.01	[-0.01, 0.02]	0.43***	[0.28, 0.57]	0.80***	[0.47, 1.13]
Infant-Initiated Behaviours					**Infant**		**Mother**	
Infant touch right hand– Mother touch right hand	0.57*	[0.24, 0.90]	0.001	[-0.01, 0.01]	0.08**	[0.03, 0.13]	0.29**	[0.11, 0.48]
Infant touch left hand – Mother touch left hand	0.42*	[0.06, 0.77]	0.01	[-0.003, 0.03]	0.14***	[0.07, 0.22]	0.23*	[0.04, 0.42]

Infant gaze mother – Mother gaze infant	2.81*	[0.57, 5.05]	0.01*	[0.005, 0.01]	0.16***	[0.10, 0.22]	0.20***	[0.11, 0.29]
Infant reaching – Mother reaching	0.21*	[0.05, 0.36]	-0.001	[-0.02, 0.02]	0.19*	[0.04, 0.35]	0.11	[-0.02, 0.24]
Infant play – Mother play	0.22	[-0.06, 0.50]	-0.03	[-0.02, 0.01]	0.49***	[0.26 - 0.73]	0.64***	[0.38, 0.90]

Statistically significant values are marked with asterisks, *p<0,05; **p<0,01; ***p<0,001.

Discussion

This study aimed to explore patterns of synchrony of mother-infant non-verbal behaviours using first-person observation in a group of mother-infant dyads from Soweto, South Africa. To our knowledge, this is the first study to assess synchrony using first-person observation in South Africa. We investigated the timing of synchrony using different time windows (3-5, and 7 seconds). Overall, there were differences in the timing of behavioural co-occurrence, with some behaviours occurring within three seconds of each other, while others required longer time windows. This co-occurrence may serve as an indicator of behavioural contingency or responsiveness, which are often considered markers of synchrony. Studies have shown that for behaviours such as gaze, the average infant's reaction time following their mother's gaze is around 2.73 seconds at 3 months, and this decreases as age increases (Northrup & Iverson, 2020). Conversely, others support the use of a longer time window, such as within 5 (Yu & Smith, 2013) and 7 seconds (Deák et al., 2018) for certain behaviours. For example, Deak (2018) observed that infants responded within 7 seconds to attention-directing cues (e.g. gestures) from their mothers, supporting the use of the 7-second window. Additionally, another study reported that infants sometimes take up to 7 seconds to respond to gaze or point cues (Flom et al., 2004). The timing and flow of interactions and responding to the infant's signals are important in studying how parents and infants connect.

The timing and flow of interactions and responding to the infant's signals are important in studying how parents and infants connect. Given the small pilot sample, n = 14, the study was underpowered to detect small effects or nuanced differences across behaviours and time

windows, which increases the risk of type II error and limits generalisability, and the analysis was descriptive and methodological rather than inferential. To situate these findings, we compare these patterns with reports from WEIRD samples, where microanalytic studies of brief face to face interactions document rapid, finely timed contingencies under structured tasks (Beebe & Lachmann, 2010; Feldman, 2007; Leclère et al., 2014). By contrast, our naturalistic home recordings in Soweto showed longer tactile bouts and shared object handling embedded in routine care, a pattern consistent with proximal caregiving described in non-WEIRD settings (Kärtner et al., 2010). We therefore treat WEIRD contrasts as checks on external validity rather than benchmarks of deficit, and we direct readers to the Key Terms entry on WEIRD contexts.

In the current study, we observed changes in the frequency and probability behaviour-pairs over time, with significant increases in their occurrence between the time periods. For example, there were significantly more rhythmic touches and reaches within 7 seconds compared to within 3 seconds. Similarly, rhythmic gaze, reaching and play exhibited significantly longer durations of co-occurrence within the 7-second compared to the 3-second window. Synchrony in mother-infant dyads involves the dynamic coordination of their behaviours over time. Measuring the three dimensions of frequency, probability and duration provides complementary perspectives on different aspects of the mother-infant interactions.

The co-regulatory experiences and achievement of mutual synchrony occur in the context of the developmental trajectory, during which the child develops motor skills and symbolic capacities influencing the mode of interaction as the child develops. According to Wright (1991), gaze becomes a key mode of interaction from the age of two months, substituting touch as the

preferred mode in earlier stages. We observed that rhythmic gazes were the most frequently observed behaviour and had the longest duration in this study, for both mother- and infant-initiated behaviour pairs. The frequency of rhythmic gaze was 7 and 8 times higher at 3 and 7 seconds compared to other behaviour pairs. The frequency of rhythmic gaze also doubled between 3 and 7 seconds for both mother- and infant-initiated behaviours. These findings align with previous research, which demonstrated that infants engage in synchronous mutual gaze with their mothers, spending more than half of their face-to-face interactions in this synchronised state (Harel et al., 2011; E. Tronick et al., 1980). The frequency of gaze synchrony peaks around 3 months of age (Northrup & Iverson, 2020), marking the early emergence of this vital social-cognitive skill (Feldman, 2012a, 2012b). This period is described as an interactive "dance" between parents and infants, characterized by rhythmic patterns of mutual gaze and shared attention (Provenzi et al., 2018; E. Tronick & Beeghly, 2011). Young infants who engage in more mutual eye contact with their mothers exhibit better attention control by the end of their first year (Niedźwiecka et al., 2018). Northrup (2019) shows that mothers and infants adapt their gaze behaviour to match each other's response speed and degree, which highlights the collaborative nature of early social interaction with both partners actively contributing to the rhythm of the "gaze dance." It is suggested that gaze synchrony "becomes the main vehicle for social interactions throughout life" (*Vision and Separation : Wright, Kenneth*, 1991).

Gaze was also a common initial or response behaviour even among non-matching behaviours. For example, when mothers touched their infants, the infants responded by gazing, while mothers responded to infant gaze by playing. The "*mother touch-infant gaze mother"* and *"infant gaze-mother play"* behaviour pairs occurred more frequently than any other behaviour.

Mismatched behaviours are recognised as a huge element of mother-infant interactions with suggestions that dyads spend most of their playtime in these behaviours (E. Z. Tronick & Cohn, 1989a, 1989b). Despite the prevalence of mismatched states, the interactions typically involve a process of self-repair which allows the dyad to restore synchrony after moments of miscoordination. Mismatched behaviours may enhance the appreciation of infants that relationship may not be fully attuned, thus fostering resilience and adaptability in social situations. These experiences help infants to internalise different models of relationships which may influence future intimate relationships (Feldman, 2007). Recent research emphasises the adaptive and communicative functions of mismatched behaviours (Beebe & Feldstein, 2001; Fogel, 2019).

The findings of this study also demonstrate the bi-directional nature of mother-infant synchrony. This suggests that mothers and infants exert mutual influences on each other's behaviours (Chow et al., 2010; Fogel, 2019; *Hart S (2010)*, n.d.). During the early months of life, mothers coordinate their behaviour towards their infants in contingent ways, laying the foundation for coordinated exchanges which show that more responsive mothers also have more responsive infants through shared or mutually reinforcing influences (Jaffe et al., 2001; Van Egeren et al., 2001). By 2-3 months, a structured reciprocal pattern emerges (Northrup & Iverson, 2020). Another study further observed 12-month-olds and their parents engaging in synchronised gaze, taking turns leading and following with a mere 5-second lag (Yu & Smith, 2013b). While mother-driven synchrony remains the predominant pattern in early infancy, evidence suggests the gradual emergence of infant-driven synchrony as well. Notably, Northrup (2019) found that at 3 months, there were infrequent and significantly higher than chance instances of mothers

following infants' gaze to mutual attention. Research also emphasized the bi-directional nature of early caregiving, suggesting the influence of infants' behaviours on the level of care they receive from their mothers (Vallotton, 2009).

Overall, we found low frequencies and probabilities of synchrony in this population, suggesting that mothers and infants were not responding sufficiently to each other, which may have limited infant's opportunities to learn from their mothers' behaviours. Responsiveness is a fundamental component of nurturing care (Martin, 2020; WHO, 2018) and plays a crucial role in synchrony, as it reflects the ability to appropriately react to a child's cues – a key foundation for the coordinated interaction and emotional attunement in mother-infant relationships. Accordingly, mothers are responsible for creating a stable environment in which young infants can learn and grow. However, the observed low frequency and probability of synchrony occurring at 3-, 5-, and 7-second windows in South African mother-infant dyads may reflect multiple influencing factors highlighted in the literature.

Firstly, cultural norms and practices could shape the temporal dynamics of mother-infant interactions, leading to different patterns of synchrony compared to predominantly Western samples (Gratier, 2003). Given that most synchrony research originates from WEIRD (Western, Educated, Industrialized, Rich, and Democratic) societies (Bell, 2020; Deák et al., 2018a; Paulina Velez-Gomez et al., 2012), the lower synchrony observed within these specific timeframes in a South African context may reflect culturally normative interactional styles rather than an inherent lack of coordination. Secondly, socioeconomic factors and caregiving demand prevalent in South Africa could impact the capacity for sustained, finely tuned interactions,

potentially leading to lower frequencies of synchrony within these window sizes (Paulina Velez-Gomez et al., 2012). Many South African infants grow up in environments where opportunities for play and interaction are limited (Lachman et al., 2021; Wrottesley et al., 2021c). For instance, approximately one-third of children receive little encouragement from caregivers to imitate actions, potentially restricting their movement, learning, and growth (Martin, 2020; WHO, 2018). In low-income settings, these caregiving relationships become even more critical for optimizing child development.

Additionally, the methodological choice of 3-, 5-, and 7-second windows might not be optimally suited for capturing the characteristic temporal scales of synchronous behaviours in this population (Deák et al., 2018b; Jaffe et al., 2001). Synchrony in these dyads may occur at different temporal scales than those typically investigated in Western literature. Moreover, the inherently discontinuous nature of synchrony in natural interactions suggests that sustained coordination over several seconds may not always be a defining feature, even in highly attuned dyads (Cuadros et al., 2020). Therefore, interpreting these findings requires critical awareness of the limitations of generalizing from Western-centric research and underscores the importance of adopting culturally sensitive approaches to studying dyadic synchrony.

The data contribute to a clearer understanding of the development of mother-infant synchrony, which is a complex process influenced by various factors such as time and the type of behaviour being investigated. The results further support existing literature concerning the exploration of ways to nurture and stimulate infants in LMIC contexts (Prioreschi et al., 2018; Wrottesley et al., 2021). The information emanating from these results should be considered when designing

interventions for promoting infant nurturing and caregiving. For example, interventions could focus on helping mothers improve their sensitivity and responsiveness to infants' cues and increasing the frequencies and durations of play. Taken alongside WEIRD laboratory reports, the lower probabilities of matched behaviours within 3 to 7 second windows and the prominence of touch-based reciprocity observed here are consistent with context specific routines rather than reduced coordination (Feldman, 2007; Kärtner et al., 2010; Leclère et al., 2014).

Strengths

We used a naturalistic approach by collecting data in the home setting, which minimised the potential for bias, and allowed for more ecologically valid observations of parent-infant interactions. In particular, recording in familiar home routines without a researcher present is likely to reduce demand characteristics, experimenter effects, and camera-awareness compared with clinic or laboratory sessions, thereby improving ecological validity. Maternal age may shape caregiving routines and availability, whereas the infant age range was narrow at 1 to 5 months, so developmental stage rather than age per se likely drove infant variability in this pilot. We did not model maternal age to avoid overfitting, given n = 14, and recommend explicit tests of age effects in larger samples.

The study also utilised a novel data collection method (headcams), which allowed for a close-up first-person and detailed view of the interactions. In addition, the study focused on a specific group of infants (those from South Africa) that have not been well-studied in the past. The study investigated behaviours relevant to mother-infant interactions at the age of the targeted infants.

Although the present study used a convenience sample of 14 infants, which may limit generalizability, the findings align with perspectives expressed in existing research on parent-infant interaction dynamics. Our study used micro-analysis approaches to code each second-by-second mother-infant video for touch, gaze, hand movement, and gaze behaviours. This rigorous method ensured reliability, as the coding by both the first author and an independent researcher yielded a perfect agreement. Micro-analysis, often implemented through software such as Observer XT, has a rich history in mother-infant interaction research. For instance, one study utilized the software to assess interactional characteristics, revealing that high-risk infants and mothers with traumatic stress exhibited less sensitivity and more controlling behaviour (Muller-Nix et al., 2004).

Limitations of the Study

Five limitations of this study should be noted. Firstly, given the small convenience sample and single site recruitment, the primary concern is external validity, not systematic selection bias. There is no evidence that enrolment procedures preferentially included dyads with unusually high synchrony, rather, findings should be interpreted as descriptive of this setting and not extrapolated beyond similar contexts. Where we refer to selection, we mean limits to representativeness that constrain generalisability, not systematic errors that would compromise internal validity. Secondly, the number of participants in the study limits the generalisability of the findings to the larger population and reduces statistical power to detect small effects or low frequency behaviours, which increases the risk of type II error. Thirdly, the study mainly recruited Black African mothers, which is not necessarily representative of the entire South

African population. This potential selection bias should be considered when interpreting the findings. We treat this as a generalisability constraint rather than evidence of systematic selection bias. Fourthly, there was a considerable amount of missing data due to the poor quality of some videos, which was caused by the incorrect positioning of the cameras during the interaction. The latter rendered the coding of most mother infant behaviours difficult, which could have provided more information regarding the issues being investigated. Although we only selected the better-quality videos for analysis, this may constitute a selection bias. This decision reduced misclassification but at the cost of completeness, and any residual influence of unequal clip length was mitigated by reporting rates per minute and by normalising sequential probabilities within initial behaviours. Fifthly, our study was limited by the selection of time windows for analysis. While previous research suggests that synchrony is more likely to be observed within 3, 5, or 7 seconds, such research does not specify whether the synchrony should be from the interaction's beginning, middle, or end. Moreover, one study has recommended that coding the beginning of the interaction is sufficient to represent the entire interaction, as the statistical patterns of behaviour do not significantly change throughout the interaction. This suggests that manual coding of the entire interaction may not be necessary. More research is needed to determine which part of the interaction would provide better synchrony. Future studies should pre-register window sensitivity analyses that compare shorter and longer windows, for example sub second to ten seconds, and explicitly test whether estimates vary by the segment of the interaction coded. Sixthly, the home environment of the participants restricted free play, which was induced by the fact that most participants lived in one room apartments shared with other family members. While this may underestimate opportunities for interaction in some circumstances, it reflects the everyday context in which caregiving occurs in Soweto and

therefore increases ecological validity. On balance, we consider this feature a methodological strength for representing real world caregiving, and future work could compare sessions with and without additional caregivers present.

On another hand our study found that mothers primarily held their infants' hands during play, which limited the infants' hand movement and their ability to respond to their mothers or actively engage in play. This finding aligns with the idea that maternal touch is task-dependent and can influence how infants participate in interactions. One study demonstrated that mothers adjust the frequency and type of touch based on task demands, particularly in relation to whether objects are involved and the difficulty of the task (Serra et al., 2020). The prevalence of handholding in our study may suggest that mothers instinctively use touch as a means of guiding, stabilizing, or structuring the interaction, especially when they perceive the activity as requiring additional regulation or support.

However, while maternal touch can facilitate engagement, it may also limit the infant's ability to initiate movements and respond contingently to their mothers. Frequent handholding may reduce opportunities for spontaneous hand movements, which could impact the natural emergence of synchrony in mother-infant interactions. Research suggest that touch is adaptable and context-sensitive, meaning that in our study, excessive handholding may reflect mothers' attempts to scaffold the interaction but at the cost of restricting independent infant play and bidirectional coordination (Serra et al., 2020).

To better understand this dynamic, future research could explore how different types of maternal

touch (e.g., guiding vs. restrictive) influence synchrony and motor development across various play contexts. As research highlight, task complexity plays a key role in shaping maternal touch behaviours, and further investigation could help clarify how these variations impact infant development and interaction quality (Serra et al., 2020).

Conclusion

This study found relatively low frequencies and probabilities of mother infant synchrony in this sample, suggesting that further research is needed to determine whether interventions could enhance synchrony in similar populations. The study supports the effectiveness of micro analytical approaches for assessing behavioural synchrony and using first person observation (headcams) to collect data on mother infant interactions in low resource settings. These findings should be interpreted with caution given the small pilot sample, and larger, adequately powered studies are needed to replicate and extend these results in diverse settings.

Future Directions for Research

The findings of the study suggest several directions for future research. Firstly, this study should be replicated with a larger sample size to improve statistical power and allow for a more robust analysis of synchrony patterns. Secondly, there is a need to investigate the temporal and longitudinal patterns of both behavioural and movement synchrony in mother-infant dyads from South Africa and other similar settings. Thirdly, future studies should explore the factors that influence the synchrony of mother-infant non-verbal behaviours during the first year of life.

Acknowledgements: The authors express their gratitude to the Wellcome Trust, the National Institute for Health Research and the Center of Excellence in Human Development (CoE) for their financial support, which made this study possible. The authors further extend their deepest gratitude to the participants of the "PLAY Love and You" study and those who contributed to the original study's design, recruitment, and data collection.

Contributors: Coding of videos: DM, AP. Data processing and analysis: DM. Manuscript: DM wrote the initial draft of the paper. LHN edited the initial versions and guided on statistical analysis. AP, LHN, IN, RB and AM read and contributed to the final version. All authors edited and critiqued the manuscript for intellectual content.

Funding: This work was supported by the National Institute for Health Research (NIHR) (using the UK's Official Development Assistance Funding) and Wellcome (222007/Z/20/Z) under the NIHR-Wellcome Partnership for Global Health Research. The views expressed are those of the authors and not necessarily those of Wellcome, the NIHR or the Department of Health and Social Care. The support of the DSI-NRF Centre of Excellence in Human Development at the University of the Witwatersrand, Johannesburg, in the Republic of South Africa, towards this research is acknowledged. This work was supported by European Research Council (ERC) under the European Union's Seventh Framework Programme (grant FP/2007-2013), European Research Council Grant Agreements (grants 758813; MHINT). Opinions expressed and conclusions reached are those of the author and are not to be attributed to the CoE in Human Development.

Conflict of interests: The authors have no relevant financial or non-financial interests to disclose.

Ethical Considerations: This study was approved by the University of the Witwatersrand's Human Research Ethics Committee (M220785).

Consent to participate*:* Written informed consent was obtained from all CAG participants at recruitment.

Consent for publication: All CAG participants signed informed consent regarding publishing their data.

Supplemental material: This content has been supplied by the author(s).

SUPPLEMENTARY TABLES FOR STUDY 1

Table S1: Demographics

	Mother **(n= 14)**	**Infant** **(n= 14)**
Age (M, ±SD)	27.93 (8.94)	2.34 (1.74)
Infant Gender (%):		
Male		42.86
Female	100	57.14
Marital status (%):		
Single	71.43	
In A Relationship	14.29	-
Engaged	7.14	
Married	7.14	
Education (%):		
Secondary	28.57	
Matric	64.29	-
Tertiary	7.14	
Employment Status (%):		
Employed	78.57	-
Unemployed	21.43	
Other Children (Median, Range)	2 (0-5)	-

Table S2: The Frequencies and mean duration for no behaviour states and not possible to code behaviour states

	No Behaviour				**Not possible to code behaviour**			
	Infant		**Mother**		**Infant**		**Mother**	
	n	**Duration**	**n**	**Duration**	**n**	**Duration**	**n**	**Duration**
Touch Right Hand	111	3.57 (5.66)	75	3.17 (4.20)	120	14.38 (23.85)	173	7.36 (9.54)
Touch Left Hand	121	3.93 (6.69)	33	2.86 (3.69)	148	10.91 (23.36))	110	15.80 (25.33)
Gaze	30	2.93 (3.14)	7	1.46 (1.64)	200	5.64 (13.66)	236	9.77 (4.51)
Hand Movement	60	2.23 (1.83)	32	4.33 (6.85)	170	7.87 (11.25)	194	5.76 (6.87)
Play	138	10.47 (25.76)	128	8.32 (11.39)	136	4.92 (6.46)	135	5.58 (6.25)

Table S3a. Cross-sectional summaries of the frequency and probability of mother-infants non-matching behaviour pairs at the 3, 5 and 7 second time windows. Differences in medians between the time points assessed using the Kruskal Wallis with Dunn multiple comparisons test.

Behaviour pairs	**3s**		**5s**		**7s**	
Mother- Initiated Behaviour	**Freq**	**Prob**	**Freq**	**Prob**	**Freq**	**Prob**
Mother touch right hand– Infant gaze mother	5 (3-9)	0.16 (0.13-0.20)	7 (3-12)	0.15 (0.13-0.23)	10 (6-16)	0.21 (0.15-0.27)
Mother touch right hand – Infant play	1 (0-2)	0.00 (0.00-0.04)	2 (1-2)	0.03 (0.00-0.06)	2 (1-2)	0.03 (0.00-0.06)
Mother touch left hand – Infant gaze mother	3 (1-6)	0.19 (0.09-0.27)	4 (3-9)	0.25 (0.16-0.29)	6 (2-11)	0.27 (0.17-0.31)
Mother touch left hand – Infant play	0 (0-1)	0.00 (0.00-0.02)	1 (0-1)	0.00 (0.00-0.70)	1 (1-2)	0.07 (0.00-0.09)
Mother gaze infant – Infant reaching	1 (0-1)	0.01 (0.00-0.05)	1 (1-2)	0.02 (0.01-0.08)	2 (1-3)	0.04 (0.02-0.07)
Mother gaze infant – Infant play	3 (3-4)	0.04 (0.01-0.05)	4 (3-6)	0.03 (0.00-0.08)	4 (3-7)	0.03 (0.30-0.80)
Mother reaching – Infant gaze mother	3 (2-5)	0.23 (0.17-0.29)	4 (2-7)	0.21 (0.17-0.31)	5 (3-9)	0.27 (0.16-0.33)
Mother play – Infant gaze mother	3 (1-6)	0.20 (0.06-0.33)	6 (2-8)	0.16 (0.07-0.31)	8 (3-10)	0.17 (0.07-0.28)
Infant-Initiated Behaviour						

Infant touch right hand– Mother gaze infant	1 (0-2)	0.15 (0.00-0.23)	2 (0-5)	0.17 (0.00-0.25)	2 (0-5)	0.14 (0.00-0.26)
Infant touch right hand – Mother play	1 (0-3)	0.10 (0.00-0.19)	2 (0-5)	0.16 (0.00-0.25)	2 (0-5)	0.14 (0.00-0.19)
Infant touch left hand – Mother gaze infant	1 (0-3)	0.03 (0.00-0.27)	2 (0-3)	0.08 (0.00-0.27)	3 (1-4)	0.21 (0.60-0.30)
Infant touch left hand – Mother play	1 (0-2)	0.11 (0.00-0.19)	2.0 (0-3)	0.10 (0.08-0.15)	3 (1-7)	0.16 (0.09-0.20)
Infant gaze mother – Mother reaching	1 (1-7)	0.04 (0.01-0.07)	2 (1-9)	0.04 (0.02-0.11)	3 (2-10)	0.05 (0.03-0.10)
Infant gaze mother – Mother play	3 (1-5)	0.08 (0.04-0.10)	4 (3-8)	0.08 (0.07-0.17)	5 (4-10)	0.09 (0.06-0.17)
Infant reaching – Mother gaze infant	1 (0-2)	0.12 (0.05-0.29)	2 (1-4)	0.23 (0.11-0.33)	3 (1-5)	0.23 (0.12-0.31)
Infant play – Mother gaze infant	0 (0-1)	0.00 (0.00-0.03)	0 (0-1)	0.00 (0.00-0.02)	1 (1-2)	0.09 (0.02-0.17)

Table S3b. Changes in frequencies, probabilities, and duration of mother-infant non-matching behaviours over time (as a continuous variable), assesses by Multilevel Linear Models (MLMs). Data presented as beta coefficients (β) and confidence intervals.

Behaviour pairs	**Freq**		**Prob**		**Mother**		**Infant**	
Mother- Initiated Behaviour	**β**	**CI**	**β**	**CI**	**β**	**CI**	**β**	**CI**
Mother touch right hand– Infant gaze mother	1.38***	0.78-1.98	0.01**	0.003-0.02	0.18***	[0.10, 0.27]	0.21***	[0.11, 0.30]
Mother touch right hand – Infant play	0.27*	0.02-0.52	0.01	-0.001-0.01	0.18***	[0.12, 0.24]	0.48***	[0.28, 0.66]
Mother touch left hand – Infant gaze mother	0.85***	0.43-1.29	0.02***	0.01-0.03	0.28***	[0.16, 0.41]	0.09	[-0.02, 0.21]
Mother touch left hand – Infant play	0.19***	0.09-0.29	0.01*	0.001-0.01	0.28***	[0.16, 0.41]	0.50***	[0.29, 0.71]
Mother gaze infant – Infant reaching	0.37***	0.19-0.55	0.004	-0.001-0.01	0.17**	[0.05, 0.28]	0.24**	[0.05, 0.42]
Mother gaze infant – Infant play	0.36**	0.07-0.64	0.005*	0.001-0.01	0.17**	[0.05, 0.28]	0.39**	[0.11, 0.66]
Mother reaching – Infant gaze mother	0.68***	0.29-1.07	0.005	-0.003-0.01	0.05*	[0.01, 0.10]	0.13***	[0.05, 0.21]
Mother play – Infant gaze mother	1.04***	0.64-1.44	-0.004	-0.01-0.005	0.43***	[0.28, 0.57]	0.21***	[0.09, 0.34]
Infant-Initiated Behaviour					**Infant**		**Mother**	
Infant touch right hand– Mother gaze infant	0.44**	0.16-0.71	0.002	-0.01-0.01	0.08**	[0.03, 0.13]	0.32***	[0.10, 0.54]
Infant touch right hand – Mother play	0.36**	0.10-0.61	0.0001	-0.01-0.01	0.08**	[0.03, 0.13]	0.40***	[0.28, 0.52]
Infant touch left hand – Mother gaze infant	0.53*	0.07-0.99	0.03**	-0.005-0.06	0.14***	[0.06, 0.23]	0.21***	[0.08, 0.33]

Infant touch left hand – Mother play	0.48***	0.25-0.72	0.03	-0.01-0.06	0.14***	[0.06, 0.23]	0.22	[-0.03, 0.46]
Infant gaze mother – Mother reaching	0.58**	0.22-0.93	0.001	-0.003-0.01	0.16***	[0.10, 0.22]	0.11*	[0.004, 0.22]
Infant gaze mother – Mother play	0.86***	0.65-1.07	0.01*	0.001-0.01	0.16***	[0.10, 0.22]	0.30***	[0.14, 0.46]
Infant reaching – Mother gaze infant	0.34**	0.13-0.55	0.01*	0.0003-0.03	0.19**	[0.04, 0.35]	0.12**	[0.04, 0.21]
Infant play – Mother gaze infant	0.29**	0.14-0.44	0.02**	0.01-0.03	0.49***	[0.26, 0.73]	0.38*	[0.03, 0.72]

Statistically significant values are marked with asterisks, *p<0.05; **p<0.01; ***p<0.001.

Table S4a. Durations in seconds of mother-infants matching behaviour pairs at each time window, with beta coefficients.

Behaviour pairs	**3s**		**5s**		**7s**	
Mother- Initiated Behaviours	**Mother**	**Infant**	**Mother**	**Infant**	**Mother**	**Infant**
Mother touch right hand– Infant touch right hand	1.59 (1.28-2.26)	0.94 (0.63-1.47)	1.81 (1.55-2.24)	1.21 (0.85-2.06)	2.12 (1.77-2.74)	1.45 (0.7-2.85)
Mother touch left hand – Infant touch left hand	1.95 (1.57-2.32)	1.45 (0.75-2.17)	2.61 (1.72-3.16)	2.04 (0.82-2.43)	2.74 (2.40-4.04)	2.09 (1.4-3.41)
Mother gaze infant – Infant gaze mother	1.33 (1.17-1.47)	1.28 (1.08-1.74)	1.41 (1.23-1.89)	1.49 (1.29-2.14)	1.59 (1.35-2.17)	1.77 (1.65-2.25)
Mother reaching – Infant reaching	1.46 (1.02-2.13)	1.07 (1.03-2.28)	1.44 (1.10-2.53)	1.87 (1.77-2.80)	1.41 (1.14-2.65)	1.87 (1.55-3.75)
Mother play – Infant play	2.31 (1.92-2.89)	1.86 (1.13-2.40)	2.97 (2.58-4.13)	3.13 (2.67-3.52)	3.41 (3.17-4.24)	5.13 (3.58-6.73)
Infant-Initiated Behaviours	**Infant**	**Mother**	**Infant**	**Mother**	**Infant**	**Mother**
Infant touch right hand– Mother touch right hand	1.97 (1.22-2.16)	1.66 (1.36-1.93)	1.80 (0.7-2.54)	2.07 (1.69-3.10)	2.00 (0.77-2.71)	2.53 (1.79-3.43)

Infant touch left hand – Mother touch left hand	1.98 (1.86-2.30)	1.92 (1.22-2.75)	2.47 (2.14-2.87)	2.63 (1.45-4.00)	2.60 (2.01-3.13)	2.44 (1.57-4.22)
Infant gaze infant – Mother gaze infant	1.39 (1.26-1.75)	1.32 (0.76-1.86)	1.78 (1.44-2.20)	1.94 (1.01-2.25)	2.12 (1.66-2.43)	2.06 (1.09-2.49)
Infant reaching – Mother reaching	1.91 (1.41-2.55)	0.88 (0.65-1.49)	1.94 (1.71-2.55)	1.00 (0.69-1.90)	2.07 (1.55-2.68)	1.36 (0.69-1.89)
Infant play – Mother play	2.62 (2.41-2.82)	2.66 (2.25-3.00)	3.54 (3.29-4.32)	4.12 (2.89-5.00)	4.54 (3.75-5.82)	5.41 (3.57-6.92)

Median (Inter-quartile range) durations are presented for mothers and infants at 3, 5 and 7 seconds.

Table S4b. Cross-sectional summaries of the duration of mother-infants non-matching behaviour pairs at the 3, 5 and 7 second time windows. Differences in medians between the time points assessed using the Kruskal Wallis with Dunn multiple comparisons test.

Behaviour pairs	**3s**		**5s**		**7s**	
Mother-Initiated Behaviour	**Mother**	**Infant**	**Mother**	**Infant**	**Mother**	**Infant**
Mother touch right hand– Infant gaze mother	1.59 (1.28-2.26)	1.24 (1.03-1.94)	1.81(1.55-2.24)	1.70 (1.30-2.91)	2.12 (1.77-2.74)	1.99 (1.29-3.25)
Mother touch right hand – Infant play	1.59 (1.28-2.26)	2.38 (1.75-2.70)	1.81 (1.55-2.24)	3.40 (2.10-4.85)	2.12 (1.77-2.74)	3.88 (2.23-5.56)
Mother touch left hand – Infant gaze mother	1.95 (1.57-2.32)	1.42 (1.10-1.92)	2.61 (1.72-3.16)	1.73 (1.17-2.06)	2.74 (2.40-4.04)	1.71 (1.26-2.27)
Mother touch left hand – Infant play	1.95 (1.57-2.32)	2.36 (1.50-3.00)	2.61 (1.72-3.16)	3.08 (2.43-4.43)	2.74 (2.40-4.04)	3.43 (2.43-6.94)
Mother gaze infant – Infant reaching	1.33 (1.17-1.47)	1.42 (0.77-2.97)	1.41 (1.23-1.89)	1.58 (1.27-4.03)	1.59 (1.35-2.17)	2.16 (1.06-4.03)

Mother gaze infant – Infant play	1.33 (1.17-1.47)	2.19 (1.23-2.95)	1.41 (1.23-1.89)	3.12 (2.23-4.95)	1.59 (1.35-2.17)	1.95 (1.86-6.23)
Mother reaching – Infant gaze mother	1.46 (1.02-2.13)	1.46 (1.02-2.13)	1.44 (1.10-2.53)	1.53 (1.20-1.71)	1.41 (1.14-2.65)	1.54 (1.03-2.05)
Mother play – Infant gaze mother	2..31 (1.92, 2.89)	1.12 (0.91, 1.78)	2.97 (2.58, 4.13)	1.56 (1.24, 2.21)	3.41 (3.17, 4.24)	1.77 (1.50, 2.73)
Infant-Initiated Behaviour	**Infant**	**Mother**	**Infant**	**Mother**	**Infant**	**Mother**
Infant touch right hand– Mother gaze infant	1.97 (1.22-2.16)	1.58 (1.16-2.81)	1.80 (0.77-2.54)	1.35 (1.12-2.96)	2.00 (0.0.77-2.71)	2.39 (1.19-4.48)
Infant touch right hand – Mother play	1.97 (1.22-2.16)	1.98 (1.16-2.81)	1.80 (0.77-2.54)	2.71 (2.60-3.62)	2.00 (0.0.77-2.71)	3.12 (2.61-3.73)
Infant touch left hand – Mother gaze infant	1.98 (1.86-2.30)	1.67 (1.00-2.27)	2.47 (2.14-2.87)	1.58 (1.32-2.64)	2.60 (2.01-3.13)	1.88 (0.91-2.72)
Infant touch left hand – Mother play	1.98 (1.86-2.30)	2.23 (1.53-2.64)	2.47 (2.14-2.87)	2.72 (2.14-3.33)	2.60 (2.01-3.13)	2.65 (1.61-4.00)

Infant gaze mother – Mother reaching	1.39 (1.26-1.75)	0.84 (0.46-1.77)	1.78 (1.44-2.20)	1.29 (0.88-1.75)	2.12 (1.66-2.43)	1.28 (0.64-0.04)
Infant gaze mother – Mother play	1.39 (1.26-1.75)	1.84 (1.38-2.59)	1.78 (1.44-2.20)	2.60 (1.76-3.53)	2.12 (1.66-2.43)	2.95 (2.08-3.74)
Infant reaching – Mother gaze infant	1.91 (1.41-2.55)	1.42 (1.07-2.08)	1.94 (1.71-2.55)	1.57 (1.30-2.50)	2.07 (1.55-2.68)	1.93 (1.34-2.32)
Infant play – Mother gaze infant	2.62 (2.41-2.82)	2.32 (2.11-3.00)	3.54 (3.29-4.32)	3.20 (2.41-5.00)	4.54 (3.75-5.82)	3.75 (2.33-6.19)

Median (Inter-quartile range) durations are presented for mothers and infants at 3, 5 and 7 seconds.

Table S5a. Kruskal Wallis p-values comparing the frequencies and probabilities of matching behaviour pairs between paired time windows

Matching behaviour pairs	**Frequencies**			**Probabilities**		
Mom's Initiated Behaviour	**3s and 5s**	**3s and 7s**	**5s and 7s**	**3s and 5s**	**3s and 7s**	**5s and 7s**
Mom touch right hand– Infant touch right hand	0.40	0.24	0.70	0.58	0.66	0.90
Mom touch left hand - Infant touch left hand	0.23	0.14	0.69	0.28	0.25	0.85
Mom gaze infant – Infant gaze mom	0.47	0.20	0.53	0.66	0.21	0.35

Mom reaching – Infant reaching	0.63	0.16	**0.38***	0.97	0.59	0.57
Mom play – Infant play	0.95	0.78	0.86	0.77	0.70	0.90
Infant's Initiated Behaviour						
Infant touch right hand– Mom touch right hand	0.20	0.11	0.66	0.90	0.92	0.76
Infant touch left hand - Mom touch left hand	0.47	0.12	0.47	0.88	0.26	0.44
Infant gaze infant – Mom gaze infant	0.34	0.14	0.41	0.22	0.13	0.45
Infant reaching – Mom reaching	0.84	0.53	0.68	0.91	0.99	0.83
Infant play – Mom play	0.86	0.82	0.96	0.90	0.81	0.81

Table S5b.7 Kruskal Wallis p-values comparing the frequencies and probabilities of non-matching behaviour pairs between paired time windows

Non-matching behaviour pairs	**Frequencies**			**Probabilities**		
Mom's Initiated Behaviour	**3s and 5s**	**3s and 7s**	**5s and 7s**	**3s and 5s**	**3s and 7s**	**5s and 7s**
Mom touch right hand– Infant gaze mom	0.38	0.08	0.35	0.97	0.22	0.30
Mom touch right hand – Infant play	0.27	0.27	0.88	0.40	0.38	1.00
Mom touch left hand - Infant gaze mom	0.34	0.13	0.48	0.48	0.11	0.35
Mom touch left hand – Infant play	0.50	0.10	0.38	0.45	0.09	0.73
Mom gaze infant – Infant reaching	0.19	**0.01***	0.11	0.39	0.13	0.51
Mom gaze infant – Infant play	0.53	0.38	0.75	0.99	0.53	0.59
Mom reaching – Infant gaze mom	0.56	0.20	0.47	0.88	0.74	0.60
Mom play – Infant gaze mom	0.19	0.04	0.22	0.94	0.79	0.97
Infant's Initiated Behaviour						
Infant touch right hand– Mom gaze infant	0.16	0.16	0.93	0.53	0.94	0.74
Infant touch right hand – Mom play	0.39	0.33	0.85	0.63	0.90	0.48
Infant touch left hand - Mom gaze infant	0.63	0.19	0.39	0.74	0.20	0.30
Infant touch left hand – Mom play	0.33	0.11	0.37	0.86	0.26	0.28

Infant gaze mom – Mom reaching	0.44	0.18	0.46	0.87	0.60	0.76
Infant gaze mom – Mom play	0.13	**0.02***	0.29	0.35	0.26	0.88
Infant reaching – Mom gaze infant	0.14	0.07	0.47	0.29	0.32	0.93
Infant play – Mom gaze infant	1.00	0.08	0.08	1.00	0.04	0.04



Figure S1. An example of paired mother-infant gaze behaviours showing less synchrony according to visual interpretation.

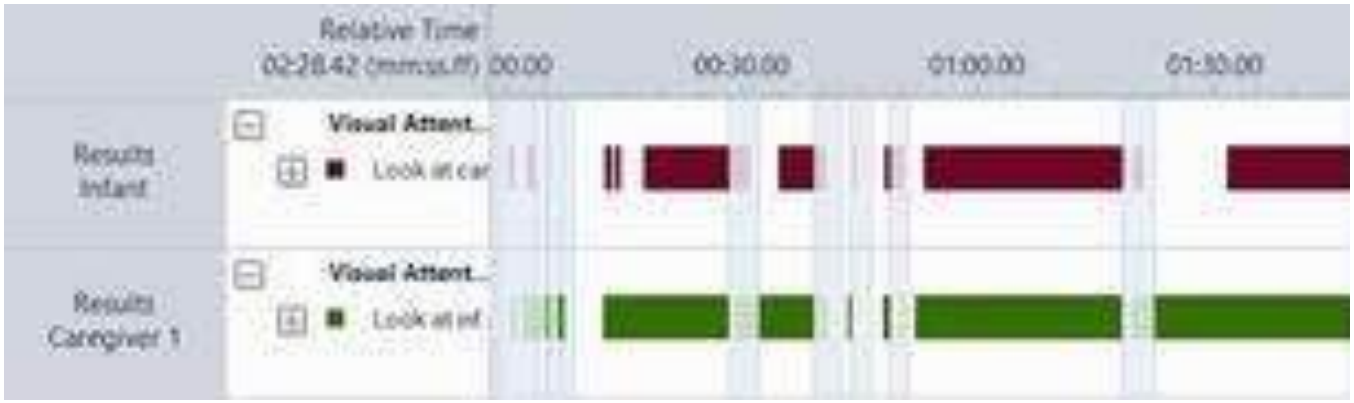


Figure S2. An example of paired mother-infant gaze behaviours showing more synchrony according to visual interpretation.

Table S6. Description of mother-infant behaviour codes according to the coding scheme used in this study.

Behaviour	Description
Touch with Right (R) Hand	
Any physical contact made by either dyad member using the right hand, lasting for at least one second, was coded.	
Infant touch right hand	A behaviour code was assigned when the infant intentionally and actively manipulated a stimulus object (object/body) with the right hand.
Touch mother's hand/body.	This modifier indicated that the infant was actively touching the hand and or the body of the mother.
No infant touch R	This modifier indicated that the infant was not actively or purposefully touching anything with the right hand.
Not possible to code touch R	This modifier indicated that the infant's right hand was not visible.
Mother touch right hand	This behaviour code was assigned when the mother actively and purposefully touched anything with the right hand.
Touch Infant	This modifier indicated that the mother touched the infant with her hand. Touch included instances when the mother adjusted the infant's position. If the mother was touching the infant using an inanimate object. In that case, we only code 'Touch infant 'if the object is made of paper or cloth and the touching occurred in a caregiving context, e.g., wiping food from the infant's face. We also coded 'Touch infant' when the infant was sitting on a surface other than the mother's body, and the mother supported their

	posture with her hands. Repetitive playful touching was coded as one continuous touch.
No caregiver touch R	This modifier indicated that the mother was not actively or purposefully touching anything with the right hand.
Not possible to code touch R	This modifier indicated that the right hand of the mother and/or of the infant was not visible.

Touch with Left (L) hand

Any physical contact made by either dyad member using the left hand, lasting for at least one second, was coded.

Infant touch left hand	This behaviour code was assigned when the infant actively and purposefully manipulated a stimulus object (object/body) with the left hand.
No infant touch L	This modifier indicated the infant did not actively or purposefully touch anything with the left hand.
Not possible to code touch L	This modifier indicated when the left hand of the infant was not visible.
Mother touch left hand	This behaviour code assigned to the mother actively and purposefully touched anything with the left hand.
No caregiver touch L	This modifier indicated when the mother was not actively or purposefully touching anything with the left hand.
Not possible to code touch L	This modifier indicated when the left hand of the mother was not visible.

Gaze or Visual Attention

This behaviour code was assigned to fixed visual focus, often accompanied by active engagement, such as brightening or widening eyes when they first look toward something.

Look at infant	This modifier indicated that the mothers looked at the infant's face or head area. The infant doesn't need to return the mother's gaze or respond in any manner.
Look at Caregiver 1	This modifier indicated that the infant looked at the mother's face or head area. The mother need not return the infant's gaze or respond in any manner. The mother was required not to be continually on film for this to be scored.
No visual attention	This modifier indicated that the mother or infant was not looking at anything codable (e.g., looking down or having eyes closed)
Not possible to code visual attention	This modifier indicated that the visual focus of the mother or infant was unclear, such as the mother or infant was off-camera, or the mother or infant's eyes were closed. When the mother or infant's location was uncertain or unsure whether the mother's face was within the infant's view, we coded "Not possible to code".

Hand movement

This behaviour code was assigned to the movement of the mother or infant's hand towards a target location with an open hand, ready to grasp an object.

Reaching	This modifier indicated that the infant's reaching was an intentional attempt to grasp a stationary or moving object. The arm movement needed not to be random but a visually guided, goal-oriented effort to reach the target object. The reaching attempt did not always result in grasping the

	object (von Hofsten & Lindhagen, 1979). Reaching behaviours included attempts to grasp, touch, or swat at objects. When the target was missed, the hands stopped and remained mid-air whilst still extended in the direction of the object. The reaching modifier code also included pre-reaching and pre-gasping movements, such as extended arms and hands to establish body contact, extended clenched fists to swat at a distant object without making contact, or extended arm and open hand to touch distant targets.
No hand movements	This modifier indicated that none of the above hand movements are occurring. The hands and arms were still, or no meaningful hand movement occurred.
Not possible to code hand movements	This modifier indicated that the footage's quality or the mother's or infant's position did not allow the coder to evaluate whether some hand movements were occurring.

Physical play

This behaviour code was assigned to the mother engaging in physical play or communicating clear positive affect to their infants through physical means with the baby or communicating clear or positive affect to the infant physically.

Caregiver:	This modifier indicated that mothers engaged in playful interactions with the infant, intending to elicit positive responses such as smiles, vocalisations, laughter, or motoric excitement. These interactions were coded regardless of their duration. The mother initiated playful physical contact such as tickling, jiggling, nibbling, bouncing the infant on her lap,

	lifting the infant high into the air, "flying" the infant, exaggerated kissing, etc. The mother's behaviour was intended to be playful, not simply touching or holding the infant. For example, the mother would play a game that involves physically manipulating the infant's body.
Infant:	This modifier indicated that infant engaged in playful behaviours with their mother or objects. The infant actively approached the mother or object with a playful intent, which included a simple and direct exploration of the object. This behaviour was coded as functional play.
No physical play:	This modifier indicated that neither the mother nor the infant engaged in playful behaviour. Although they might have touched toys simultaneously, this did not constitute physical play unless their actions were motivated by entertainment, joy, exploration, or amusement.
Not possible to code physical play	This modifier indicated that it was uncertain whether a specific behaviour occurred or was not observable due to factors such as the mother or infant being off-camera or low video quality.

3.3. Study 2: Movement synchrony (Accelerometry)

Determining synchrony of mother-infant movement behaviours using accelerometry

Dumsile Maduna[1*], Lukhanyo H. Nyati[1,2], Alessandra Prioreschi[1], Rebecca Pearson[3], Ansuyah Magan[1], Ian Nabney[4]

Author affiliations

[1]SAMRC/Wits Developmental Pathways for Health Research Unit, Department of Paediatrics and Child Health, Faculty of Health Sciences, School of Clinical Medicine, University of the Witwatersrand, Johannesburg, South Africa. [2]Interprofessional Education Unit, Faculty of Health Sciences, University of the Western Cape, South Africa. [3]Department of Psychology, Manchester Metropolitan University. United Kingdom. [4]School of Engineering Mathematics and Technology, University of Bristol. United Kingdom.

Correspondence to Dumsile Maduna; dumsilesdmaduna@gmail.com

Abstract

Background: Movement synchrony between mothers and infants is a marker of relational health, yet evidence from low and middle-income countries is limited. We examined synchrony structure and timing using accelerometry in South African dyads.

Methods: Sixty-two mother-infant pairs from Soweto wore Axivity AX3 accelerometers for seven days at four months postpartum. Raw acceleration was processed as ENMO, Euclidean Norm Minus One, vector magnitude minus 1 g, averaged in one-second epochs. High activity periods used participant-specific 75th percentile thresholds. Synchrony was assessed with rolling correlations, 10-minute window, time-lagged cross-correlation on minute ENMO with a five-minute lag window; positive lags denote mother leading and negative lags infant leading, Dynamic Time Warping, and wavelet coherence. Diurnal windows were defined a priori: morning 06:00 to 11:59, midday 12:00 to 14:59, late afternoon 15:00 to 19:59.

Results: Co-active high activity periods comprised 5.8 percent of monitoring time. Synchrony was stronger during these windows, mean r 0.35, than during general periods, mean r 0.22. Lagged cross-correlation showed mother-led and infant-led sequences at small positive or negative lags. Dynamic Time Warping indicated close alignment, and wavelet coherence showed peaks in the 4 to 16-minute band. Synchrony recurred in mid-morning and late afternoon, aligning with household routines.

Conclusion: This first objective characterisation in South Africa shows synchrony is dynamic, episodic, and structured by daily routines, with implications for early relationship support.

Keywords: mother-infant synchrony, accelerometry, movement behaviour, early interaction, South Africa

1.0 Introduction

Movement during infancy lays the foundation for later physical, cognitive, and emotional development. In the Soweto context, where infants often share sleeping and living spaces with multiple family members, the types and timing of movements are shaped by household routines, space constraints, and caregiver availability. Extensive literature supports the need to establish healthy movement habits in early childhood to promote long-term child development (Bruijns et al., 2020; Ward et al., 2010). Movement behaviours, such as physical activity, controlled screen time, and adequate sleep, have a significant impact on the physical, cognitive, social and emotional development of children under the age of five (Draper et al., 2020; WHO., 2019; Laureus.)

Notably, physical activity habits formed during early life often continue into later childhood and adolescence (Bruijns et al., 2020), highlighting the need to encourage physical activity from an early age. Engaging in physical movement from birth through early childhood (0-5 years) provides numerous benefits, including improved cardiometabolic biomarkers (Müller et al., 2020; Timmons et al., 2012), enhanced mental and cognitive development (Carson et al., 2017), and improved social development (Müller et al., 2020; Prioreschi, Brage, et al., 2018; Timmons et al., 2012) (Chaput et al., 2014).

To promote optimal mobility and overall health in children, international age-specific guidelines have been developed and adopted locally (Draper, Tomaz, Cook, et al., 2020; WHO, 2019). In South Africa, the “The South African 24-hour movement guidelines for birth to 5 years”

highlight the importance of encouraging children to engage in age-appropriate physical activity that is both enjoyable and safe. These guidelines also discourage sedentary behaviours, such as sitting activities involving watching screens, and emphasise the need for adequate sleep for children under five years of age (WHO., 2019). Striving for a balanced combination of activities throughout a typical 24-hour day is crucial for optimising child development (Draper, Tomaz, Biersteker, et al., 2020).

Caregivers are essential in supporting infant movement, often through routine tasks like walking while holding the child or placing toys just out of reach to encourage crawling. In our study, mothers often noted that movement occurred most during play, feeding, or household chores, suggesting that synchrony is embedded in everyday activities rather than structured play sessions alone.

While movement behaviours offer valuable insights into the quality of relationship traits and emotional states, measuring and assessing bodily movement can be complex and challenging (Albinali et al., 2009). Traditional methods like behavioural observations and motion sensors (Skender et al., 2016) have limitations such as costs, time consumption, recall bias and subjective measurement (Ferrari et al., 2007; Neilson et al., 2008). However, recent advances in motion capture technology, particularly wearable devices (An et al., 2012) like body-worn accelerometers, offer a more precise and objective means of measuring movement.

Accelerometry has become popular as a data collection tool (Troiano, 2005) and is considered the gold standard for objectively measuring physical activity in infants and toddlers (Bruijns et

al., 2020). These small battery-operated devices measure acceleration allowing real-time evaluation of movement intensity, duration, and frequency (Taffoni et al., 2018; Yang & Hsu, 2010). A wearable band with an accelerometer designed to measure an infant's 24-hour movement has been developed (Prioreschi, Nappey, et al., 2018). In the present study we focus on movement synchrony, defined as time aligned covariation in wrist acceleration between mothers and infants across seconds to minutes. Wrist worn devices record tri axial acceleration that we convert to Euclidean Norm Minus One, ENMO, a gravity corrected vector magnitude that indexes movement intensity rather than the content of the activity.

We operationalise synchrony with complementary time series tools. Pearson correlations of aligned ENMO streams quantify overall coupling, time lagged cross correlation examines directionality, with positive lags interpreted as mother leading and negative lags as infant leading, and wavelet coherence summarises the timescales at which coupling is strongest (van Hees et al., 2013; Chetouani et al., 2017). Movement synchrony, as used here, is distinct from behavioural synchrony coded from video and from physiological synchrony, for example heart rate variability, and it complements these modalities in an integrated framework (Feldman, 2007; Leclère et al., 2014).

Interpretation depends on developmental stage and proximity. At around four months, mothers and infants are typically in close contact during routine care, so co movement can reflect shared tasks and brief sequences of leading and following (Draper et al., 2018; Prioreschi et al., 2017). As children enter toddlerhood and school age, increasing independence and time apart mean that accelerometry based coupling is more likely to index specific shared activities rather than

constant co presence. Our inferences are therefore constrained to early infancy and should not be generalised to older ages without designs that account for changing proximity and roles.

When applied to assessing interactions between mothers and infants, advancements in wearable accelerometry provide detailed, objective measurements of movement synchrony through first-person observation in a natural, free-living home environment (Prioreschi et al., 2023c). These technologies allow for a more comprehensive approach to analysing mother-infant movement synchrony compared to traditional laboratory settings (Ward et al., 2010). In this study, we aim to quantify the degree of synchrony in mother-infant movement behaviours using Accelerometer data collected over 7 days. By using motion capture technology, we explored the dynamics of synchrony in raw acceleration data to gain insights into movement patterns throughout the day (Ward et al., 2010). We examined coupling at daily and sub daily timescales using Pearson correlations, time lagged cross correlation, and wavelet coherence

The primary objective of this study was to assess the degree of synchrony in movement between mothers and infants over time, identifying patterns of synchrony at different times of day across the 7 days. Additionally, we sought to examine how movement synchrony changed within dyads across repeated measures, such as hours and days. We hypothesise that greater synchrony in mother-infant movement behaviours is associated with higher levels of physical activity and reflects the quality of their interactions.

2.0 Methods

2.1 Study setting and participants.

This study was conducted as part of the Play, Love, and You (PLAY) study, a randomised controlled trial. The PLAY study aimed to implement and test the efficacy of an intervention designed to promote growth and development through responsive caregiving and interactive play (Prioreschi et al., 2023). Movement data were collected from 66 mother-infant dyads in Soweto, specifically from a group of play study participants who had previously had movement data recorded when their infants were 4 months old. Inclusion criteria for participants were women aged >18 years, mothers with 4-month-old infants, primary caregivers, and those living in Soweto. Participants with any disabilities, impairments, or diseases that could restrict movement or limit common behaviour, as indicated by the Road to Health book and medical records, were excluded. Participants provided their consent to participate in the study and for their movement data collected from the accelerometers to be shared with colleagues for analysis by signing a consent form. This study was approved by the University of the Witwatersrand's Human Research Ethics Committee (REF: M220785 and is a sub-study of the PLAY Study (REF: M220217).

2.2 Accelerometer Training for the PLAY Study

The research team of the PLAY Study underwent comprehensive training on accelerometry to ensure accurate and efficient collection and analysis of Accelerometer data. The entire team,

consisting of seven members, attended a week-long workshop in 2022 for this training. The training covered the theoretical and practical aspects of accelerometry, including initialising accelerometers on the team's laptops, retrieving data from accelerometers, and implementing quality assessment techniques to address any issues that arose during fieldwork. The emphasis was placed on recognizing malfunctioning monitors to remove them from the device pool and prevent their use (Westgate et al., 2019). The Principal Investigator (PI) conducted a demonstration during the practical sessions, illustrating the proper placement of accelerometers on participants. Staff members were then given accelerometers and straps to engage in partnered exploration, with a simple reference guide provided to assist them in explaining and attaching the accelerometers to their partners in a role-play scenario (Westgate et al., 2019). The PI supervised this exercise to ensure accurate device placement.

In preparation for the 4-month visit, a refresher training was conducted exclusively for fieldwork staff. The training focused on the technical aspects of using accelerometers including a recap on device initialisation, data retrieval, data scrutiny, and identification of accelerometers issues before returning to the field. Furthermore, in 2021, the first author participated in an online training (WAAMA training), offered by the MRC Epidemiology Unit. The training focused on Accelerometer data processing, analysis, and interpretation.

To ensure the proper functioning of the accelerometers and the team's readiness to collect and manage data from study participants, the research team conducted pilot testing. As part of this process, members of the research team volunteered to wear the accelerometers with their infants. This allowed for testing the functionality of all three axes of the monitors and provided practical

experience wearing the accelerometers (Westgate et al., 2019). After the 7-day test, the recorded data were downloaded and reviewed to confirm their accuracy, providing the research team with real-world data to download, analyse and become familiar with all aspects of the data collection and management process (Westgate et al., 2019). This pilot testing instilled confidence in the research team to address any questions from study participants(Westgate et al., 2019).

2.3 Data Collection

2.3.1 Primary outcome data: Accelerometry

Movement data **were** collected from mother infant dyads between May and October 2023. We used Axivity AX3 devices, Axivity Ltd, Newcastle, UK, worn on the non-dominant wrist by mothers and on the left wrist by infants, recording raw tri axial acceleration at 100 Hz. The AX3 measures acceleration only and does not record heart rate. Device clocks were synchronised prior to deployment and data were downloaded with OMGUI. Placing the monitor on the less dominant wrist is a common research practice and is believed to have a stronger association with overall physical activity across the body (White et al., 2019; White, Westgate, Wareham, and Brage, 2016). This protocol was adapted from the STEPS pilot study in Malawi (Westgate et al., 2019).

Device preparation processes: The accelerometer-handling system used in this study was similar to the one used in the STEPS pilot study in Malawi. This system includes initialising

accelerometers, deploying them, collecting data, downloading data, and performing quality control (QC) (Westgate et al., 2019).

Accelerometer initialisation: Before data collection, the accelerometers were fully charged on site, and the battery was tested to ensure it would last for the required 7 of data collection in the field. All devices were initialised to ensure proper configuration and labelling before being assigned to participants. Device parameters were set using Omgui, a software installed on the research assistants' laptops. During the initialization step, accelerometers were programmed with the participant study (PID) number, accelerometer serial number, and usage start time. This was done to ensure that each accelerometer file contained the current participant PID number, avoiding problems in subsequent stages of data processing and analysis when matching accelerometer files to participants. A log file was kept, recording the details of device deployment, which enabled the linking of the participant and device during later analysis.

Accelerometer Deployment: Research assistants deployed accelerometers to participants on site during the 4-month visit. In cases where participants could not attend this visit, home visits were conducted by the research assistants to deploy the devices. All devices were kept in pre prepared packs labelled with participants' ID numbers. Research assistants provided instructions on how to use the accelerometers and demonstrated their use during hospital or home visits. Instructions were provided verbally, with a one-page sheet and a short video in local languages and included wear for 24 hours for seven consecutive days, removal only for marked skin irritation, and contact details for study staff. Participants left the facility already wearing their devices and were

instructed not to remove them unless they experienced discomfort or wrist allergies, such as a rash. In such cases, they were told to contact the research assistant immediately.

Accelerometer Collection: After 7 days of wear, accelerometers were collected from participants, primarily through home visits by the research assistants.

2.3.2 Demographic data:

During the recruitment process, an electronic questionnaire was utilized to collect demographic information such as the age and gender of the infant, maternal age, marital status, employment status, and education. The marital status categories were single, married, engaged, or in a relationship. Employment status was classified as either employed or unemployed. Education status was classified at three levels: grade 12, secondary (grades 8-11), and higher education. The research assistants administered the questionnaires. All the data collected from the questionnaire were stored in the Research Electronic Data Capture (REDCap) tool maintained by the University of Witwatersrand (Harris et al. 2009; Harrist et al. 2019). Maternal age was calculated using the self-reported date of birth, while the infant age was calculated using the date of birth obtained from the Road to Health Booklet.

3.0 Statistical Analysis

All statistical analyses were conducted using R (version 4.4.2), alongside Stata for selected descriptive analyses. The analytical strategy was developed to reflect the longitudinal, dyadic structure of the data, the time-series nature of accelerometry, and the real-world caregiving

routines observed in urban South African households. The main objective was to examine how mother-infant movement synchrony unfolded across seven continuous days, with specific attention to the timing, strength, and structure of shared movement behaviour.

3.1 Data Processing and Outcome Measures

After retrieval from the field, accelerometers were connected to laptops, where data were downloaded, labelled, and quality-checked using OmGui open-source software (Version 1.0.0.28, Open Movement, Newcastle, UK) (Prioreschi et al., 2023). Data were initially stored in .cwa format, auto calibrated, and converted to .wav files. Each device records three continuous acceleration streams, x, y, and z, that we auto-calibrated to local gravity and aggregated into 5-second epochs before deriving analysis variables.

Basic quality control (QC) procedures were conducted to evaluate:

- The number of days recorded,
- Compliance with the wear protocol (minimum 5 days, with 24-hour recording),
- File download success,
- Timestamp stability (no jumps or repeated timestamps),
- Battery consistency over the recording period,
- Movement responsiveness across all axes (with expected fluctuation when worn, and flat lines when not).

Accelerometers that did not meet QC standards were removed from circulation and logged for re-testing. A detailed study logbook was maintained to document device deployment, retrieval dates, and any device-specific issues.

Further in-depth processing was carried out using the Wave software (https://github.com/MRC-Epid/Wave/releases/tag/v1.0.0-Beta), applying the following parameters:

- Sampling rate: 100 Hz,
- Noise cut-off: 13 mg,
- Dynamic range set for Axivity AX3 devices, approximately ±8 g,
- Epochs of 5 seconds,
- Noise and gravity removal,
- Vector magnitude and ENMO processing, with ENMO defined as $\sqrt{(x^2+y^2+z^2)}$ minus 1 g, negative values rounded to zero, expressed in milligravity units, mg,
- Removal of non-wear periods.

The processed output is a time series where each 5 second epoch represents mean ENMO, mg, for that interval.

A harmonised R and Stata script, adapted from the MRC Epidemiology Unit at the University of Cambridge, and contextualised for South African data, was used for the final cleaning, merging, and labelling process.

3.2 Descriptive Statistics and Participant Characteristics

To provide an overview of the study population, categorical variables such as infant sex, maternal marital status, educational attainment, and employment status were summarised using frequencies and percentages. For continuous and discrete variables such as infant age, maternal age, and the number of other children in the household, medians and interquartile ranges (IQRs) were reported due to skewed distributions.

In addition, core accelerometry related indicators were summarised, including:

- Daily wear time (in hours),
- Average, maximum, and total ENMO values (in milligravity, mg) for both mothers and infants.

These descriptive summaries provided context for the sample and informed decisions regarding inclusion in subsequent synchrony analyses. Only dyads with at least five full days of wear time and a daily average of 13+ hours were retained. The first and last recording days were excluded due to partial wear or artefacts related to device placement and removal.

3.3 Generating Physical Activity Indicators

Each mother and infant's movement profile was processed at minute, hourly, and daily levels using ENMO (Euclidean Norm Minus One) as the key indicator of physical movement. ENMO, the Euclidean Norm Minus One, was computed as the square-root of x^2 plus y^2 plus z^2 minus 1 g, negative values truncated to zero, and expressed in milligravity, mg. ENMO is a validated,

device-agnostic measure of total body acceleration and is well-suited to summarise free-living movement behaviours (Westgate et al., 2019).

To capture within-day movement variation, the 24-hour period was segmented into four diurnal intervals:

- Morning (00:00–05:59),
- Noon (06:00–11:59),
- Afternoon (12:00–17:59),
- Night (18:00–23:59).

The average time spent moving during each interval was calculated to explore diurnal movement rhythms across the week and by participant type (mother vs infant).

3.4 Identifying High-Activity Periods

To identify meaningful episodes of interaction, high activity thresholds were derived for each participant by calculating the 75th percentile ENMO mean values across the recording period. When both mother and infant simultaneously exceeded their individual thresholds, these time points were flagged as co active high activity periods. For each dyad and day, we derived the number of co-active bouts, total minutes in co-activity, mean bout duration, and the proportion of monitored time spent co-active. Within each co active bout we also recorded the lag at which the peak cross correlation occurred to indicate directionality. These windows likely represent moments of shared engagement, for example play or caregiving transitions, and were analysed

separately from general activity windows to examine whether synchrony was more prominent during these co regulated episodes.

3.5 Generating Movement Synchrony Variables

The core aim of this analysis was to evaluate movement synchrony between mothers and infants over time. Due to the absence of validated movement intensity cut-offs for infants, we opted to assess synchrony using continuous correlation of ENMO signals, rather than categorising movement by intensity levels.

Three key questions were explored to describe synchrony:

- *Frequency of synchrony* – How often were the mother's and infant's movement signals aligned? This was measured by calculating the proportion of time points with correlated signals across the monitoring period.
- *Duration of synchrony (bouts)* – How long did each episode of synchrony last? Bout lengths were calculated based on uninterrupted windows of high correlation.
- *Timing of synchrony* – At what times of the day was movement alignment most likely. Synchrony was stratified by diurnal period to assess how patterns followed caregiving routines.

3.6 Rolling Correlation Analysis

We applied a rolling window correlation using a 10-minute window to calculate Pearson

correlation coefficients between mother and infant ENMO values over time. This allowed us to examine short-term fluctuations in synchrony throughout each day and to capture dynamic changes in relational coordination. Rolling correlation results were summarised overall and stratified by high activity versus general periods. Results were visualised in shaded time series plots to show variability in synchrony over time.

3.7 Cross-Correlation for Directionality

To detect potential leading following patterns, cross correlation analysis was performed with time lags ranging from minus 5 to plus 5 minutes. Positive lags indicate that the infant's movement followed the mother's, mother led, whereas negative lags indicate that the mother followed the infant, infant led. For each dyad, peak correlation values and the direction of lags were summarised to characterise dyadic directionality.

3.8 Dynamic Time Warping (DTW)

Dynamic Time Warping was used to assess the global alignment of mother infant movement trajectories, even when not perfectly time matched. DTW accounts for flexible timing differences by warping one time series to match the other. Prior to DTW, ENMO series were z scored within participant and day to place partners on a common scale. DTW returns a unitless distance that reflects the minimal cumulative absolute difference between the two standardised series after local time stretching. Smaller distances indicate more similar trajectories, and larger distances indicate poorer alignment.

3.9 Wavelet Coherence Analysis

To capture synchrony across multiple timescales, we conducted wavelet coherence analysis. This method identifies synchrony not only in time but also in frequency, allowing us to detect nested behavioural rhythms. Coherence was examined primarily within the 4–16-minute range, as this window often reflects typical interactional episodes (e.g., feeding, soothing, transitions between sleep and wakefulness).

3.10 Synthesis of Synchrony Measures

By combining results from four complementary methods, rolling correlation, cross correlation, DTW, and wavelet coherence, we constructed a comprehensive picture of movement synchrony. Each method contributed a distinct view of synchrony, and together they provided a multi-dimensional understanding of how mother infant coordination emerges, fluctuates, and repeats over time.

3.11 Synthesis of Synchrony Measures

By combining results from four complementary methods—rolling correlation, cross-correlation, DTW, and wavelet coherence—we constructed a comprehensive picture of movement synchrony. Each method contributed a distinct view of synchrony, and together they provided a multi-dimensional understanding of how mother–infant coordination emerges, fluctuates, and repeats over time. Face-validity assessed using this Accelerometer data suggested that: coupling

was stronger during co-active high-activity windows than during general periods, and it attenuated toward zero when only one partner exceeded their activity threshold or during extended low-activity epochs, supporting that the synchrony metrics reflect shared movement rather than artefact. Results were presented using descriptive statistics, graphs, and heatmaps, facilitating interpretation within a relational and ecological framework.

3.12 Justification for Analytical Approach

This multi-method strategy was carefully selected to reflect the fluid, embodied, and context-dependent nature of synchrony in early relationships. By applying both fine-grained (e.g., rolling correlation) and global (e.g., DTW) techniques, we were able to account for temporal variability, directionality, and frequency-specific patterns of interaction. This approach was particularly appropriate for exploring how synchrony unfolds in the everyday lives of mothers and infants in Soweto, providing evidence that is both rigorous and responsive to the local context.

4.0 Results

4.1 Participant Characteristics of the Analytical Sample

Participant socio demographic characteristics are reported for the analytical sample of 66 mother infant dyads, that is, those who contributed valid, paired wrist accelerometry. Mothers ranged in age from 18 to 43 years, with a median age of (26.6) years (IQR: 23.5–29.7). The infants had a median age of 4.2 months (IQR: 3.9–4.6), and were predominantly male (38 infants, 60.3%)

compared to females (25 infants, 39.7%). In terms of maternal relationship status, 27 mothers (42.9%) reported being single, 17 (27.0%) were in a relationship, 13 (20.6%) were either engaged or cohabiting, and 6 (9.5%) were married. The majority of mothers had completed Grade 12 (n=46, 73.0%), while 14 (22.2%) had completed Grade 11, and 3 (4.8%) had a Grade 10 education. Tertiary education was reported by a smaller subset, including 3 with a bachelor's degree (4.8%) and 8 with a diploma (12.7%). Notably, half of the mothers (32, 50.8%) were still enrolled in school. Employment levels were low, with only 14 mothers (22.2%) reporting formal employment. Most participants lived in modest housing conditions—typically two-roomed homes shared by an average of five individuals, including two adults. These demographic and contextual characteristics provide important context for interpreting the movement synchrony patterns observed in this cohort. These sixty-six dyads constitute the accelerometry subsample drawn from the one hundred and fifty dyads enrolled at the four-month visit, and the size reflects device availability and quality control filters rather than participant refusals. Because accelerometry was collected during usual daily routines with no prescribed tasks, we foreground ecological validity and read movement patterns as they occur in Soweto households.

4.2 Accelerometer data Quality and Inclusion Criteria

The PLAY Study recruited 150 mother infant dyads at the 4-month visit. Given device availability, twenty Axivity AX3 units were prepared, of which eight failed pre deployment checks, leaving twelve functional devices. These were rotated across participants and deployed to seventy-eight dyads, of which sixty-six dyads, 85 percent, returned usable paired mother and infant accelerometry. Validity required paired files, at least five full wear days, stable

timestamps, successful download and calibration, and absence of major device artefacts. On detailed inspection, five dyads were excluded for missing data, mother n = 2 and infant n = 3, and one dyad for insufficient wear, fewer than four days. The analytical sample for socio demographic description comprised sixty-six dyads with paired accelerometry, while the final synchrony analyses were restricted to sixty-two dyads that met all completeness and wear time criteria. Dyads not meeting these criteria were not included in the analytical sample for synchrony. Losses reflected device faults, missing paired files, or insufficient wear, not participant refusal, and available socio demographic comparisons for included versus not included dyads.

4.3 Wear Time Compliance

Accelerometer wear-time compliance was moderately high. The median wear time was 13 hours per day (IQR: 7–19 hours), translating to an average compliance rate of 54.2% across the study period (Table 2). Participants who wore the device for fewer than five full days were excluded from synchrony analysis to preserve the robustness of the findings. The final dataset reflects only those dyads who met the five-day minimum wear-time criterion, with some participants contributing up to seven full days of complete data. This ensured representativeness and reduced the potential bias associated with partial or irregular wear.

4.4 Mother-Infant Movement Volume

Across the study period, median movement intensity measured in ENMO (expressed in milligravity units, mg) was 20.2 mg (IQR: 5.7–41.1) for mothers and 11.8 mg (IQR: 4.2–28.4) for infants (Table 3). Although there are no established ENMO cutoffs for defining physical activity intensity in this age group, this pattern reflects a consistent trend of mothers being more active overall than their infants. To minimise bias, the first and last recorded days were excluded from the ENMO analysis due to frequent inconsistencies associated with device deployment and removal. The resulting movement profiles across valid days served as the foundation for the synchrony analysis described below.

4.5 Movement Synchrony: Overview and High Activity Thresholds

Following data cleaning and time alignment, movement synchrony was examined using the ENMO_mean metric across the 66 valid dyads. High-activity periods were defined using the 75th percentile ENMO values for each group:

- Infant High Activity Threshold: 20.72 mg
- Mother High Activity Threshold: 37.17 mg

Using these thresholds, we found that approximately 5.78% of total recorded time reflected periods in which both mother and infant were simultaneously active above their respective thresholds. These moments likely correspond to interactive episodes such as play, co-regulated tasks, or routine caregiving transitions. Simultaneous values above these thresholds are used as a practical marker of co engaged caregiving, for example shared play, settling, or moving between tasks.

4.6 Rolling Correlation Analysis: Temporal Dynamics of Synchrony

Synchrony over time was assessed using a rolling correlation analysis based on a 10-minute moving window. This approach provided a dynamic picture of how closely mother and infant movement intensities aligned throughout the day. Because recordings were obtained in situ during ordinary routines, without staged activities, the rolling window captures synchrony as it naturally ebbs and flows across the day. The rolling window shows how alignment tightens during shared tasks and loosens when mother and infant act separately across the day.

Table 1. Summary of Rolling Correlation Values

Statistic	**Value**
Minimum	-1.0
1st Quartile	-0.1
Median	0.3
Mean	0.2
3rd Quartile	0.6
Maximum	1.0
NA Windows	583,696

We further explored synchrony within high-activity versus normal-activity periods:

- Mean correlation during high activity: 0.348
- Mean correlation during normal activity: 0.224

These findings demonstrate that synchrony between mother and infant movement intensities was significantly higher during concurrent high activity, reinforcing the idea that physical co-regulation is most evident when both partners are mutually engaged.

Rolling correlation of mother infant ENMO signals over 24 hours at 4 months

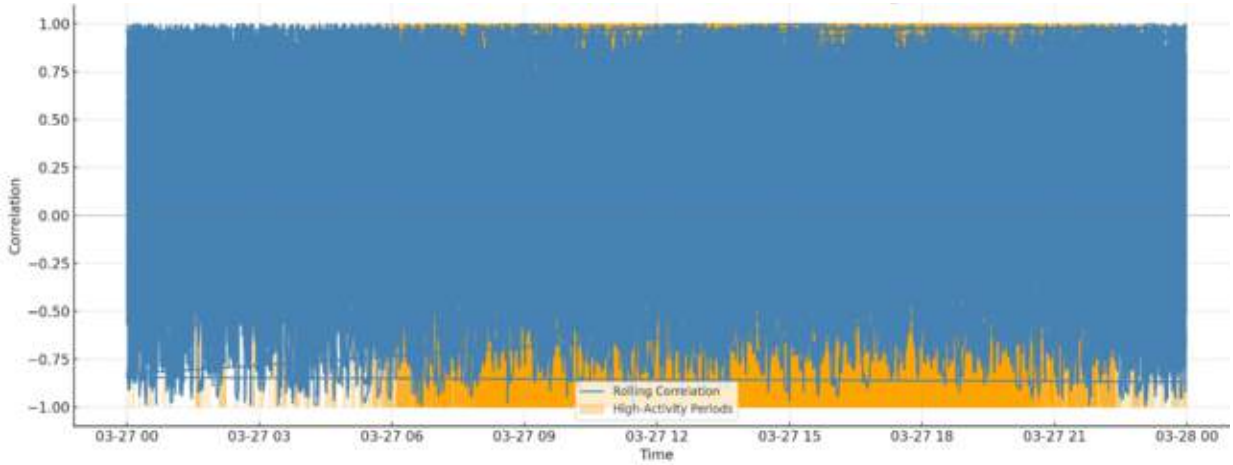


Figure 1. This graph illustrates the temporal dynamics of movement synchrony between a representative mother-infant dyad at 4 months postpartum, based on continuous Accelerometer data collected over a 24-hour period. Movement was measured using the Euclidean Norm Minus One (ENMO) signal derived from Axivity AX3 wrist-worn accelerometers. A rolling Pearson correlation was computed using a 10-minute moving window to capture synchrony in movement intensity between the mother and infant over time. The black line shows the rolling correlation values, ranging from –1 to 1, where values closer to 1 indicate strong positive synchrony and values near –1 indicate inverse synchrony. The orange-shaded segments highlight high-activity periods—defined as moments when both the mother and infant simultaneously exceeded their individual 75th percentile movement thresholds—indicating co-active moments likely associated with feeding, play, or routine caregiving.

The graph above is drawn from one dyad out of a total of 63 mother-infant pairs who participated in the study and contributed valid Accelerometer data at the 4-month timepoint. Across the full sample, rolling correlation scores had a median of 0.30 (IQR: –0.10 to 0.60), with higher synchrony typically observed during high-activity periods (mean r = 0.35) compared to non-activity periods (mean r = 0.22). This visual highlight the episodic and context-sensitive nature of mother-infant synchrony. Peaks in correlation often align with shared activity bursts, reinforcing the view that synchrony is most evident when both mother and infant are physically co-engaged. The moment-by-moment fluctuation in correlation underscores how synchrony is dynamic, rather than constant, and varies across the day depending on caregiving routines and environmental context. This rolling analysis method captures synchrony as it unfolds in real-life home settings, offering a unique and objective lens into dyadic coordination during early infancy.

4.7 Integration of Multiple Synchrony Metrics

To complement the rolling correlation approach, three additional methods were used: cross-correlation, Dynamic Time Warping (DTW), and wavelet coherence analysis. These methods allowed us to examine not only immediate synchrony but also time-lagged, nonlinear, and multi-scale rhythmic alignment.

Table 2. Summary of Synchrony Measures

Method	**Synchrony Metric**	**High Activity Mean**	**Normal Activity Mean**
Cross-Correlation	r = 0.30	---	---
Dynamic Time Warping	DTW Distance = 0.25	---	---
Wavelet Coherence	Coherence = 0.40	---	---
Rolling Correlation	Mean r = 0.243	0.348	0.224

These methods consistently supported the finding that mother-infant synchrony, while moderate overall, intensified during periods of shared activity and appeared to follow structured, often recurring, patterns.

5.0 Discussion

This study investigated the synchrony of movement behaviours between mothers and infants in Soweto, South Africa, using continuous, wrist-worn accelerometry over a seven-day period. By capturing time-aligned acceleration data in real-world, home environments, the study aimed to characterise how dyads coordinate their movement across time, identify routine patterns of synchrony, and explore the nature and frequency of these interactions.

Our findings confirmed that synchrony between mother-infant pairs is not random, but rather dynamic and often concentrated during shared episodes of heightened activity. These periods,

though infrequent, were marked by significantly higher correlations in movement intensity, suggesting moments of mutual engagement. This affirms that synchrony is embedded in the rhythms of everyday caregiving and influenced by how mothers and infants organise their routines around each other.

5.1 Interpretation of Key Findings

This study presents robust evidence that mother-infant synchrony is dynamic, episodic, and most evident during periods of mutual high activity. These interactive windows—though limited in duration—show significantly greater coupling in physical movement, likely reflecting shared routines such as play, feeding, or caregiving transitions.

Time-lagged correlations revealed leading-following dynamics, with both mother-led and infant-led episodes emerging across different time windows. This highlights the fluidity of dyadic interaction, in which both the caregiver and infant actively shape and respond to one another's behaviour. The Dynamic Time Warping (DTW) and wavelet coherence analyses further confirmed that synchrony is not purely simultaneous but unfolds in a rhythmic and flexible manner, often aligning across multiple time scales.

Notably, synchrony patterns appeared to repeat consistently at specific times of day—particularly mid-morning and late afternoon—suggesting that caregiving routines play a central role in structuring co-regulated movement. These findings reinforce the significance of predictable rhythms and structured routines in shaping the quality of early relational interactions.

In turn, such patterns have important implications for early childhood intervention, where supporting mothers to establish responsive and routine-based caregiving environments may enhance bonding and developmental outcomes.

5.2 Daily Movement Trends and Behavioural Rhythms

Across the seven days, we observed generally low levels of movement for both mothers and infants. Notably, movement levels were highest on the first day and declined steadily, with the lowest levels occurring by the eighth day. This decline may be attributed to reduced novelty or changes in participant adherence but also reflects broader patterns in daily activity observed in postpartum and early caregiving contexts.

It is well established that both adult women and young children often fall short of daily movement recommendations, particularly in resource-constrained environments where space and time for unstructured play or movement are limited. These findings highlight how constrained maternal circumstances—such as overcrowded living conditions, limited support, or the demands of multitasking—can influence the opportunities and nature of mother-infant engagement throughout the day.

5.3 Patterns of Synchrony and Directionality

Synchrony, as assessed through rolling correlation, peaked during short bursts of simultaneous movement between mother and infant. Though these moments comprised only a small portion of

the overall monitoring period, they were highly structured and routine-like, often occurring at similar times across days. This repetition indicates that even in households with limited resources, caregivers and infants establish reliable rhythms—possibly around feeding, bathing, or transitioning between activities.

The cross-correlation and DTW analyses revealed that synchrony was not always simultaneous. In several instances, movement initiated by the mother was followed by infant activity, and vice versa. These findings support the notion of bidirectional regulation, where both mother and infant shape the timing and nature of their interaction. Rather than one partner constantly leading, synchrony appears to unfold as a mutual, responsive process—a hallmark of attuned and healthy dyadic interaction (Feldman, 2007; Leclère et al., 2014).

5.4 Time-of-Day Effects and Embedded Routine

A key finding was the emergence of synchrony patterns that aligned with time-of-day routines. Mothers were most active around mid-morning and, in the afternoon, while infants exhibited higher movement levels in the morning. This is likely linked to caregiving routines such as feeding, bathing, or playtime. Evening hours were associated with lower synchrony and more sedentary behaviour, a pattern supported by prior research on daily activity trends in adults and infants (Tudor-Locke et al., 2011).

Wavelet coherence analysis demonstrated that mother-infant synchrony operates across multiple time scales, reflecting both short bursts of engagement and broader daily rhythms. These layered

patterns highlight how physical proximity, and interaction may reinforce behavioural alignment over time, even in non-verbal and pre-verbal stages of development.

6.0 Implications of the Study

This study makes a valuable contribution to the understanding of early mother-infant synchrony within the South African context. As the first to use continuous wrist-worn accelerometry to measure dyadic movement in free-living settings in the country, it fills an important gap in the literature and aligns with global calls by the World Health Organization for more objective, context-sensitive data on early childhood movement behaviours.

By highlighting when and how synchrony occurs, the study offers practical insights into caregiving practices and routine structuring. These findings can inform early intervention programmes aimed at promoting responsive caregiving, particularly in low-income communities. They also underscore the importance of designing health and development strategies that support caregivers in creating structured, predictable routines—critical not only for physical interaction but also for emotional and cognitive growth.

7.0 Strengths of the Study

A key strength of this study lies in its ecological validity. By collecting data in naturalistic, real-world settings, the study captures the true variability and richness of mother-infant interaction that might otherwise be lost in laboratory or short-duration observational research. The use of

objective accelerometry also enhanced the reliability of the findings. Unlike self-reported data, these measures allowed for minute-by-minute tracking of movement, offering a more precise and unbiased reflection of behavioural synchrony. Additionally, the combination of multiple analytical approaches—rolling correlation, cross-correlation, DTW, and wavelet coherence—provided a robust and layered understanding of synchrony patterns over time.

The community-based recruitment approach and the diversity of the sample strengthen the relevance of these findings for public health programming and early childhood development policies in similar settings.

8.0 Limitations

Despite its contributions, the study had some limitations. The target sample of 150 dyads was not reached, and despite efforts to retain participants, a higher-than-anticipated dropout rate was observed. This may limit the generalisability of the findings.

Wear time compliance also posed a challenge. Although the average wear time was acceptable, some participants did not meet the full 7-day protocol. Most data loss occurred on the first and last day, which were subsequently excluded from analysis to maintain data quality. Additionally, while ENMO offers a robust movement measure, the lack of agreed-upon thresholds for classifying activity in infants makes comparisons across studies difficult.

Another important limitation relates to the interpretability of accelerometer-derived synchrony. While the devices provided continuous and objective measurement of movement alignment, they

did not capture the specific behavioural contexts in which synchrony occurred. For instance, synchronised wrist movements could reflect feeding, soothing, or play, yet accelerometry alone cannot disaggregate these activities. This highlights the need to combine accelerometry with richer observational data, such as headcam footage or caregiver time-use diaries, to improve interpretability (Nomikou et al., 2016; Bruijns et al., 2020).

Lastly, while this study focused on movement synchrony, it did not assess other important dimensions of early interaction such as facial expression, or vocalisation. These elements are integral to relational synchrony and should be included in future multimodal studies.

9.0 Conclusion

This study offers meaningful insight into the patterns, timing, and structure of mother-infant movement synchrony in a South African urban setting, using continuous wrist-worn accelerometry in natural home environments. Through this research, we have shown that synchrony is not a constant or linear process, but rather one that is episodic, dynamic, and deeply shaped by daily caregiving rhythms.

Synchrony was strongest during brief periods of concurrent high movement, often occurring around structured moments such as play, feeding, or transitions between caregiving tasks. Although these windows were limited in duration, they represented important opportunities for co-regulation and mutual engagement core processes that support early social, cognitive, and emotional development. Notably, synchrony patterns tended to repeat at consistent times of day,

suggesting that families, even in resource-constrained settings, establish routine-based interactional rhythms that structure relational exchanges.

Our analyses confirmed that movement synchrony is flexibly aligned across time, with both mothers and infants contributing to the pacing and timing of shared behaviour. The presence of leading and following dynamics across different time windows further underscores the bidirectional nature of interaction, a vital aspect of early relationship quality and infant developmental outcomes.

From a methodological standpoint, this study demonstrates the value of integrating multiple time-series approaches including rolling correlation, cross-correlation, DTW, and wavelet coherence—to better understand the temporal and rhythmic complexity of dyadic synchrony. The use of objective, high-frequency movement data allowed for a more detailed, ecologically valid view of early interactions, while the context-sensitive analysis grounded the findings within the lived realities of young families in Soweto.

Importantly, this study builds on global and local calls to strengthen research on early movement behaviours, responding to gaps identified by the World Health Organization and the South African 24-Hour Movement Guidelines. The findings contribute evidence that can inform the design of routine-based interventions aimed at enhancing responsive caregiving, promoting maternal-infant bonding, and ultimately supporting better developmental outcomes for children in low- and middle-income settings.

While the study faced some limitations—such as wear-time variability, partial protocol adherence, and a lower-than-anticipated sample size—the insights generated are foundational. They lay the groundwork for larger, multimodal, and longitudinal studies that explore synchrony not only in physical movement but also in gaze, emotion, language, and attention.

In conclusion, this research affirms that synchrony is a powerful, naturally occurring phenomenon in early relationships—one that reflects the rhythm, resilience, and reciprocity of caregiving in South Africa. It highlights how attuned, structured, and responsive routines, even in contexts of socioeconomic adversity, can provide infants with the relational scaffolding they need to thrive.

Acknowledgements: The authors extend their sincere gratitude to the Wellcome Trust, the National Institute for Health Research (NIHR), and the DSI-NRF Centre of Excellence in Human Development at the University of the Witwatersrand for their generous support, which made this research possible. We would also like to acknowledge the Johannesburg Health District Research Committee for approving and supporting the implementation of this study in the local context. Special thanks are due to the mothers and infants who participated in the Play, Love, and You (PLAY) study for their time and commitment. We are equally grateful to the dedicated field team involved in participant recruitment, device deployment, data collection, and data entry, as well as to all contributors to the original study design.

Contributors: Conceptualisation: Dumsile Maduna (DM), Alessandra Prioreschi (AP); **Data processing and analysis**: DM; **Manuscript preparation:** DM drafted the manuscript. AP, Lukhanyo Nyati (LN), Ian Nabney (IN), and Ansuyah Megan (AM) reviewed and provided

critical intellectual input. All authors contributed to the final manuscript and approved it for submission.

Funding: This study was funded by the National Institute for Health Research (NIHR) (using the UK's Official Development Assistance funding) and Wellcome [grant number 222007/Z/20/Z], under the NIHR-Wellcome Partnership for Global Health Research. Additional support was provided by the DSI-NRF Centre of Excellence in Human Development at the University of the Witwatersrand, Johannesburg, South Africa.

The views expressed are those of the authors and do not necessarily reflect those of Wellcome, NIHR, the UK Department of Health and Social Care, or the CoE in Human Development.

Declarations: *Conflict of interest:* The authors declare no financial or non-financial conflicts of interest. *Ethical approval:* Ethical clearance was obtained from the University of the Witwatersrand's Human Research Ethics Committee (Clearance number: M220785). *Consent to participate*: Written informed consent was obtained from all participants prior to their enrolment in the study. *Consent for publication:* All participants provided informed consent for their anonymised data to be included in publications. *Supplementary material:* Additional content and supporting data are available upon request or provided as supplementary material by the authors.

Table S1. Participant characteristics of mothers and infant dyads from Soweto, South Africa that participated in the PLAY Love and You randomized trial

	Mother (n= 63)	**Infant (n= 63)**
Age (Median, IQR)		4.2 (3.9-4.6)
Infant Gender (%):		
Male		60.3
Female	100	39.7
Marital Status (%):		
Single	42.9	
In A Relationship	27.0	-
Cohabiting/engaged	20.6	
Married	9.5	
Employment Status (%):		
Employed	22.2	-
Unemployed	77.7	
Education (%):		
Completed Grade 12	73.0	
Grade 11	22.2	-
Grade 10	4.8	
Highest degree obtained		
Bachelor's degree	4.8	
Diploma	12.7	

Currently enrolled at school		
Tertiary	6.3	
Other (full-time)	50.8	
Number of people living at home (Median, IQR)	5 (4-6)	-
Number of rooms for sleeping (Median, IQR)	2 (1-2)	
Number of adults (18 years+ old) at home	2 (2-3)	

3.4. Study 3: Longitudinal patterns of synchrony and predictors of synchrony (headcam & Accelerometry)

Longitudinal patterns of synchrony of movement- and interaction behaviours between mother-infant dyads in the first year of life

Dumsile Maduna[1*], Lukhanyo H. Nyati[1,2], Alessandra Prioreschi[1], Rebecca Pearson[3], Ansuyah Magan[1], Ian Nabney[4]

Author affiliations

[1]SAMRC/Wits Developmental Pathways for Health Research Unit, Department of Paediatrics and Child Health, Faculty of Health Sciences, School of Clinical Medicine, University of the Witwatersrand, Johannesburg, South Africa. [2]Interprofessional Education Unit, Faculty of Health Sciences, University of the Western Cape, South Africa. [3]Department of Psychology, Manchester Metropolitan University. United Kingdom. [4]School of Engineering Mathematics and Technology, University of Bristol. United Kingdom.

Correspondence to Dumsile Maduna; dumsilesdmaduna@gmail.com

Abstract

Background: Mother-infant synchrony, coordinated movement, gaze, and behaviour, supports socio-emotional and cognitive development. We tracked synchrony with wrist accelerometry and used headcam footage at four months for context in South Africa.

Methods: Within the PLAY Study in Soweto, we analysed 63 dyads with valid paired wrist accelerometry at four or eight months. Dyads wore Axivity AX3 accelerometers for seven consecutive days at each timepoint. Synchrony metrics were the mean rolling Pearson correlation r of ENMO in a 10-minute window, the proportion of minutes with r greater than 0.50, and directionality from the lag at the peak cross-correlation within five minutes; negative indicates mother-led, positive indicates infant-led. Predictors, including maternal employment, household structure, and demographics, were tested in mixed effects models. Headcam clips at four months were micro-coded second by second to document co-occurring behaviours within three to seven second windows, context only.

Results: Mean r showed no significant change from four to eight months, with within-dyad variability. Cross-correlation showed both mother-led and infant-led patterns with no net shift. Maternal employment predicted lower synchrony, beta minus 0.131 on the r scale, p equals 0.004. Headcam segments corroborated movement coupling in short windows.

Conclusion: In this South African cohort, accelerometer-based synchrony was moderate and stable across early infancy, and lower among employed mothers. Findings motivate larger replications to test structurally informed supports for early dyadic coordination.

Keywords: synchrony, mother-infant interactions, movement behaviours, accelerometry, headcams, South Africa, longitudinal study

Introduction

Mother–infant synchrony refers to the time-linked coordination of partners' signals such as gaze, touch, posture, and movement, through which responsiveness and co-regulation emerge (Feldman, 2012b). In Soweto households, these patterns commonly arise during everyday caregiving, for example soothing, shared handling, or transitions between activities, rather than in structured play. Naturalistic measurement is therefore important for ecological validity.

Much of the existing literature from high-income settings relies on brief observer-rated episodes, which limits insight into the continuous and dynamic character of synchrony across the day (Bernieri et al., 1988; Bigelow et al., 2008). Evidence from LMICs remains limited, despite sociocultural factors—household crowding, maternal employment, and shared caregiving—that plausibly shape the timing and form of synchrony.

Tri-axial accelerometers record linear acceleration along three orthogonal axes at high sampling rates. Signals are summarised as Euclidean Norm Minus One (ENMO; milligravity units) after removal of static gravity. In this study, movement synchrony is operationalised as coupling between paired ENMO time series using concurrent covariation (rolling Pearson *r*) and short time-lag cross-correlation to indicate directionality (mother-led or infant-led) (Bruijns et al., 2020; Westgate et al., 2019). Because mother–infant co-presence at 4–8 months is typically high, coupling of wrist movements is a plausible proxy for shared activity in this age range; at older ages, greater separation and independent mobility require additional contextual data.

Synchrony develops from rhythmic tactile and postural exchanges in early months towards increasingly reciprocal gaze, gesture, and play by late infancy (Kjellmer, 2018; Feldman, 2012b; Moon, 1988). Longitudinal, objective data tracking this progression in LMIC contexts are scarce. Head-mounted

cameras (headcams) can situate movement coupling within first-person behavioural context (e.g., matched gaze or touch) but were available here at 4 months only and are used descriptively.

In this paper we quantify accelerometer-derived movement synchrony at 4 and 8 months, examine maternal and household predictors, and use 4-month headcam exemplars to aid interpretation. We address two questions: whether synchrony changes from 4 to 8 months, and whether selected maternal or household factors are associated with the continuous synchrony index. Secondary descriptors (e.g., lags, dynamic time warping, and coherence) characterise structure but are not primary endpoints. We hypothesised a modest decline in synchrony with increasing infant autonomy, and lower mean synchrony among employed mothers in this setting (WHO, 2019; Prioreschi et al., 2023).

Methods

2.1 Study Design and Setting

This study was nested within the Play, Love and You (PLAY) Randomised Controlled Trial (RCT), a longitudinal intervention aimed at promoting early childhood development through responsive caregiving and play-based practices. A total of 150 mother-infant dyads were recruited from public community clinics across Soweto, Johannesburg, during their routine 3-day postnatal follow-up visits. Participants were randomly assigned to either the intervention group, which received a structured responsive caregiving package, or the control group, which received standard government-provided postnatal care. The cohort was followed from birth to 12 months, with primary data collection occurring at 4 and 8 months postpartum. For the present analysis, we included the subsample of dyads with valid, paired accelerometry at 4 and/or 8 months (n = 63); all longitudinal models were restricted to this analytical sample. A small headcam subsample at 4 months only was used descriptively to illustrate context and was not entered into longitudinal models.

2.2 Participant Eligibility

Mothers were eligible if they were aged 18 years or older, serving as the infant's primary caregiver, and living in Soweto with plans to remain in the area throughout the study period. Infants had to be between 0 and 3 months at recruitment. Dyads were excluded if either the mother or infant had a condition likely to interfere with movement or naturalistic interaction, as determined through medical records and the Road to Health booklet.

2.4 Ethical Approval

All participants provided written informed consent before taking part in the study. Ethical clearance was granted by the University of the Witwatersrand's Human Research Ethics Committee for the PLAY RCT (Ref: M220217) and this PhD study (Ref: M220785). Headcam footage used for contextual illustration at 4 months also derived from the main trial and was analysed descriptively. The research team adhered to the principles of confidentiality, voluntary participation, and the right to withdraw without prejudice.

2.5 Data Collection

2.4.1 Primary Outcome Data: Accelerometry and Headcam Data

Headcam and Accelerometer data were collected between May 2023 and May 2024. Each mother-infant dyad wore Axivity AX3 tri-axial accelerometers (Open Movement, Newcastle, UK) on their non-dominant wrist for seven consecutive days at 4 and again at 8 months. AX3 devices recorded raw acceleration at 100 Hz (±8 g dynamic range) on three orthogonal axes; they do not record heart rate. Infants wore the device on their left wrist to standardise placement across participants. Primary synchrony analyses focused on diurnal periods (06:00–18:00); nocturnal data were retained for completeness but

were not used to estimate synchrony outcomes. Headcams were mounted on soft headbands and worn during free-play sessions to capture naturalistic interactions. Each dyad was asked to record three 5-minute play episodes over three days at 4 months. Headcam recordings were available only at 4 months and were used to illustrate behavioural context (e.g., joint handling, soothing) rather than to generate inferential estimates.

Research assistants demonstrated the devices to participants and conducted home visits to support use. Devices were collected, checked for data completeness and wear compliance, and then uploaded onto secure storage for processing. Quality control (QC) checks assessed recording duration, battery function, and signal activity. Files that did not meet the minimum wear-time requirement were excluded. Field procedures were scheduled around household and clinic routines, with minimal researcher intrusion, so recordings reflect typical caregiving and strengthen ecological validity.

2.4.2 Demographic Data

Demographic and household information was collected using electronic REDCap questionnaires. Infant age and sex were recorded from the Road to Health Booklet. Maternal age, marital status, education, and employment status were self-reported. Household composition, number of rooms, and adult/child ratios were also collected to assess socioeconomic status and caregiving context.
All data were anonymised, stored securely, and linked to accelerometry and headcam datasets for integrated analysis.

2.6 Data Processing and Outcome Measures

2.5.1 Accelerometer data

Accelerometers recorded raw acceleration signals at a sampling frequency of 100 Hz and a dynamic range of ±8g. All data were downloaded in .cwa format, auto-calibrated, and converted to .wav format using OmGui software (Version 1.0.0.28; Open Movement, Newcastle, UK) (Prioreschi et al., 2023). To preserve ecological validity, no activity was prescribed, and devices were worn during usual daily routines, allowing movement signals to reflect typical caregiving. Free-living wrist signals capture co-activity such as settling, carrying, and short play bursts, which are motor correlates of interaction.

The processing pipeline involved several standardised steps:

1. **Quality Control and Signal Verification:** Ensured data completeness, battery life, and device calibration.
2. **Noise and Gravity Removal:** Applied filters to isolate true movement signals.
3. **Vector Magnitude Processing:** Computed Euclidean Norm Minus One (ENMO; milligravity, mg) after gravity removal to quantify movement intensity.
4. **Non-Wear Period Identification:** Detected and excluded segments with no activity to ensure only valid data were analysed.

Processed acceleration data were summarised to generate variables for mean, maximum, and total movement intensity. High-activity periods were defined per participant using the 75th percentile of ENMO; co-active high-activity windows required concurrent exceedance by mother and infant. Diurnal windows were defined a priori (06:00–18:00) to align with caregiving routines.

Synchrony variables included:

- **Frequency of synchrony:** Number of time points with aligned movement.
- **Mean synchrony:** Average movement correlation.
- **Lag directionality:** Whether synchrony was mother- or infant-led.
- **Synchrony intensity:** Strength of alignment in movement.

2.5.2 Operationalisation of accelerometer-derived synchrony

Movement synchrony was operationalised from paired mother–infant ENMO time series as follows:

- **Mean synchrony (primary outcome**): rolling Pearson correlation (*r*) using a 10-minute window across diurnal time; averaged per dyad and timepoint.
- **Proportion of high synchrony:** percentage of rolling windows with $r > 0.50$ (a priori threshold).
- **Peak synchrony:** maximum rolling *r* observed per dyad and timepoint.
- **Directionality (mother-led vs infant-led):** time-lagged cross-correlation with lags −5 to +5 minutes; the lag of the maximum correlation indicates leading partner (negative = mother leads; positive = infant leads). We report the peak cross-correlation coefficient and its corresponding lag (minutes).
- **Secondary structure metrics (descriptive only):** Dynamic Time Warping (DTW) distance (unitless; lower = closer alignment) and wavelet coherence (0–1) within the 4–16-minute band to characterise rhythmic coupling. These were not used in inferential models.

2.5.3 Headcam Data

Headcam data (4 months only) were analysed to describe interactional context and were neither pooled with accelerometry nor used in longitudinal or predictor models. Videos were recorded in usual caregiving spaces (e.g., homes, clinics), supporting naturalistic capture of synchrony cues. Footage was coded second-by-second in The Observer XT 16.0 (Noldus Information Technology, Wageningen, Netherlands) for gaze, touch, reaching, and play. Coders marked onsets and offsets for each behaviour; from these timestamps we derived (i) frequency of synchronous events, (ii) duration of synchrony (defined as the shorter of the paired durations), (iii) timing of first response, and (iv) directionality by initiator code. Synchrony was defined as co-occurrence within 3, 5, or 7 seconds, with windows selected a priori from micro-analytic and time-series traditions; no formal sensitivity analyses beyond these

windows were conducted in this thesis. Metrics were computed for matched and unmatched behaviour pairs. Inter-rater reliability exceeded $\kappa = 0.80$ across codes following drift checks and reconciliation. Boundary agreement was comparatively lower for very brief gaze shifts and shorthand movements under partial occlusion, although all κ values remained ≥ 0.80. To maintain consistency over long coding runs, we scheduled periodic drift checks, held brief recalibration meetings, double-coded rotating subsets, and applied a written reconciliation rule prioritising agreement on behaviour onsets and offsets when overlaps occurred. Coding rules were reviewed against local caregiving practices to ensure transferability to the Soweto context; any clarifications or minor adaptations are documented within this subsection. These behavioural outputs are presented descriptively to illustrate the kinds of episodes that correspond to movement coupling (e.g., matched gaze during joint handling or soothing).

2.7 Statistical Analysis

To explore longitudinal patterns and changes in mother–infant synchrony during the first year of life, we analysed time-series data from accelerometry and headcam recordings at 4 and 8 months postpartum. Headcam-coded behavioural synchrony (touch, hand movement, gaze, play) and accelerometer-derived movement synchrony were analysed separately to capture distinct aspects of dyadic coordination. Headcam data were available at 4 months only and were used descriptively for context, not combined with accelerometry in models. Comparisons with reports from high-income cohorts are included for context only; we read these contrasts as checks on external validity for Soweto, not as evidence of equivalence. Interpretation emphasises effect sizes and 95% confidence intervals.

Primary accelerometry synchrony outcomes were pre-specified as: (i) mean rolling Pearson correlation $\bar{r}$ between mother and infant ENMO signals (10-min window, 1-min step), aggregated within day and averaged across valid days; (ii) the proportion of time in "high synchrony", defined as the share of windows with $\boldsymbol{r \geq 0.50}$**;** and (iii) directionality from time-lagged cross-correlation. For (iii), we computed

the cross-correlation function (±5 min) between mother (x_t and infant (y_t) ENMO; the peak correlation r_{max} and its lag τ_{max} were extracted per dyad and timepoint. By convention here, $\tau_{max} > 0$ indicates mother-led (mother precedes infant), $\tau_{max} < 0$ indicates infant-led. We also summarised peak synchrony as r_{max} within the lag window. Synchrony outcomes were summarised with descriptive statistics (including the frequency and percentage of time in high synchrony) and mean ENMO levels to contextualise activity volume.

Because correlations are bounded, $\bar{r}$ and r_{max} were Fisher z-transformed prior to modelling and back-transformed for presentation. The high-synchrony proportion was modelled with the observed number of high-synchrony windows as the numerator and the total number of valid windows as the binomial denominator.

To explore temporal patterns in movement synchrony, we fitted Vector Autoregressive Models (VAR[1]) to each dyad–timepoint series to detect short-lag dependencies and to corroborate directionality inferred from cross-correlation. From VAR, we extracted the cross-lag coefficients (mother $_{t-1} \rightarrow$ infant $_{t-1}$; infant $_{t-1} \rightarrow$ mother $_{t-1}$) as secondary indicators of leadership. These VAR quantities were summarised rather than entered as predictors, given sample size constraints.

To assess change over time and predictors of synchrony, linear mixed-effects models (LMMs) with Gaussian errors were used for continuous synchrony outcomes on the Fisher z scale, with a random intercept for dyad and fixed effects for timepoint (4 vs 8 months) and selected covariates. Candidate predictors were maternal age, education, employment, and household composition. Given the modest N, we reported both unadjusted models (timepoint only) and parsimonious adjusted models (timepoint + maternal employment + one additional covariate chosen a priori), to avoid over-fitting. Model assumptions were checked via residual diagnostics on the z scale.

For count outcomes (e.g., number of high-synchrony bouts), we used Poisson mixed models with a log link, a random intercept for dyad, and an offset for exposure (total valid windows or wear minutes). Coefficients were exponentiated and reported as incidence rate ratios (IRR) with 95% CIs. Where over-dispersion was detected (Pearson $\chi^2/df>1.5$), we refitted negative-binomial mixed models or applied robust (sandwich) standard errors. This choice reflects the discrete, skewed distribution of bout counts; a Gaussian LMM would be inappropriate for these non-negative, right-skewed outcomes. For the high-synchrony proportion, we also fitted a binomial logistic mixed model with the window-level numerator/denominator as described above, providing odds ratios for sensitivity alongside the continuous z-based analyses.

Directionality (r_{max}) was summarised categorically (mother-led/infant-led/none) and modelled with mixed-effects logit regression (mother-led as reference) as an exploratory outcome; results are presented descriptively given limited margins. As a within-dyad robustness check, we conducted paired tests (paired t or Wilcoxon, as appropriate) for change from 4 to 8 months on the Fisher z scale; these are reported in Supplementary Tables.

Headcam-coded behavioural synchrony (4 months only) was summarised (frequency, duration, timing, initiator) and presented descriptively to illustrate context; no inferential linkage to accelerometer outcomes was modelled. All analyses were conducted in R (v4.3.0) and Stata; visualisations were produced with ggplot2. Statistical significance was set at $p<0.05$; given the exploratory scope, no multiplicity adjustment was applied, and emphasis is placed on effect sizes and confidence intervals.

Results

3.1 Participant Characteristics

This analysis included 63 mother–infant dyads who contributed synchrony/Accelerometer data at either the 4- or 8-month timepoints. Infants were predominantly male (60.3%). The average household comprised 5.4 individuals (SD = 1.72), with 2.54 adults (SD = 1.22) and 2.81 rooms used for sleeping (SD = 1.70). Most mothers were unemployed (76.2%); 6.3% were enrolled in education. 17.5% reported tertiary education (diploma or higher). Relationship status varied (single 42.9%, in a relationship 27.0%, living with partner 20.6%, married 9.5%).

Table 1. Demographic Characteristics of Participants (N = 63)

Characteristic	**Category**	**n (%) or Mean (SD)**
Infant age (years)		0.02 (0.02)
Household size		5.40 (1.72)
Rooms used for sleeping		2.81 (1.70)
Adults in household		2.54 (1.22)
Infant sex	Male	38 (60.3%)
	Female	25 (39.7%)
Maternal employment	Unemployed	48 (76.2%)
	Employed	14 (22.2%)
Currently enrolled in education	Yes	4 (6.3%)
	No	59 (93.7%)
Maternal education	No tertiary qualification	52 (82.5%)
	Diploma	8 (12.7%)

	Bachelor's degree	3 (4.8%)
Relationship status	Single	27 (42.9%)
	In a relationship	17 (27.0%)
	Living with partner	13 (20.6%)
	Married	6 (9.5%)

3.2 Longitudinal Patterns of Mother–Infant Movement Synchrony

Synchrony metrics derived from paired wrist accelerometry showed small mean differences between timepoints (Table 2). The mean synchrony score (rolling Pearson *r*, aggregated per dyad) was 0.33 at 4 months vs 0.31 at 8 months; the proportion of time in high synchrony ($r \geq 0.50$) was 0.34 vs 0.30. In formal mixed-effects models, the timepoint effect (8 vs 4 months) was not statistically significant for the mean synchrony score ($\beta_time = -0.045$, $p = 0.270$) or for the high-synchrony proportion ($\beta_time = -0.045$, $p = 0.187$), consistent with the visual overlap in Figures 1. The mean peak (max) correlation declined slightly (0.54 → 0.52).

Time-lagged cross-correlation of ENMO signals indicated a developmental shift in directionality: at 4 months the mean best lag was negative (–1.8 min), consistent with mother-led coordination, whereas at 8 months it was positive (+1.6 min), indicating relatively more infant-led patterns (Figure 2). Short lag coupling (±2 min) was observed at both timepoints.

Table 2 Summary of Mother–Infant Synchrony Metrics Across 4- and 8-Month Timepoints

Timepoint	**Mean synchrony score**	**Mean max correlation**	**Mean best lag (min)**	**Mean proportion high synchrony**
4 months	0.33	0.54	-1.8	0.34

8 months	0.31	0.52	+1.6	0.30

Within-dyad changes in synchrony scores between the two timepoints, demonstrating variability across dyads.

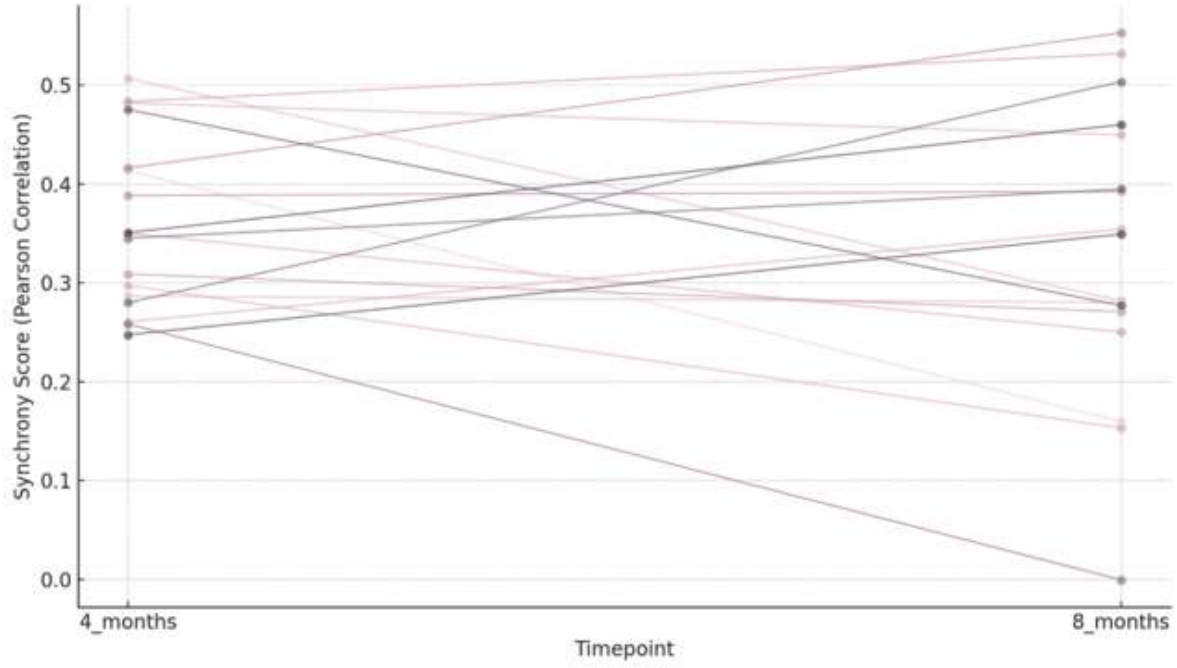


Figure 1. Change in mother–infant synchrony scores within dyads from 4 to 8 months. Lines represent dyads measured at both timepoints; trajectories illustrate within-dyad variability with no consistent directional shift.

Cross-correlation analyses suggested a developmental shift in the directionality of mother-infant synchrony. At 4 months, synchrony patterns were predominantly mother led, indicated by a negative mean best lag. By 8 months, this shifted toward more infant-led coordination, reflected in a positive mean best lag. Notably, short-lag synchrony (±2 minutes) was consistently observed across both timepoints, highlighting a sustained responsiveness within dyads. These patterns are visually presented in Figure 2.

Distribution of Lead-lag in Synchrony (best_lag_minutes)

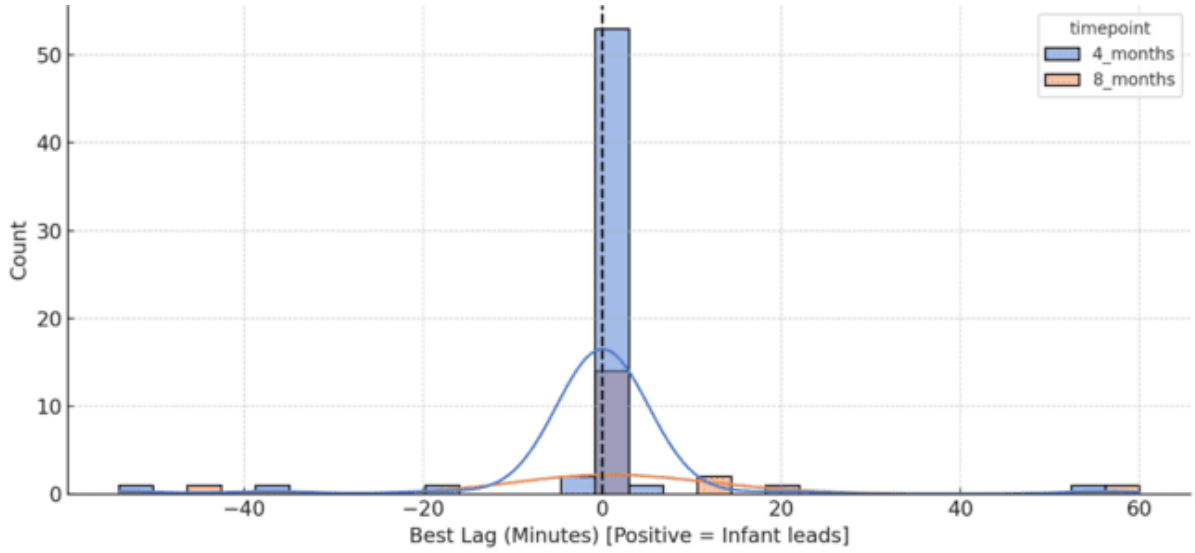


Figure 2. Distribution of lead–lag in synchrony (best lag, minutes).

Negative lags denote mother-led; positive lags infant-led; both timepoints center near 0 with a rightward shift at 8 months.

Boxplot comparisons of synchrony proportion ($r > 0.5$) further illustrate the decline from 4 to 8 months. There was a slight reduction in the proportion of time that dyads spent in high synchrony ($r > 0.5$) from 4 to 8 months postpartum.

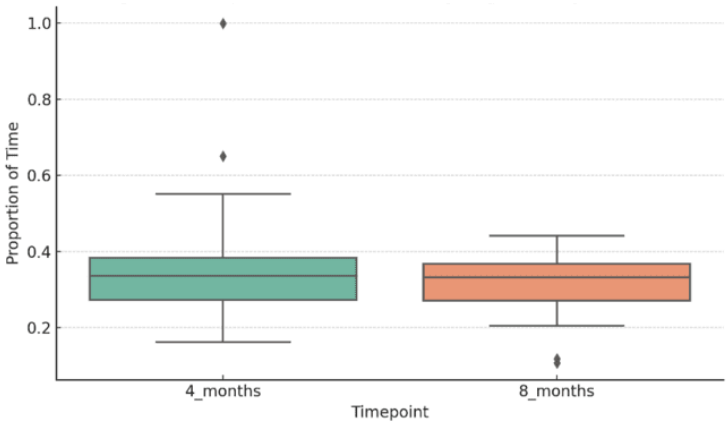


Figure 3. Proportion of time in high synchrony ($r \geq 0.50$) at 4 and 8 months.

Boxplots show slightly lower central tendency and similar spread at 8 months.

3.3 Predictors of Mother-Infant Movement Synchrony

In multivariable models, maternal employment emerged as the most consistent predictor. Employed mothers had a lower mean synchrony score (β = –0.131, p = 0.004)—that is, the accelerometer-derived synchrony index was, on average, 0.131 units lower among employed versus unemployed mothers, adjusting for other covariates. For the proportion of high synchrony, the employment effect was β = –0.072 (p = 0.057) with the same direction of association. Timepoint, infant sex, household size, rooms used for sleeping, and relationship status were not statistically significant predictors in the adjusted models (Table 3). Figure 4 has been updated to display 95% CIs for all estimates.

Table 3 Multivariable Linear Regression Models Predicting Synchrony

Predictor	**β (Synchrony Score)**	**p-value**	**β (High Synchrony Proportion)**	**p-value**
Intercept	0.405	<0.001	0.364	<0.001
Timepoint: 8 months	-0.045	0.270	-0.045	0.187
Infant sex: Male	-0.054	0.133	-0.034	0.254
Maternal employment: Yes	**-0.131**	**0.004**	-0.072	0.057
Relationship status: Married	0.079	0.288	-0.032	0.615
Relationship status: Single	-0.032	0.435	-0.006	0.865
Relationship status: Living with partner	0.028	0.566	0.043	0.303
Infant age	~0	0.482	~0	0.072
People living at home	0.009	0.440	0.010	0.280
Rooms used for sleeping	-0.006	0.567	-0.015	0.119

Coefficient Plot of Predictors of Mother–Infant Synchrony Visual representation of Table 3. Bars represent 95% confidence intervals.

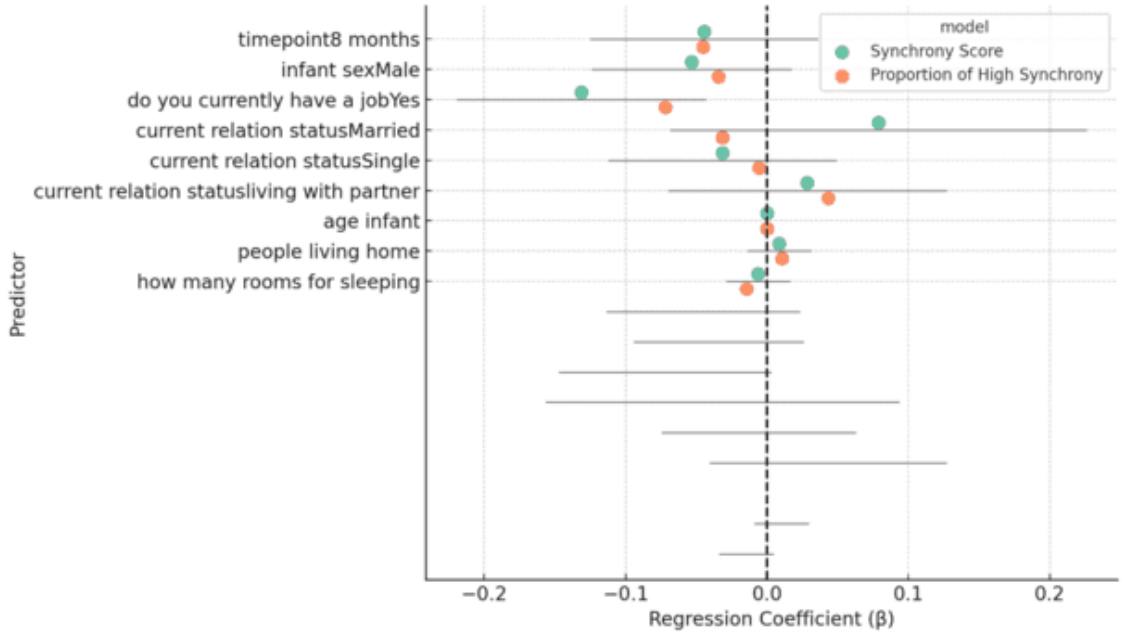


Figure 410 Coefficient Plot of Predictors of Mother–Infant Synchrony.

Regression coefficients (points) and 95% confidence intervals (bars) for (i) synchrony score and (ii) proportion of time in high synchrony. All predictors shown; CIs rendered for every estimate.

3.4 Headcam Synchrony Outcomes (From Study 1)

Headcam recordings were available at 4 months only and were used to illustrate context rather than to support longitudinal inference. Second-by-second coding (gaze, touch, reaching, play) documented brief co-regulated episodes such as mutual gaze during joint handling and soothing with rhythmic touch**,** aligning with the accelerometer-derived synchrony windows. These 4-month headcam data were not pooled with accelerometry nor entered into predictor models. For detailed microanalytic results from the separate pilot sample, see Study 1 (thesis Chapter 3); they are not reproduced here to avoid conflating datasets.

Table 4 Changes in Matching Behaviours Between Mothers and Infants Over Time (MLM Analysis) Key synchrony behaviours (e.g., mother and infant gaze, touch) increased in frequency and duration. For example, coordinated hand touch showed significant growth across timepoints.

Behaviour pairs	**Freq**		**Prob**		**Duration**			
					Mother		**Infant**	
Mother-Initiated Behaviours	**β**	**CI**	**β**	**CI**	**B**	**CI**	**B**	**CI**
Mother touch right hand– Infant touch right hand	0.57*	[0.14, 0.99]	0.003	[-0.04, 0.01]	0.18***	[0.10, 0.27]	0.16**	[0.04,0.27]
Mother touch left hand - Infant touch left hand	0.34*	[0.10, 0.57]	0.01*	[0.0004, -0.02]	0.28***	[0.16, 0.41]	0.24*	[0.04, 0.43]
Mother gaze infant – Infant gaze mother	2.18*	[1.31, 3.06]	0.02*	[0.01, 0.03]	0.17**	[0.05, 0.28]	0.17**	[0.06, 0.27]
Mother reaching – Infant reaching	0.27*	[0.13, 0.41]	0.01	[-0.003, 0.01]	0.05*	[0.01, 0.10]	0.27**	[0.07, 0.47]
Mother play – Infant play	0.13	[-0.03, 0.29]	-0.01	[-0.01, 0.02]	0.43***	[0.28, 0.57]	0.80***	[0.47, 1.13]
Infant-Initiated Behaviours					**Infant**		**Mother**	
Infant touch right hand– Mother touch right hand	0.57*	[0.24, 0.90]	0.001	[-0.01, 0.01]	0.08**	[0.03, 0.13]	0.29**	[0.11, 0.48]
Infant touch left hand – Mother touch left hand	0.42*	[0.06, 0.77]	0.01	[-0.003, 0.03]	0.14***	[0.07, 0.22]	0.23*	[0.04, 0.42]
Infant gaze mother – Mother gaze infant	2.81*	[0.57, 5.05]	0.01*	[0.005, 0.01]	0.16***	[0.10, 0.22]	0.20***	[0.11, 0.29]
Infant reaching – Mother reaching	0.21*	[0.05, 0.36]	-0.001	[-0.02, 0.02]	0.19*	[0.04, 0.35]	0.11	[-0.02, 0.24]
Infant play – Mother play	0.22	[-0.06, 0.50]	-0.03	[-0.02, 0.01]	0.49***	[0.26-0.73]	0.64***	[0.38, 0.90]

Statistically significant values are marked with asterisks, *p<0,05; **p<0,01; ***p<0,001.

Table 5 Changes in Non-Matching Behaviours Non-matching behaviours (e.g., mismatched play and gaze) were less common but showed age-appropriate developmental trends.

Behaviour pairs	**Freq**		**Prob**		**Mother**		**Infant**	
Mother- Initiated Behaviour	**β**	**CI**	**β**	**CI**	**β**	**CI**	**B**	**CI**
Mother touch right hand– Infant gaze mother	1.38***	0.78-1.98	0.01**	0.003-0.02	0.18***	[0.10, 0.27]	0.21***	[0.11, 0.30]
Mother touch right hand – Infant play	0.27*	0.02-0.52	0.01	-0.001-0.01	0.18***	[0.12, 0.24]	0.48***	[0.28, 0.66]
Mother touch left hand – Infant gaze mother	0.85***	0.43-1.29	0.02***	0.01-0.03	0.28***	[0.16, 0.41]	0.09	[-0.02, 0.21]
Mother touch left hand – Infant play	0.19***	0.09-0.29	0.01*	0.001-0.01	0.28***	[0.16, 0.41]	0.50***	[0.29, 0.71]
Mother gaze infant – Infant reaching	0.37***	0.19-0.55	0.004	-0.001-0.01	0.17**	[0.05, 0.28]	0.24**	[0.05, 0.42]
Mother gaze infant – Infant play	0.36**	0.07-0.64	0.005*	0.001-0.01	0.17**	[0.05, 0.28]	0.39**	[0.11, 0.66]
Mother reaching – Infant gaze mother	0.68***	0.29-1.07	0.005	-0.003-0.01	0.05*	[0.01, 0.10]	0.13***	[0.05, 0.21]
Mother play – Infant gaze mother	1.04***	0.64-1.44	-0.004	-0.01-0.005	0.43***	[0.28, 0.57]	0.21***	[0.09, 0.34]
Infant-Initiated Behaviour					Infant		Mother	
Infant touch right hand– Mother gaze infant	0.44**	0.16-0.71	0.002	-0.01-0.01	0.08**	[0.03, 0.13]	0.32***	[0.10, 0.54]
Infant touch right hand – Mother play	0.36**	0.10-0.61	0.0001	-0.01-0.01	0.08**	[0.03, 0.13]	0.40***	[0.28, 0.52]
Infant touch left hand – Mother gaze infant	0.53*	0.07-0.99	0.03**	-0.005-0.06	0.14***	[0.06, 0.23]	0.21***	[0.08, 0.33]

Infant touch left hand – Mother play	0.48***	0.25-0.72	0.03	-0.01-0.06	0.14***	[0.06, 0.23]	0.22	[-0.03, 0.46]
Infant gaze mother – Mother reaching	0.58**	0.22-0.93	0.001	-0.003-0.01	0.16***	[0.10, 0.22]	0.11*	[0.004, 0.22]
Infant gaze mother – Mother play	0.86***	0.65-1.07	0.01*	0.001-0.01	0.16***	[0.10, 0.22]	0.30***	[0.14, 0.46]
Infant reaching – Mother gaze infant	0.34**	0.13-0.55	0.01*	0.0003-0.03	0.19**	[0.04, 0.35]	0.12**	[0.04, 0.21]
Infant play – Mother gaze infant	0.29**	0.14-0.44	0.02**	0.01-0.03	0.49***	[0.26, 0.73]	0.38*	[0.03, 0.72]

Statistically significant values are marked with asterisks, *p<0.05; **p<0.01; ***p<0.001.

4. Discussion

4.1 Interpretation of Findings

This study contributes new evidence to the growing field of early relational health by examining mother–infant movement synchrony in a real-world urban South African context. Using continuous accelerometry (at 4 and 8 months) and complementary headcam data (4 months only for context), the study tracked synchrony patterns across two early timepoints in Soweto—a setting marked by dense households, high unemployment, and limited formal caregiving infrastructure.

Synchrony in movement, as measured through dynamic alignment of wrist accelerometry signals, showed small, non-significant differences between 4 and 8 months (with within-dyad variability), consistent with the developmental shift toward increased infant autonomy. The cross-correlation analysis further revealed a descriptive change in synchrony directionality—shifting from predominantly mother-led patterns at 4 months to more infant-led synchrony by 8 months. This finding is consistent with existing literature on developmental trajectories of relational engagement, which suggests that as infants begin to gain motor independence and social awareness, they play a more active role in initiating and sustaining coordinated exchanges (Feldman, 2007; Leclère et al., 2014).

A particularly noteworthy and policy-relevant finding was the adjusted association between maternal employment and lower accelerometer-derived synchrony ($\beta = –0.131$, $p = 0.004$). In a context like Soweto, where many women engage in informal or unstable work and rely on extended family networks, maternal availability can be compromised. Prior studies in similar South African communities have noted that employment—while economically beneficial—can reduce co-presence and interactive time, potentially reshaping dyadic dynamics (Tomlinson et al., 2005; Prioreschi et al., 2018). Given observational design and sample size, we interpret this as hypothesis-generating rather than causal.

Interestingly, other socio-demographic variables (education, relationship status, household composition) were not associated with synchrony in adjusted models, suggesting that movement-based synchrony may be more sensitive to time-use and relational availability than to static profiles.

The headcam data from 4 months provided illustrative behavioural synchrony in gaze, touch, and hand movement. These segments contextualised what co-movement can look like (e.g., mutual gaze during joint handling) but were not pooled with accelerometry nor used for longitudinal inference. This supports earlier observational work emphasising the mutual, co-regulated nature of early interactions (Bigelow et al., 2008; Vally et al., 2015).

4.2 Implications for Practice and Policy

In settings like Soweto—where formal childcare is limited and maternal workloads are high—these findings point to testable avenues for supporting responsive caregiving. Rather than issuing prescriptive recommendations, we propose evaluating strategies that protect brief, regular windows of co-presence (e.g., flexible work hours around feeding/bedtime routines, caregiver relief) to maintain opportunities for coordinated engagement in the first year. Methodologically, the feasibility of continuous, low-intrusion accelerometry suggests a scalable approach for monitoring early relational processes in low-resource settings.

4.3 Strengths

Strengths include: **(i)** objective, continuous dyadic measurement with paired wrist accelerometry; **(ii)** ecological validity from free-living capture; **(iii)** longitudinal assessment at two early timepoints; and **(iv)** a transparent analytic strategy linking rolling correlations and cross-correlation lags (directionality) with

mixed-effects models for predictors. Headcam vignettes at 4 months provided convergent illustration without overextending their inferential role.

4.4 Limitations

Several limitations qualify interpretation. First, the analytic sample limits power to detect small timepoint differences (risk of type II error). Second, headcam data were available only at 4 months and served a contextual, not confirmatory, function; we lacked concurrent headcam at 8 months. Third, wrist accelerometry indexes total acceleration and cannot distinguish interactive from parallel movement; co-movement may reflect shared context (e.g., being carried) as well as interaction. Fourth, maternal employment was coded coarsely (yes/no) without hours, schedule, commute, or proxy-care detail. Fifth, unmeasured psychosocial factors (e.g., maternal mental health) could confound or modify synchrony (Leclère et al., 2014). Sixth, generalisability is limited to similar urban, low-resource settings. Finally, our primary inferential models were linear mixed-effects models for continuous synchrony; results align with the descriptive overlap between timepoints.

4.5 Conclusion and Future Directions

Movement synchrony in this cohort was moderate and broadly stable from 4 to 8 months, with directionality shifting descriptively toward infant-led patterns and lower mean synchrony among employed mothers. These results underscore the context sensitivity of early coordination. Replication in larger samples with concurrent multimodal measures (movement, gaze/vocal affect) and fine-grained time-use is warranted. Future work should pre-register lag/timescale analyses, include maternal well-being measures, and experimentally evaluate whether brief, protected co-presence windows help sustain synchrony in the first year.

Acknowledgements: The authors would like to thank the Wellcome Trust, the National Institute for Health Research and the Center of Excellence in Human Development (CoE) for their financial support, which made this study possible. The authors are also grateful to the participants of the PLAY Love And You study and those involved in the original study design, recruitment, and data entry.

Contributors: Coding of videos: DM. Data processing and analysis: DM. Manuscript: DM wrote the initial draft of the paper. AP, LN, IN and AM read and contributed to the final version. All authors provided edits and critiqued the manuscript for intellectual content.

Funding: This work was supported by the National Institute for Health Research (NIHR) (using the UK's Official Development Assistance Funding) and Wellcome (222007/Z/20/Z) under the NIHR-Wellcome Partnership for Global Health Research. The views expressed are those of the authors and not necessarily those of Wellcome, the NIHR or the Department of Health and Social Care. The support of the DSI-NRF Centre of Excellence in Human Development at the University of the Witwatersrand, Johannesburg, in the Republic of South Africa, towards this research is acknowledged. Opinions expressed and conclusions arrived at are those of the author and are not to be attributed to the CoE in Human Development.

Conflict of interests: The authors have no relevant financial or non-financial interests to disclose.

Ethical Considerations: This study was approved by the University of the Witwatersrand's Human Research Ethics Committee (M220785).

Consent to participate: Written informed consent was obtained from all participants at recruitment.

Consent for publication: All participants signed informed consent regarding publishing their data.

Supplemental material: This content has been supplied by the author(s).

3.5.Chapter Summary

In summary, across the three studies, mother-infant dyads displayed measurable synchrony in both behavioural and movement domains, with clear developmental progression between 4 and 8 months. Longitudinal findings highlighted maternal employment and socio-economic context as important predictors of synchrony. These results provide the empirical foundation for the integrated discussion in the next chapter.

CHAPTER FOUR: INTEGRATED DISCUSSION AND CONCLUSION

4.1. Introduction

This thesis examined mother infant synchrony using a multimodal framework that integrates first person observation from head mounted cameras with objective movement data from wrist worn accelerometers. This combination enabled detailed analysis of overt behavioural exchanges and subtle, time aligned movement patterns in an urban, resource constrained South African context (Draper et al., 2018; Tomaz et al., 2020). Definitions follow Chapter 1 and Section 2.5 to keep usage consistent across behavioural, movement, and physiological discussions.

Across the three linked studies, synchrony emerged as a dynamic, bidirectional phenomenon that is shaped by development, socioeconomic conditions, and caregiving practices. As elaborated in Section 4.5, synchrony underpins key developmental domains (Feldman, 2007; Leclère et al., 2014). In Study 3, the observed negative association between maternal employment and accelerometer-derived synchrony is interpreted as a modest, context-dependent correlation rather than a strong or causal effect. Given unmeasured factors (e.g., detailed time-use, childcare arrangements, work schedules), we treat this finding as hypothesis-generating and suitable for targeted replication, not as a basis for prescriptive policy on its own. Shorter analytic windows privilege rapid, micro-contingent exchanges (e.g., brief gaze or gesture alignment), whereas longer windows may be more sensitive to extended contingencies (e.g., sustained touch or vocal rhythms). Thus, timescale choice can influence detection and may vary across cultural routines.

Although this thesis did not collect qualitative data, we interpret observed patterns alongside South African literature on communal caregiving and context specific feeding and soothing practices, for example extended kin involvement in daily routines and responsive caregiving under economic constraint,

and we signpost the Key Terms entry on WEIRD contexts to caution against over generalising from high income samples (Tomlinson et al., 2005; Cooper et al., 2009; Wrottesley et al., 2021; Madhavan and Gross, 2013).

This chapter integrates the findings, positions them within the literature, and sets out their theoretical, methodological, and practical implications. It also revisits the conceptual framework from Chapter One, and concludes with recommendations for research, policy, and practice.

4.2. Objectives and Summary of Results

Table 1. Objectives of the thesis and corresponding results

Objective	**Methodology**	**Key Results**
1. To determine synchrony of mother-infant non-verbal behaviours using first-person observation **(Study 1).**	First-person head-mounted camera (headcam) footage was collected and analysed using behavioural micro-coding at 4-month postpartum.	- Synchrony was observable through intimate caregiver-infant interactions (e.g., gaze, touch, gestures). - Delayed emergence of behavioural synchrony compared to WEIRD contexts, suggesting contextual developmental variations. - While synchrony was clearly observable, the frequencies and probabilities of matched behaviours within the 3–7 second windows were low compared to reports from WEIRD contexts. This discrepancy suggests contextual differences in the timing and strength of synchrony.
2. To determine synchrony in diurnal movement behaviours of mother-	Objective movement data from wrist-worn accelerometers analysed using cross-	- Clear temporal coupling concentrated in routine caregiving periods (mid-morning, late afternoon).

infant dyads using accelerometer data **(Study 2).**	correlation and Vector Autoregressive Models at 4-month postpartum.	- Co-movement bursts constituted a small proportion of the 7-day record, overall movement levels modest. - Directionality at 4 months showed short-lag responsiveness; inference about leadership shifts requires longitudinal data (addressed in Study 3).
3. To assess longitudinal patterns and predictors of synchrony in movement and interaction behaviours across the first year of life **(Study 3).**	Integrated longitudinal analysis combining accelerometer and headcam data at 4 and 8 months postpartum using mixed-model statistical approaches (Linear Mixed Models, APIM).	- Mean movement synchrony was broadly stable from 4 to 8 months with substantial between-dyad variability. - Cross-correlation suggested a shift toward more infant-led timing by 8 months. - Maternal employment showed a modest negative association with synchrony; other demographic covariates had limited or null associations.

Note: Contrary to our expectation that synchrony would decrease as infants gained autonomy, synchrony remained stable, and leadership increasingly shifted toward infants between 4 and 8 months.

4.3. Revisiting the Conceptual Framework

The conceptual framework presented in Chapter One (Figure 1.1) proposed that synchrony emerges from the interplay between caregiver availability, infant developmental stage, socio-cultural caregiving norms, and broader structural constraints. Each component of this model was supported by findings across the studies:

1. **Relational Dynamics**: Study One found that non-verbal behaviours like gaze, touch, and gesture occurred in temporally coordinated sequences. Study Two revealed that while synchrony was initially mother led, by four months, infants were increasingly initiating matched movement, suggesting a developmental progression (Feldman, 2007; Bornstein et al., 2015). Within dyads, leadership varied across episodes rather than remaining fixed, consistent with moment-to-moment adaptation, and activity type was not coded, therefore stability by context cannot be determined in this dataset.
2. **Structural Constraints**: Study 3's maternal employment finding is best read as a modest correlation consistent with reduced co-presence, not a causal effect. Other demographic covariates, including caregiver education and household structure, had limited or null associations, highlighting that synchrony appears less dependent on broad socio-demographic markers and more on specific structural constraints such as caregiver time availability. The broader South African caregiving context, characterised by communal caregiving and shared responsibility, further underscores the importance of situating synchrony within culturally specific frameworks, as discussed in Section 4.7. Policy and programme implications of these findings are expanded in Section 4.5. Mechanistically, reduced synchrony with maternal employment likely reflects constrained shared time, more fragmented interaction windows, and possible stress related reductions in moment-to-moment sensitivity. We did not directly measure maternal stress or detailed time use in this thesis, nor did we capture the intensity or timing of support from other caregivers, therefore potential buffering effects could not be tested.

3. **Cultural Context**: Although the thesis focused on mother-infant dyads, the broader South African caregiving context, characterised by communal caregiving and shared responsibility, highlights the need to expand future frameworks to include fathers, grandparents, and siblings (Lachman et al., 2022; Keller, 2016). While we did not collect qualitative data, interpretations are situated alongside South African work documenting communal caregiving and everyday caregiving routines, and readers are directed to the Key Terms entry on WEIRD contexts to avoid over generalising from high income samples (Tomlinson et al., 2005; Cooper et al., 2009; Wrottesley et al., 2021; Madhavan and Gross, 2013).

4.4. Methodological Contributions

Each of the three studies in this thesis contributed uniquely to the advancement of synchrony research in low-resource, real-world contexts. The integration of behavioural and Accelerometer data over time represents a significant methodological innovation in early childhood development research, particularly within LMIC settings. For instance, during a quiet episode characterised by sustained mutual gaze and gentle touch, the accelerometry signals in both partners showed low amplitude movement, a concordant pattern consistent with calm co regulation. In a more active episode marked by higher physical activity, accelerometry captured brief aligned movement bursts while video showed limited mutual gaze, a discordant pattern in which movement synchrony occurred without concurrent behavioural matching. Activity type was not coded; therefore, examples are framed by observed behavioural markers and movement dynamics rather than specific activities.

- **Study One** demonstrated the use of first-person head-mounted cameras (headcams) to collect ecologically valid behavioural data within home environments. The unobtrusive nature of the technology, combined with second-by-second micro-coding of gaze, touch, and facial expressions, enabled a level of detail rarely achieved in synchrony research conducted in LMICs. The approach allowed for the detection of subtle non-verbal synchrony patterns and developmental lags

compared to global reference populations (Leclère et al., 2014; Feldman, 2012; Tomaz et al., 2019). Importantly, the delayed emergence of behavioural synchrony relative to WEIRD samples represents a meaningful discrepancy. Rather than a deficit, this likely reflects contextual caregiving practices in Soweto, highlighting the importance of situating synchrony trajectories within local cultural frameworks.

- **Study Two** introduced accelerometry to quantify physical activity synchrony. Cross-correlation and time-series modelling of wrist-worn accelerometer data revealed not only the presence of movement synchrony but also diurnal rhythms and directional shifts from mother- to infant-led synchrony. These findings highlighted developmental transitions in co-regulation and offered objective, reproducible metrics free from observer bias (Draper et al., 2018; Bruijns et al., 2020).
- **Study Three** represented the most comprehensive analysis, integrating data streams from both methods at two timepoints. Advanced statistical techniques, including Linear Mixed Models and Actor-Partner Interdependence Models (APIM), were used to examine longitudinal synchrony trajectories and the influence of structural variables like maternal employment. This dual-modality approach, implemented successfully in Soweto, demonstrates the feasibility of sophisticated research designs in under-resourced settings (Prioreschi et al., 2023; Tomaz et al., 2020).

The combined use of headcam and accelerometry methodologies established a rigorous and context-sensitive model for future synchrony studies, reinforcing the possibility of conducting high-quality, multimodal developmental research in LMICs.

4.5. Implications for Research, Practice, and Policy

Implications for Research

When interpreting the implications of these findings, it is important to note several null and discrepant results. Synchrony within short behavioural windows occurred infrequently, synchronised co-movements

made up only a small fraction of the accelerometry record, and most socio-demographic variables showed no consistent associations with synchrony. These results temper generalisation and highlight the importance of focusing on structural constraints, particularly caregiver time availability, while avoiding over-reliance on traditional demographic predictors.

Study three found maternal employment to be a consistent and significant predictor of reduced synchrony, while education and household structure had minimal effects. This suggests that structural and temporal availability, rather than socioeconomic or educational status alone, most strongly influence relational engagement. Future research should therefore incorporate maternal mental health, stress levels, and emotional availability to provide a fuller picture of how synchrony is shaped (Nomikou et al., 2016). Additionally, South African families often rely on shared caregiving. Expanding synchrony research to include fathers, grandparents, and other caregivers would better reflect local caregiving ecologies (Keller, 2016). Further, the multimodal methods used in this thesis, especially headcam and accelerometry, should be applied longitudinally across early childhood to test links between synchrony and later outcomes. To support replication and secondary analysis, de identified accelerometry time series and headcam annotation files will be discoverable via the project and Wits Library websites and released on application under a data use agreement and ethics approval, while raw headcam video remains restricted to secure archive, staged access protects participants and aligns with DPHRU policy. These resources can inform intervention timing by identifying daily windows when synchrony is most likely and by developing simple monitoring indicators aligned with national and WHO frameworks.

Implications for Practice

Study One showed that synchrony behaviours such as mutual gaze and gesture matching can be observed even in short interactions. This has practical value for community health workers and early childhood practitioners, who can be trained to identify and encourage such behaviours during home visits, clinic

appointments, or group parenting sessions. Visual and audio tools developed from headcam footage, integrated into parenting support programmes and the Road to Health Booklet, can enhance caregiver understanding and confidence and support implementation at scale.

Implications for Policy

Study Three revealed a strong relationship between maternal employment and reduced synchrony. These findings support policy measures that expand parental leave and flexible work arrangements, to preserve responsive interactions in the first year, and to embed synchrony as a measurable, modifiable factor in early childhood strategies through training for health and childcare professionals and access to culturally relevant resources.

These recommendations align with the South African Integrated ECD Policy (2015) and the WHO Nurturing Care Framework, both of which emphasise responsive caregiving as a central pillar of early childhood development. Positioning synchrony explicitly within these frameworks could strengthen policy uptake and ensure that **caregiver infant** relational processes are recognised alongside health, nutrition, and early learning priorities.

4.6. Strengths

A key strength of this thesis is the innovative and objective methodological approach, combining first-person headcam observation and wrist-worn accelerometry. These advanced tools provided unparalleled insights into the timing, structure, and directional aspects of mother-infant synchrony within authentic home environments. Specifically, integrating first-person observational techniques with accelerometry facilitated simultaneous capture of detailed behavioural interactions and precise movement data, significantly enhancing ecological validity and methodological robustness (Draper et al., 2018; Prioreschi

et al., 2017; Tomaz et al., 2019, 2020). Additionally, the objective and quantitative nature of Accelerometer data effectively reduced observer biases common in traditional observational studies, thus increasing the reliability and reproducibility of findings (Bruijns et al., 2020).

The mixed-methods design, which combined detailed behavioural micro-coding with sophisticated signal analysis, allowed for a comprehensive exploration of both overt and subtle dimensions of mother-infant coordination. Furthermore, the longitudinal nature of this research, involving data collection at two crucial developmental periods, enabled meaningful interpretation of synchrony trajectories over time. The use of advanced analytical techniques, such as Vector Autoregressive Models, Linear Mixed Models, and Actor-Partner Interdependence Models, provided robust insights into the temporal, bidirectional, and contextual influences on synchrony.

Finally, recruiting participants from primary care clinics in Soweto significantly enhances the ecological validity of the findings, ensuring their relevance to urban, resource-limited environments.

4.7. Limitations

Despite the significant methodological strengths of this thesis, several practical and methodological limitations should be acknowledged. Firstly, integrating and synchronising multimodal data streams from headcam video recordings and accelerometry is inherently complex, requiring substantial methodological expertise and advanced technological infrastructure. These demands can pose significant barriers in resource-constrained settings such as Soweto, potentially limiting the broader adoption and scalability of these methods (Prioreschi et al., 2023; Tomaz et al., 2019, 2020).

Secondly, the extensive amount of data generated through simultaneous video and accelerometry necessitates considerable analytical resources. The sheer volume and complexity of multimodal datasets

often result in increased analytical burden, which can complicate data processing, interpretation, and subsequent reporting (Bruijns et al., 2020; Nomikou et al., 2016).

Additionally, while the technology used is generally lightweight and minimally intrusive, potential participant discomfort or behavioural alterations due to device wearing cannot be completely ruled out (Nomikou et al., 2016). Furthermore, ethical considerations regarding privacy and informed consent remain particularly pertinent, given the intimate and sensitive nature of recording mother-infant interactions within private, naturalistic home environments (Powers et al., 2011; Yarrow & Goodwin, 1965). For headcam video only, participants could pause or stop recording at any time, review their footage, and request deletion of any segment, although no deletion requests were made, and any such requests would have been honoured and logged prior to analysis, with no identifiable images reproduced in this thesis.

Another methodological limitation relates specifically to the observational data: headcam recordings were confined to three brief 5-minute intervals, potentially missing broader, ongoing daily interaction patterns. Although accelerometry provided continuous data collection, the placement of sensors on the wrist may not have captured the full spectrum of infant locomotor behaviours, particularly movements involving the lower limbs. Moreover, while the accelerometry results offered robust, objective evidence of measurable synchrony in daily life, an inherent limitation is that accelerometer-derived measures lack contextual detail regarding what activities underlie synchronised movements. For instance, aligned wrist activity could signal shared play, feeding, or soothing, yet accelerometry alone cannot distinguish between these behaviours. This highlights the importance of integrating accelerometry with first-person headcam footage, which provides rich contextual information. In this thesis, Studies 1 and 3 illustrate how headcam observations complemented accelerometry by capturing micro-level behavioural synchrony and caregiving interactions in context. Because analyses in this thesis focused on diurnal synchrony, nocturnal co regulation was not modelled and inferences pertain to waking behaviour only.

Substantial data dropout at the 8-month assessment timepoint constrained the completeness and generalizability of longitudinal accelerometry analyses. Additionally, relevant psychosocial variables, such as maternal mental health and stress, were not explicitly measured in this study, despite their documented impact on mother-infant synchrony. Hence, interpretations of the findings must remain cautious concerning these unmeasured factors.

A further limitation is that the main dataset was drawn from a randomized controlled trial of an early caregiving intervention. Although the trial arm allocation was not the focus of this thesis, it is possible that the intervention enhanced synchrony in some dyads, thereby confounding natural developmental trajectories (Jeong et al., 2021; Yousafzai et al., 2016).

Also, this thesis focused exclusively on mother–infant dyads in a single cultural and socio-economic context. While this provided valuable depth in understanding synchrony in Soweto, the findings cannot be assumed to generalise to other cultural or socio-economic groups. In addition, the exclusive focus on mothers overlooks the influential roles played by fathers, grandparents, siblings, and other caregivers. Future research should therefore incorporate multiple caregiver roles and extend to diverse cultural and socio-economic settings to better understand how synchrony operates across contexts.

Nevertheless, despite these limitations, the integrated multimodal framework employed in this research represents a significant methodological advance in the study of synchrony. By capturing comprehensive data on both complex qualitative interactions and objective movement coordination, this multimodal approach enhances our understanding of mother-infant synchrony in diverse sociocultural contexts, particularly those typical of low-resource, urban South African settings. Future studies should aim to refine these methodological approaches, optimize multimodal data integration, and address ethical and practical challenges to further strengthen the applicability and impact of synchrony research globally.

Finally, null and discrepant findings in this thesis (such as low synchrony frequencies within short windows, small proportions of co-movement bursts, and non-significant effects of most demographic variables) should be seen as informative. They provide important boundary conditions for synchrony research and help refine theoretical models, preventing over-generalisation from positive results alone.

4.8. Conclusions

This thesis presents the first longitudinal, multimodal analysis of mother-infant synchrony conducted in an urban South African setting. The integration of headcam and accelerometry methods, applied through a series of structured studies, revealed that synchrony is a developmental process shaped by both relational and structural factors. The consistent finding that maternal employment constrains synchrony highlights the urgency of aligning public health, labour, and ECD policies with the realities of caregiving in LMICs. These findings make a strong case for embedding synchrony-enhancing interventions into maternal and child health systems.

4.9. Knowledge Gaps and Future Priorities

- **Methodological Issues:** Although significant methodological advancements were made, challenges persist. Future research should address the technical complexities of synchronising multimodal datasets and optimise analytical approaches for resource-constrained environments. Standardised protocols regarding optimal duration and frequency of observational sessions should be established to enhance data reliability and validity (Bruijns et al., 2020; Tomaz et al., 2020). Future studies should also expand multimodal integration and consider combining accelerometry with caregiver diaries, time use reports, or extended video recordings to strengthen interpretability of synchrony patterns (Nomikou et al., 2016; Bruijns et al., 2020). Use the existing continuous

accelerometry to examine nocturnal co regulation and test associations with infant sleep and developmental outcomes. Pre-register window sensitivity analyses that compare sub second to longer windows, for example up to 10 seconds, across settings to test timescale dependence of synchrony.

- **Culturally Sensitive Synchrony Assessment:** Existing synchrony frameworks, predominantly Western-based, inadequately capture culturally specific caregiving practices such as communal caregiving, rhythmic vocalisations, and tactile interactions common in South African communities. Developing culturally valid assessment tools through community-engaged participatory approaches is essential to accurately measure synchrony across diverse populations (Keller, 2016; Lachman et al., 2022).

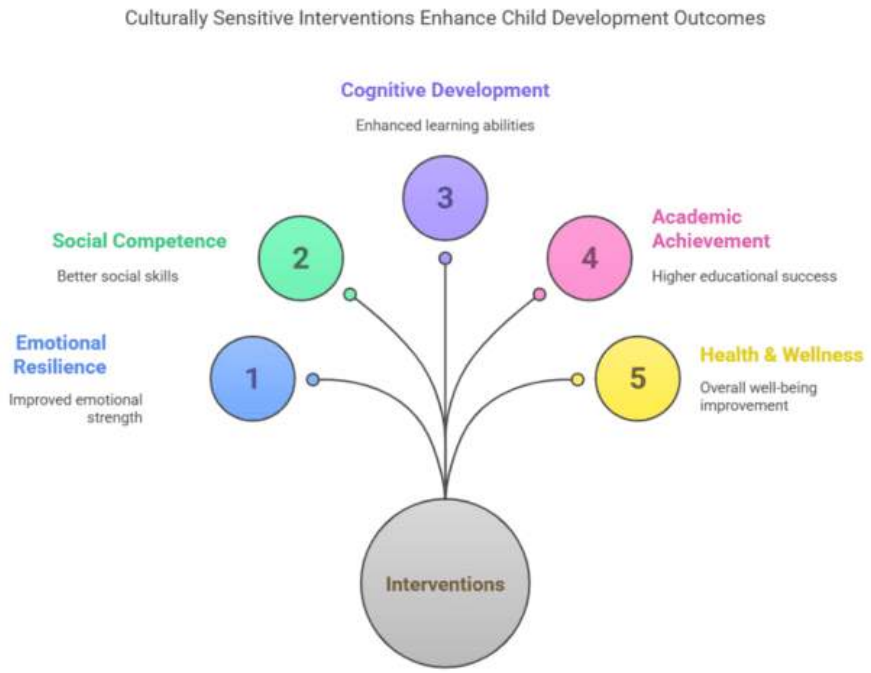


Figure 1. Infographic summarizing the potential impacts of culturally sensitive, synchrony-informed interventions tailored to South African caregiving contexts. The visual highlights anticipated improvements in child developmental outcomes, such as emotional resilience, enhanced social competence, cognitive development, and academic achievement, directly addressing the knowledge gaps and future research directions outlined in Section 10.0.

More Future Research Priorities

- Building upon the insights from this research, future studies should:
- Extend longitudinal assessments beyond infancy to capture longer-term developmental trajectories of synchrony and child outcomes.
- Explicitly incorporate measures of maternal mental health, psychosocial stress, and cultural factors to better understand their impact on synchrony dynamics.
- Broaden caregiving contexts by involving fathers, grandparents, siblings, and other community caregivers to reflect the caregiving ecologies common in South African households.
- Expand synchrony research across diverse cultural and socio-economic groups in both LMICs and HICs, enabling cross-cultural comparisons and reducing the risk of over-generalising from a single township-based cohort.
- Employ qualitative methodologies to complement quantitative data, enriching the understanding of lived experiences, caregiving behaviours, and synchrony processes from participants' perspectives.
- Explicitly evaluate synchrony outcomes by trial arm to distinguish intervention effects from baseline developmental change (Jeong et al., 2021; Yousafzai et al., 2016).
- Pair headcam segments with brief post recording interviews to capture caregiver intent and context for observed episodes, quotes or paraphrases would be presented alongside coded sequences.
- Add simple time use diaries or short activity logs and include additional caregivers, for example fathers or grandparents, to test whether synchrony varies by caregiver role and routine.
- Measure the presence, intensity, and timing of support from other caregivers, for example fathers, grandparents, or paid carers, using time use diaries and contact logs, and test whether such support buffers the association between maternal employment and synchrony.

- Include brief measures of maternal stress and affect to examine whether stress mediates the association between maternal employment and synchrony.

Synchrony-Informed Interventions

Synchrony is a measurable and modifiable relational process that should be positioned at the core of early childhood development (ECD) programmes. When identified and supported early, it has the potential to mitigate developmental risks associated with socio-economic adversity and maternal mental health challenges. Rigorous evaluation of synchrony-focused interventions through randomised controlled trials is essential, ideally using multimodal assessments to capture both behavioural and movement-based indicators of caregiver–infant interaction.

For translation into practice, future intervention design should be anchored within **structured policy frameworks**. Embedding synchrony-enhancing practices into the **WHO Nurturing Care Framework (NCF)** would ensure that responsive caregiving is systematically promoted, monitored, and evaluated as part of global child development strategies. At the national level, alignment with the **South African Integrated ECD Policy (2015)** would provide a concrete pathway for implementation, since this policy already recognises responsive caregiving as a critical pillar of early development.

At the programmatic level, this could involve integrating synchrony indicators into the **Road to Health Booklet**, embedding synchrony-focused modules into community health worker and parenting training curricula, and developing culturally sensitive educational resources for caregivers. Such steps would create measurable pathways linking research findings to existing policy platforms, thereby enabling scalable, contextually relevant solutions to strengthen caregiver–child relationships and promote both developmental and caregiver well-being in South Africa (Leclère et al., 2014; Lachman et al., 2022).

4.10. Chapter Summary

Overall, this thesis demonstrates that mother infant synchrony is a dynamic, contextually shaped process with important developmental implications in LMIC settings. By integrating headcam and Accelerometer data, the work advances methodological approaches while providing culturally relevant insights. The findings underscore the need for interventions that strengthen synchrony in socioeconomically constrained contexts and contribute to global frameworks on early childhood development. Given the small pilot sample for the headcam analyses, we caution against broad generalisation and call for larger longitudinal replications in varied socio-cultural contexts

CHAPTER FIVE: REFERENCES

Abu Salih, M., Abargil, M., Badarneh, S., klein Selle, N., Irani, M., & Atzil, S. (2023). Evidence for cultural differences in affect during mother–infant interactions. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-31907-y

Ainsworth, M. D. S. (1979). Attachment as Related to Mother-Infant Interaction. *Advances in the Study of Behavior*, *9*(C), 1–51. https://doi.org/10.1016/S0065-3454(08)60032-7

Albinali, F., Goodwin, M. S., & Intille, S. S. (2009). Recognizing stereotypical motor movements in the laboratory and classroom: A case study with children on the autism spectrum. *ACM International Conference Proceeding Series*, 71–80. https://doi.org/10.1145/1620545.1620555

An, Q., Ishikawa, Y., Nakagawa, J., Kuroda, A., Oka, H., Yamakawa, H., Yamashita, A., & Asama, H. (2012). Evaluation of wearable gyroscope and accelerometer sensor (PocketIMU2) during walking and sit-to-stand motions. *Proceedings - IEEE International Workshop on Robot and Human Interactive Communication*, 731–736. https://doi.org/10.1109/ROMAN.2012.6343838

Atzil, S., Hendler, T., & Feldman, R. (2011). Specifying the Neurobiological Basis of Human Attachment: Brain, Hormones, and Behavior in Synchronous and Intrusive Mothers. *Neuropsychopharmacology 2011 36:13*, *36*(13), 2603–2615. https://doi.org/10.1038/npp.2011.172

Ayob, Z., Christopher, C., & Naidoo, D. (2021). Caregivers' Perception of their Role in Early Childhood Development and Stimulation Programmes in the Early Childhood Development Phase within a Sub-Saharan African Context: An Integrative Review. *South African Journal of Occupational Therapy*, *51*(3), 84–92. https://doi.org/10.17159/2310-3833/2021/VOL51N3A10

Barry, E. S. (2019). Co-sleeping as a proximal context for infant development: The importance of physical touch. *Infant Behavior and Development*, *57*, 101385. https://doi.org/10.1016/J.INFBEH.2019.101385

Beebe, B. (2010). Mother-infant research informs mother-infant treatment. *Clinical Social Work Journal*, *38*(1), 17–36. https://doi.org/10.1007/s10615-009-0256-7

Beebe, B., & Feldstein, S. (2001). *Article in Monographs of the Society for Research in Child Development*. http://www.jstor.org/page/info/about/policies/terms.jsp

Beebe, B., Messinger, D., Bahrick, L. E., Margolis, A., Buck, K. A., & Chen, H. (2016). A Systems view of mother-infant face-to-face communication. *Developmental Psychology*, *52*(4), 556–571. https://doi.org/10.1037/a0040085

Bell, M. A. (2020). Mother-child behavioral and physiological synchrony. In *Advances in Child Development and Behavior* (Vol. 58, pp. 163–188). Academic Press Inc. https://doi.org/10.1016/bs.acdb.2020.01.006

Bigelow, A. E., Power, M., McQuaid, N., Ward, A., & Rochat, P. (2008). Distinguishing Mother–Infant Interaction From Stranger–Infant Interaction at 2, 4, and 6 Months of Age. *Infancy*, *13*(2), 158–171. https://doi.org/10.1080/15250000701795614

Black, M. M., Walker, S. P., H Fernald, L. C., Andersen, C. T., DiGirolamo, A. M., Lu, C., McCoy, D. C., Bhutta, Z. A., Britto, P. R., Daelmans, B., Darmstadt, G. L., Dua, T., Gertler, P., Heymann, J., Lombardi, J., Lopez Boo, F., Lye, S. J., MacMillan, H., Perez-Escamilla, R., … Grantham-McGregor, S. (2016). Advancing Early Childhood Development: from Science to Scale 1: Early childhood development coming of age: science through the life course. *Lancet (London, England)*, *389*(10064), 77. https://doi.org/10.1016/S0140-6736(16)31389-7

Bornstein, M. H., & Gov, M. (2012). Cultural Approaches to Parenting. *Parenting, Science and Practice*, *12*(2–3), 212. https://doi.org/10.1080/15295192.2012.683359

Bowlby, J. (1969). *ATTACHMENT AND LOSS VOLUME I ATTACHMENT*.

Bruijns, B. A., Truelove, S., Johnson, A. M., Gilliland, J., & Tucker, P. (2020). Infants' and toddlers' physical activity and sedentary time as measured by accelerometry: A systematic review and meta-analysis. In *International Journal of Behavioral Nutrition and Physical Activity* (Vol. 17, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s12966-020-0912-4

Bullowa, Margaret. (1979). *Before speech : the beginning of interpersonal communication*. 400.

Burgess, R., Costantini, I., Bornstein, M. H., Campbell, A., Cordero Vega, M. A., Culpin, I., Dingsdale, H., John, R. M., Kennedy, M. R., Tyson, H. R., Pearson, R. M., & Nabney, I. (2023a). A Quantitative Evaluation of Thin Slice Sampling for Parent–Infant Interactions. *Journal of Nonverbal Behavior*. https://doi.org/10.1007/s10919-022-00420-7

Burgess, R., Costantini, I., Bornstein, M. H., Campbell, A., Cordero Vega, M. A., Culpin, I., Dingsdale, H., John, R. M., Kennedy, M. R., Tyson, H. R., Pearson, R. M., & Nabney, I. (2023b). A Quantitative Evaluation of Thin Slice Sampling for Parent–Infant Interactions. *Journal of Nonverbal Behavior*, *47*(2), 117–210. https://doi.org/10.1007/s10919-022-00420-7

Caplan, B., Neece, C. L., & Baker, B. L. (2015). Developmental level and psychopathology: Comparing children with developmental delays to chronological and mental age matched controls. *Research in Developmental Disabilities*, *37*, 143–151. https://doi.org/10.1016/J.RIDD.2014.10.045

Carson, V., Lee, E. Y., Hewitt, L., Jennings, C., Hunter, S., Kuzik, N., Stearns, J. A., Unrau, S. P., Poitras, V. J., Gray, C., Adamo, K. B., Janssen, I., Okely, A. D., Spence, J. C., Timmons, B. W., Sampson, M., & Tremblay, M. S. (2017). Systematic review of the relationships between physical activity and health indicators in the early years (0-4 years). *BMC Public Health*, *17*. https://doi.org/10.1186/s12889-017-4860-0

Cekaite, A., & Bergnehr, D. (2018). Affectionate touch and care: embodied intimacy, compassion and control in early childhood education. *European Early Childhood Education Research Journal*, *26*(6), 940–955. https://doi.org/10.1080/1350293X.2018.1533710

Chaput, J. P., Carson, V., Gray, C. E., & Tremblay, M. S. (2014). Importance of all movement behaviors in a 24 hour period for overall health. *International Journal of Environmental Research and Public Health*, *11*(12), 12575–12581. https://doi.org/10.3390/ijerph111212575

Chetouani, M., Delaherche, E., Dumas, G., & Cohen, D. (2017). Interpersonal Synchrony: From Social Perception to Social Interaction. *Social Signal Processing*, 202–212. https://doi.org/10.1017/9781316676202.015

Chorney, J. M. L., Garcia, A. M., Berlin, K. S., Bakeman, R., & Kain, Z. N. (2010). Time-window sequential analysis: An introduction for pediatric psychologists. *Journal of Pediatric Psychology*, *35*(10), 1061–1070. https://doi.org/10.1093/jpepsy/jsq022

Chow, S. M., Haltigan, J. D., & Messinger, D. S. (2010). Dynamic Infant-Parent Affect Coupling During the Face-to-Face/Still-Face. *Emotion*, *10*(1), 101–114. https://doi.org/10.1037/a0017824

Cohen, D. (2012). The developmental being. Modeling a probabilistic approach to child development and psychopathology. *Neuropsychiatrie de l'Enfance et de l'Adolescence*, *60*(5), S25–S26. https://doi.org/10.1016/J.NEURENF.2012.05.069

Cooper, P. J., Tomlinson, M., Swartz, L., Landman, M., Molteno, C., Stein, A., McPherson, K., & Murray, L. (2009). Improving quality of mother-infant relationship and infant attachment in socioeconomically deprived community in South Africa: Randomised controlled trial. *BMJ (Online)*, *338*(7701), 997. https://doi.org/10.1136/bmj.b974

Costantini, I., Cordero, M., Campbell, A., Burgess, R., Glen, K., Moraitopoulou, G., Paul, E., Bornstein, M. H., Culpin, I., & Pearson, R. M. (n.d.-a). *Mental Health Intergenerational Transmission (MHINT) Process Manual *Use alongside the MHINT Micro-Coding Scheme provided as Observer XT© file*.

Costantini, I., Cordero, M., Campbell, A., Burgess, R., Glen, K., Moraitopoulou, G., Paul, E., Bornstein, M. H., Culpin, I., & Pearson, R. M. (n.d.-b). *Mental Health Intergenerational Transmission (MHINT) Process Manual *Use alongside the MHINT Micro-Coding Scheme provided as Observer XT© file*.

Cote, L. R., & Bornstein, M. H. (2021). Synchrony in mother-infant vocal interactions revealed through timed event sequences. *Infant Behavior & Development*, *64*. https://doi.org/10.1016/J.INFBEH.2021.101599

Cuadros, Z., Hurtado, E., & Cornejo, C. (2020). Infant-adult synchrony in spontaneous and nonspontaneous interactions. *PLoS ONE*, *15*(12 December). https://doi.org/10.1371/journal.pone.0244138

Davis, M., Bilms, J., & Suveg, C. (2017). In Sync and in Control: A Meta-Analysis of Parent–Child Positive Behavioral Synchrony and Youth Self-Regulation. *Family Process*, *56*(4), 962–980. https://doi.org/10.1111/famp.12259

Deák, G. O., Krasno, A. M., Jasso, H., & Triesch, J. (2018a). What Leads To Shared Attention? Maternal Cues and Infant Responses During Object Play. *Infancy*, *23*(1), 4–28. https://doi.org/10.1111/infa.12204

Deák, G. O., Krasno, A. M., Jasso, H., & Triesch, J. (2018b). What Leads To Shared Attention? Maternal Cues and Infant Responses During Object Play. *Infancy*, *23*(1), 4–28. https://doi.org/10.1111/infa.12204

Doherty, A., Jackson, D., Hammerla, N., Plötz, T., Olivier, P., Granat, M. H., White, T., Van Hees, V. T., Trenell, M. I., Owen, C. G., Preece, S. J., Gillions, R., Sheard, S., Peakman, T., Brage, S., & Wareham, N. J. (2017). Large scale population assessment of physical activity using wrist worn accelerometers: The UK biobank study. *PLoS ONE*, *12*(2). https://doi.org/10.1371/journal.pone.0169649

Draper, C. E., Tomaz, S. A., Biersteker, L., Cook, C. J., Couper, J., De Milander, M., Flynn, K., Giese, S., Krog, S., Lambert, E. V., Liebenberg, T., Mendoza, C., Nunes, T., Pienaar, A., Priorieschi, A., Rae, D. E., Rahbeeni, N., Reilly, J. J., Reynolds, L., … Okely, A. D. (2020). The South African 24-hour movement guidelines for birth to 5 years: An integration of physical activity, sitting behavior, screen time, and sleep. *Journal of Physical Activity and Health*, *17*(1), 109–119. https://doi.org/10.1123/jpah.2019-0187

Draper, C. E., Tomaz, S. A., Cook, C. J., Jugdav, S. S., Ramsammy, C., Besharati, S., Heerden, A., Vilakazi, K., Cockcroft, K., Howard, S. J., & Okely, A. D. (2020). Understanding the influence of 24-hour movement behaviours on the health and development of preschool children from low-income South African settings: The SUNRISE pilot study. *South African Journal of Sports Medicine*, *32*(1). https://doi.org/10.17159/2078-516X/2020/v32i1a8415

Encyclopaedia Britannica. (2025). *Soweto | History, Map, & Facts | Britannica*. https://www.britannica.com/place/Soweto?utm_source=chatgpt.com

Feldman, R. (2003). Infant-mother and infant-father synchrony: The coregulation of positive arousal. *Infant Mental Health Journal*, *24*(1), 1–23. https://doi.org/10.1002/imhj.10041

Feldman, R. (2007). *Parent-Infant Synchrony Biological Foundations and Developmental Outcomes*.

Feldman, R. (2012a). Bio-behavioral Synchrony: A Model for Integrating Biological and Microsocial Behavioral Processes in the Study of Parenting. *Parenting*, *12*(2–3), 154–164. https://doi.org/10.1080/15295192.2012.683342

Feldman, R. (2012b). Parent-infant synchrony: A biobehavioral model of mutual influences in the formation of affiliative bonds. *Monographs of the Society for Research in Child Development*, *77*(2), 42–51. https://doi.org/10.1111/j.1540-5834.2011.00660.x

Feldman, R. (2016). Parent–Infant Synchrony: Biological Foundations and Developmental Outcomes. *Https://Doi.Org/10.1111/j.1467-8721.2007.00532.x*, *16*(6), 340–345. https://doi.org/10.1111/J.1467-8721.2007.00532.X

Feldman, R. (2017). The Neurobiology of Human Attachments. *Trends in Cognitive Sciences*, *21*(2), 80–99. https://doi.org/10.1016/J.TICS.2016.11.007

Feldman, R., Greenbaum, C. W., & Yirmiya, N. (1999). Mother-Infant Affect Synchrony as an Antecedent of the Emergence of Self-Control. In *Developmental Psychology* (Vol. 35, Issue 5).

Ferrari, P., Friedenreich, C., & Matthews, C. E. (2007). The role of measurement error in estimating levels of physical activity. *American Journal of Epidemiology*, *166*(7), 832–840. https://doi.org/10.1093/AJE/KWM148

Field, T. (2010). Touch for socioemotional and physical well-being: A review. *Developmental Review*, *30*(4), 367–383. https://doi.org/10.1016/J.DR.2011.01.001

Flom, R., Deák, G. O., Phill, C. G., & Pick, A. D. (2004). Nine-month-olds' shared visual attention as a function of gesture and object location. *Infant Behavior and Development*, *27*(2), 181–194. https://doi.org/10.1016/j.infbeh.2003.09.007

Fogel, A. (2019). Two principles of communication. In *New Perspectives in Early Communicative Development* (pp. 9–22). Routledge. https://doi.org/10.4324/9781315111322-3

Ginsburg, K. R., Shifrin, D. L., Broughton, D. D., Dreyer, B. P., Milteer, R. M., Mulligan, D. A., Nelson, K. G., Altmann, T. R., Brody, M., Shuffett, M. L., Wilcox, B., Kolbaba, C., Noland, V. L., Tharp, M., Coleman, W. L., Earls, M. F., Goldson, E., Hausman, C. L., Siegel, B. S., … Smith, K. (2007). The Importance of Play in Promoting Healthy Child Development and Maintaining Strong Parent-Child Bonds. *Pediatrics*, *119*(1), 182–191. https://doi.org/10.1542/PEDS.2006-2697

Giusti, L., Provenzi, L., & Montirosso, R. (2018). The Face-to-Face Still-Face (FFSF) paradigm in clinical settings: Socio-emotional regulation assessment and parental support with infants with neurodevelopmental disabilities. *Frontiers in Psychology*, *9*(MAY). https://doi.org/10.3389/fpsyg.2018.00789

Gratier, M. (2003). Expressive timing and interactional synchrony between mothers and infants: Cultural similarities, cultural differences, and the immigration exprerience. *Cognitive Development*, *18*(4), 533–554. https://doi.org/10.1016/j.cogdev.2003.09.009

Guerrera, G. (2015). Neonatal and pediatric healthcare worldwide: A report from UNICEF. *Clinica Chimica Acta*, *451*, 4–8. https://doi.org/10.1016/j.cca.2015.03.004

GUIDELINES ON PHYSICAL ACTIVITY, SEDENTARY BEHAVIOUR AND SLEEP FOR CHILDREN UNDER 5 YEARS OF AGE. (n.d.).

Harel, H., Gordon, I., Geva, R., & Feldman, R. (2011). Gaze Behaviors of Preterm and Full-Term Infants in Nonsocial and Social Contexts of Increasing Dynamics: Visual Recognition, Attention Regulation, and Gaze Synchrony. *Infancy*, *16*(1), 69–90. https://doi.org/10.1111/j.1532-7078.2010.00037.x

Harris, P. A., Taylor, R., Minor, B. L., Elliott, V., Fernandez, M., O'Neal, L., McLeod, L., Delacqua, G., Delacqua, F., Kirby, J., & Duda, S. N. (2019). The REDCap consortium: Building an international community of software platform partners. In *Journal of Biomedical Informatics* (Vol. 95). Academic Press Inc. https://doi.org/10.1016/j.jbi.2019.103208

Harris, P. A., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., & Conde, J. G. (2009). Research electronic data capture (REDCap)-A metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of Biomedical Informatics*, *42*(2), 377–381. https://doi.org/10.1016/j.jbi.2008.08.010

Hart S (2010). (n.d.).

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world? *The Behavioral and Brain Sciences*, *33*(2–3), 61–83. https://doi.org/10.1017/S0140525X0999152X

Hoch, J. E., Ossmy, O., Cole, W. G., Hasan, S., & Adolph, K. E. (2021). "Dancing" Together: Infant–Mother Locomotor Synchrony. *Child Development*, *92*(4), 1337–1353. https://doi.org/10.1111/cdev.13513

Ilyka, D., Johnson, M. H., & Lloyd-Fox, S. (2021). Infant social interactions and brain development: A systematic review. *Neuroscience and Biobehavioral Reviews*, *130*, 448. https://doi.org/10.1016/J.NEUBIOREV.2021.09.001

Isabella, R. A., & Belsky, J. (1991). *Interactional Synchrony and the Origins of Infant-Mother Attachment: A Replication Study* (Vol. 62, Issue 2).

Jaffe, J., Beebe, B., Feldstein, S., Crown, C. L., Jasnow, M. D., Rochat, P., & Stern, D. N. (2001). *Rhythms of Dialogue in Infancy: Coordinated Timing in Development* (Vol. 66, Issue 2). https://www.jstor.org/stable/3181589?seq=1&cid=pdf-

Jamieson, L., Berry, L., & Lake, L. (n.d.). *2017 ®*. www.childrencount.uct.ac.za.

Jeong, J., Franchett, E. E., Ramos de Oliveira, C. V., Rehmani, K., & Yousafzai, A. K. (2021). Parenting interventions to promote early child development in the first three years of life: A global systematic review and meta-analysis. *PLOS Medicine*, *18*(5), e1003602. https://doi.org/10.1371/JOURNAL.PMED.1003602

Kärtner, J., Keller, H., & Yovsi, R. D. (2010). Mother–Infant Interaction During the First 3 Months: The Emergence of Culture-Specific Contingency Patterns. *Child Development*, *81*(2), 540–554. https://doi.org/10.1111/J.1467-8624.2009.01414.X

Keller, H. (2013). Attachment and Culture. *Journal of Cross-Cultural Psychology*, *44*(2), 175–194. https://doi.org/10.1177/0022022112472253

Keller, H. (2018). Universality claim of attachment theory: Children's socioemotional development across cultures. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(45), 11414–11419. https://doi.org/10.1073/PNAS.1720325115

Keller, H., Voelker, S., & Yovsi, R. D. (n.d.). *Conceptions of Parenting in Different Cultural Communities: The Case of West African Nso and Northern German Women*.

Kohrt, B. A., Rai, S., Vilakazi, K., Thapa, K., Bhardwaj, A., & van Heerden, A. (2019). Procedures to select digital sensing technologies for passive data collection with children and their caregivers: Qualitative cultural assessment in South Africa and Nepal. *JMIR Pediatrics and Parenting*, *2*(1). https://doi.org/10.2196/12366

Lachman, A., Burger, M., Jordaan, E. R., Leppanen, J., Puura, K., & Niehaus, D. J. H. (2021). Maternal Shared Pleasure, Infant Withdrawal, and Developmental Outcomes in a High Risk Setting in South Africa. *Frontiers in Psychiatry*, *12*. https://doi.org/10.3389/fpsyt.2021.668009

Lachman, A., Jordaan, E. R., Stern, M., Donald, K. A., Hoffman, N., Lake, M. T., Zar, H. J., Niehaus, D. J. H., Puura, K., & Stein, D. J. (2022). The Shared Pleasure Paradigm: A study in an observational birth cohort in South Africa. *Archives of Women's Mental Health*, *25*(1), 227–235. https://doi.org/10.1007/s00737-021-01199-0

Leclère, C., Viaux, S., Avril, M., Achard, C., Chetouani, M., Missonnier, S., & Cohen, D. (2014). Why synchrony matters during mother-child interactions: A systematic review. In *PLoS ONE* (Vol. 9, Issue 12). Public Library of Science. https://doi.org/10.1371/journal.pone.0113571

Lee, R., Skinner, A., Bornstein, M. H., Radford, A. N., Campbell, A., Graham, K., & Pearson, R. M. (2017). Through babies' eyes: Practical and theoretical considerations of using wearable technology to measure parent-infant behaviour from the mothers' and infants' view points. *Infant Behavior & Development*, *47*, 62–71. https://doi.org/10.1016/J.INFBEH.2017.02.006

Leong, V., Byrne, E., Clackson, K., Georgieva, S., Lam, S., & Wass, S. (2017). Speaker gaze increases information coupling between infant and adult brains. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(50), 13290–13295. https://doi.org/10.1073/PNAS.1702493114

Lillard, A. S., Lerner, M. D., Hopkins, E. J., Dore, R. A., Smith, E. D., & Palmquist, C. M. (2013). The impact of pretend play on children's development: A review of the evidence. *Psychological Bulletin*, *139*(1), 1–34. https://doi.org/10.1037/A0029321

Little, E. E., Legare, C. H., & Carver, L. J. (2019). Culture, carrying, and communication: Beliefs and behavior associated with babywearing. *Infant Behavior & Development*, *57*. https://doi.org/10.1016/J.INFBEH.2019.04.002

Mackay, L. J., Komanchuk, J., Hayden, K. A., & Letourneau, N. (2022). Impacts of parental technoference on parent-child relationships and child health and developmental outcomes: a scoping review protocol. *Systematic Reviews*, *11*(1). https://doi.org/10.1186/s13643-022-01918-3

MartinVA. (n.d.-a). *Statistical release*. www.statssa.gov.za

MartinVA. (n.d.-b). *Statistical release*. www.statssa.gov.za

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J. A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J. J., Devereaux, P. J., Dickersin, K., Egger, M., Ernst, E., Gøtzsche, P. C., … Tugwell, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Medicine*, *6*(7). https://doi.org/10.1371/JOURNAL.PMED.1000097

Montague, E., Xu, J., Asan, O., Chen, P., Chewning, B., & Barrett, B. (n.d.). *Modeling Eye Gaze Patterns in Clinician-Patient Interaction with Lag Sequential Analysis*.

Moore, G. A., Quigley, K. M., Voegtline, K. M., & DiPietro, J. A. (2015). Don't worry, be (moderately) happy: Mothers' anxiety and positivity during pregnancy independently predict lower mother–infant synchrony. *Infant Behavior & Development*, *42*, 60. https://doi.org/10.1016/J.INFBEH.2015.11.002

Müller, I., Walter, C., Du Randt, R., Aerts, A., Adams, L., Degen, J., Gall, S., Joubert, N., Nqweniso, S., Des Rosiers, S., Smith, D., Seelig, H., Steinmann, P., Wadhwani, C., Probst-Hensch, N., Utzinger, J., Pühse, U., & Gerber, M. (2020). Association between physical activity, cardiorespiratory fitness and clustered cardiovascular risk in South African children from disadvantaged communities: results from a cross-sectional study. *BMJ Open Sport & Exercise Medicine*, *6*(1), e000823. https://doi.org/10.1136/BMJSEM-2020-000823

Muller-Nix, C., Forcada-Guex, M., Pierrehumbert, B., Jaunin, L., Borghini, A., & Ansermet, F. (2004). Prematurity, maternal stress and mother-child interactions. *Early Human Development*, *79*(2), 145–158. https://doi.org/10.1016/J.EARLHUMDEV.2004.05.002

Neilson, H. K., Robson, P. J., Friedenreich, C. M., & Csizmadi, I. (2008). Estimating activity energy expenditure: how valid are physical activity questionnaires? *The American Journal of Clinical Nutrition*, *87*(2), 279–291. https://doi.org/10.1093/AJCN/87.2.279

Ngalokhulu. (2018). *About us*. https://joburg.org.za/about_/regions/Pages/Region%20D%20-%20Greater%20Soweto/about-us.aspx

Niedźwiecka, A., Ramotowska, S., & Tomalski, P. (2018). Mutual Gaze During Early Mother–Infant Interactions Promotes Attention Control Development. *Child Development*, *89*(6), 2230–2244. https://doi.org/10.1111/cdev.12830

Nomikou, I., Leonardi, G., Rohlfing, K. J., & Raczaszek-Leonardi, J. (2016). Constructing Interaction: The Development of Gaze Dynamics. *Infant and Child Development*, *25*(3), 277–295. https://doi.org/10.1002/icd.1975

Northrup, J. B., & Iverson, J. M. (2019a). The Development of Mother-Infant Coordination Across the First Year of Life. *Developmental Psychology*. https://doi.org/10.1037/dev0000867

Northrup, J. B., & Iverson, J. M. (2019b). The Development of Mother-Infant Coordination Across the First Year of Life. *Developmental Psychology*. https://doi.org/10.1037/dev0000867

Northrup, J. B., & Iverson, J. M. (2020). The Development of Mother–Infant Coordination Across the First Year of Life. *Developmental Psychology*, *56*(2), 221–236. https://doi.org/10.1037/dev0000867

Nsamenang, A. B. (2006). Human ontogenesis: An indigenous African view on development and intelligence. *International Journal of Psychology*, *41*(4), 293–297. https://doi.org/10.1080/00207590544000077

NURTURING CARE FOR EARLY CHILDHOOD DEVELOPMENT IN SUPPORT OF. (n.d.).

Paulina Velez-Gomez, by, Yvonne Caldera, A. M., & Colwell Michael McCarty Peggy Gordon Miller, M. (2012). *Mother-Child Dyadic Synchrony and its Association with Children's Socio-Emotional Competence in Mexican American Families*.

Pedersen, G. A., Smallegange, E., Coetzee, A., Hartog, K., Turner, J., Jordans, M. J. D., & Brown, F. L. (2019). A Systematic Review of the Evidence for Family and Parenting Interventions in Low- and Middle-Income Countries: Child and Youth Mental Health Outcomes. In *Journal of Child and Family Studies* (Vol. 28, Issue 8, pp. 2036–2055). Springer New York LLC. https://doi.org/10.1007/s10826-019-01399-4

Pereira, D. G., Afonso, A., & Medeiros, F. M. (2015). Overview of Friedmans Test and Post-hoc Analysis. *Communications in Statistics: Simulation and Computation*, *44*(10), 2636–2653. https://doi.org/10.1080/03610918.2014.931971

Powers, N. G., Parham, D. F., & Goldberg, L. R. (2011). Overcoming Barriers to Investigating Mother–Infant Interactions in the First Two Hours of Life. *Journal of Human Lactation*, *27*(3), 286–292. https://doi.org/10.1177/0890334411409752

Prioreschi, A., Brage, S., Westgate, K., & Micklesfield, L. K. (2018). Describing the diurnal relationships between objectively measured mother and infant physical activity. *The International Journal of Behavioral Nutrition and Physical Activity*, *15*(1). https://doi.org/10.1186/S12966-018-0692-2

Prioreschi, A., Nappey, T., Westgate, K., Olivier, P., Brage, S., & Micklesfield, L. K. (2018). Development and feasibility of a wearable infant wrist band for the objective measurement of physical activity using accelerometery. *Pilot and Feasibility Studies*, *4*(1), 60. https://doi.org/10.1186/S40814-018-0256-X

Prioreschi, A., Pearson, R., Richter, L., Bennin, F., Theunissen, H., Cantrell, S. J., Maduna, D., Lawlor, D. A., & Norris, S. A. (n.d.). *The PLAY study trialtrail protocol: an intervention to improve infant growth and development by encouraging responsive caregiving through interactive play*. https://www.who.int/clinical-trials-

Prioreschi, A., Pearson, R., Richter, L., Bennin, F., Theunissen, H., Cantrell, S. J., Maduna, D., Lawlor, D., & Norris, S. A. (2023a). Protocol for the PLAY Study: A randomised controlled trial of an intervention to improve infant development by encouraging maternal self-efficacy using behavioural feedback. *BMJ Open*, *13*(3). https://doi.org/10.1136/bmjopen-2022-064976

Prioreschi, A., Pearson, R., Richter, L., Bennin, F., Theunissen, H., Cantrell, S. J., Maduna, D., Lawlor, D., & Norris, S. A. (2023b). Protocol for the PLAY Study: a randomised controlled trial of an intervention to improve infant development by encouraging maternal self-efficacy using behavioural feedback. *BMJ Open*, *13*(3), e064976. https://doi.org/c

Prioreschi, A., Pearson, R., Richter, L., Bennin, F., Theunissen, H., Cantrell, S. J., Maduna, D., Lawlor, D., & Norris, S. A. (2023c). Protocol for the PLAY Study: A randomised controlled trial of an intervention to improve infant development by encouraging maternal self-efficacy using behavioural feedback. *BMJ Open*, *13*(3). https://doi.org/10.1136/bmjopen-2022-064976

Provenzi, L., di Minico, G. S., Giusti, L., Guida, E., & Müller, M. (2018). Disentangling the dyadic dance: Theoretical, methodological and outcomes systematic review of mother-infant dyadic processes. In *Frontiers in Psychology* (Vol. 9, Issue MAR). Frontiers Media S.A. https://doi.org/10.3389/fpsyg.2018.00348

Ramseyer, F., & Tschacher, W. (2011). Nonverbal synchrony in psychotherapy: Coordinated body movement reflects relationship quality and outcome. *Journal of Consulting and Clinical Psychology*, *79*(3), 284–295. https://doi.org/10.1037/a0023419

Rocha, N. A. C. F., dos Santos Silva, F. P., dos Santos, M. M., & Dusing, S. C. (2020). Impact of mother–infant interaction on development during the first year of life: A systematic review. *Journal of Child Health Care*, *24*(3), 365–385. https://doi.org/10.1177/1367493519864742

Serra, J., Miguel, H., Moura, A. A., Sampaio, A., & Pereira, A. F. (2020). The effect of play task on maternal touch patterns when interacting with their 12 months-old infants: An exploratory study. *Infant Behavior and Development*, *59*, 101438. https://doi.org/10.1016/J.INFBEH.2020.101438

Skender, S., Ose, J., Chang-Claude, J., Paskow, M., Brühmann, B., Siegel, E. M., Steindorf, K., & Ulrich, C. M. (2016). Accelerometry and physical activity questionnaires - A systematic review. *BMC Public Health*, *16*(1), 1–10. https://doi.org/10.1186/S12889-016-3172-0/FIGURES/2

Smith, K. E., & Pollak, S. D. (2020). Early life stress and development: potential mechanisms for adverse outcomes. *Journal of Neurodevelopmental Disorders 2020 12:1*, *12*(1), 1–15. https://doi.org/10.1186/S11689-020-09337-Y

Sroufe, L. A., & Waters, E. (1977). Attachment as an Organizational Construct. *Child Development*, *48*(4), 1184. https://doi.org/10.2307/1128475

Stern, D. N. (2018). The interpersonal world of the infant: A view from psychoanalysis and developmental psychology. *The Interpersonal World of the Infant: A View from Psychoanalysis and Developmental Psychology*, 1–304. https://doi.org/10.4324/9780429482137/INTERPERSONAL-WORLD-INFANT-DANIEL-STERN

Tabachnick, A. R., He, Y., Zajac, L., Carlson, E. A., & Dozier, M. (2021). Secure Attachment in Infancy Predicts Context-Dependent Emotion Expression in Middle Childhood. *Emotion (Washington, D.C.)*, *22*(2), 258. https://doi.org/10.1037/EMO0000985

Taffoni, F., Rivera, D., Camera, A. La, Nicolò, A., Velasco, J. R., & Massaroni, C. (2018). A wearable system for real-time continuous monitoring of physical activity. *Journal of Healthcare Engineering*, *2018*. https://doi.org/10.1155/2018/1878354

Tamis-LeMonda, C. S., & Bornstein, M. H. (2002). Maternal responsiveness and early language acquisition. *Advances in Child Development and Behavior*, *29*(C), 89–127. https://doi.org/10.1016/S0065-2407(02)80052-0

The Chris Hani Baragwanath Hospital, 2025. (n.d.). *The Chris Hani Baragwanath Hospital, South Africa | The World's 3rd Biggest Hospital, in South Africa - Contact Details (Address, Phone Numbers,*

Email Address) and Map. Retrieved October 1, 2025, from https://www.chrishanibaragwanathhospital.co.za/?utm_source=chatgpt.com

The Chris Hani Baragwanath Hospital, South Africa | The World's 3rd Biggest Hospital, in South Africa - Contact Details (Address, Phone Numbers, Email Address) and Map. (n.d.). Retrieved October 1, 2025, from https://www.chrishanibaragwanathhospital.co.za/?utm_source=chatgpt.com

Thelen, Esther., & Smith, L. B. . (19961994). *A dynamic systems approach to the development of cognition and action*. 376.

Timmons, B. W., Leblanc, A. G., Carson, V., Gorber, S. C., Dillman, C., Janssen, I., Kho, M. E., Spence, J. C., Stearns, J. A., & Tremblay, M. S. (2012). Systematic review of physical activity and health in the early years (aged 0-4 years). *Applied Physiology, Nutrition and Metabolism*, *37*(4), 773–792. https://doi.org/10.1139/H2012-070

Tomaz, S. A., Jones, R. A., Hinkley, T., Twine, R., Kahn, K., Norris, S. A., & Draper, C. E. (2019). Physical activity in early childhood education and care settings in a low-income, rural South African community: An observational study. *Rural and Remote Health*, *19*(4). https://doi.org/10.22605/RRH5249

Tomlinson, M., Cooper, P., & Murray, L. (2005). The Mother–Infant Relationship and Infant Attachment in a South African Peri-Urban Settlement. *Child Development*, *76*(5), 1044–1054. https://doi.org/10.1111/J.1467-8624.2005.00896.X

Troiano, R. P. (2005). A timely meeting: objective measurement of physical activity. *Medicine and Science in Sports and Exercise*, *37*(11 Suppl). https://doi.org/10.1249/01.MSS.0000185473.32846.C3

Tronick, E., Als, H., & Berry Brazelton, T. (1980). *MONADIC PHASES: A STRUCTURAL DESCRIPTIVE ANALYSIS OF INFANT-MOTHER FACE TO FACE INTERACTION* (Vol. 26, Issue 1). https://about.jstor.org/terms

Tronick, E., & Beeghly, M. (2011). Infants' meaning-making and the development of mental health problems. *American Psychologist*, *66*(2), 107–119. https://doi.org/10.1037/a0021631

Tronick, E. Z., & Cohn, J. F. (1989a). *Infant-Mother Face-to-Face Interaction: Age and Gender Differences in Coordination and the Occurrence of Miscoordination* (Vol. 60, Issue 1).

Tronick, E. Z., & Cohn, J. F. (1989b). *Infant-Mother Face-to-Face Interaction: Age and Gender Differences in Coordination and the Occurrence of Miscoordination* (Vol. 60, Issue 1).

Vallotton, C. D. (2009). Do infants influence their quality of care? Infants' communicative gestures predict caregivers' responsiveness. *Infant Behavior and Development*, *32*(4), 351–365. https://doi.org/10.1016/j.infbeh.2009.06.001

Vally, Z., Murray, L., Tomlinson, M., & Cooper, P. J. (2015). The impact of dialogic book-sharing training on infant language and attention: a randomized controlled trial in a deprived South African community. *Journal of Child Psychology and Psychiatry*, *56*(8), 865–873. https://doi.org/10.1111/JCPP.12352

Van Egeren, L. A., Barratt, M. S., & Roach, M. A. (2001). Mother-infant responsiveness: timing, mutual regulation, and interactional context. *Developmental Psychology*, *37*(5), 684–697. https://doi.org/10.1037/0012-1649.37.5.684

Vision and separation : Wright, Kenneth. (1991). 392.

Ward, D. S., Vaughn, A., McWilliams, C., & Hales, D. (2010). Interventions for increasing physical activity at child care. *Medicine and Science in Sports and Exercise*, *42*(3), 526–534. https://doi.org/10.1249/MSS.0B013E3181CEA406

Ward, J. A., Hunter, K., Richardson, D., & Orgs, G. (2010). Sensing interpersonal synchrony between actors and autistic children in theatre using wrist-worn accelerometers. In *ACM Trans. Graph* (Vol. 9). https://doi.org/0000001.0000001_2

Westgate, K., Ridgway, C., Rennie, K., Strain, T., Wijndaele, K., & Brage, S. (n.d.-a). *Feasibility of incorporating objective measures of physical activity in the STEPS program. A pilot study in Malawi. Location: Malawi (Lilongwe and Dowa districts)*.

Westgate, K., Ridgway, C., Rennie, K., Strain, T., Wijndaele, K., & Brage, S. (n.d.-b). *Feasibility of incorporating objective measures of physical activity in the STEPS program. A pilot study in Malawi. Location: Malawi (Lilongwe and Dowa districts)*.

WHO, UNICEF, & The World Bank. (2018). Nurturing care for early childhood development: a framework for helping children survive and thrive to transform health and human potential. *Who*, *April 2018*, 1–4. http://www.who.int/maternal_child_adolescent/child/nurturing-care-framework/en/

Why are 24-hour movement guidelines important for children from birth to 5 years? (n.d.). www.laureus.co.za.

WOLD HEALTH ORGANIZATION. (2019). Guidelines on physical activity, sedentary behaviour and sleep. *World Health Organization*, 4. https://apps.who.int/iris/bitstream/handle/10665/325147/WHO-NMH-PND-2019.4-eng.pdf?sequence=1&isAllowed=y%0Ahttp://www.who.int/iris/handle/10665/311664%0Ahttps://apps.who.int/iris/handle/10665/325147

Woodman, A. C., Mawdsley, H. P., & Hauser-Cram, P. (2015). Parenting stress and child behavior problems within families of children with developmental disabilities: Transactional relations across 15 years. *Research in Developmental Disabilities*, *36C*, 264–276. https://doi.org/10.1016/J.RIDD.2014.10.011

Worku, S. (2023). Child Series Volume IV Children living with grandparents in South Africa, 2023 Statistics South Africa Risenga Maluleke Statistician-General. *Statistics South Africa. Pretoria: Statistics South Africa*, *IV*, 2025. www.statssa.gov.za

Wrottesley, S. V., Pearson, R., & Prioreschi, A. (2021a). The headcam mother-infant interaction assessment tool: testing the feasibility and acceptability in Soweto, South Africa, using participatory engagement. *Pilot and Feasibility Studies*, *7*(1). https://doi.org/10.1186/s40814-021-00875-3

Wrottesley, S. V., Pearson, R., & Prioreschi, A. (2021b). The headcam mother-infant interaction assessment tool: testing the feasibility and acceptability in Soweto, South Africa, using participatory engagement. *Pilot and Feasibility Studies*, *7*(1). https://doi.org/10.1186/s40814-021-00875-3

Wrottesley, S. V., Pearson, R., & Prioreschi, A. (2021c). The headcam mother-infant interaction assessment tool: testing the feasibility and acceptability in Soweto, South Africa, using participatory engagement. *Pilot and Feasibility Studies*, *7*(1). https://doi.org/10.1186/s40814-021-00875-3

Wrottesley, S. V., Pearson, R., & Prioreschi, A. (2021d). The headcam mother-infant interaction assessment tool: testing the feasibility and acceptability in Soweto, South Africa, using participatory engagement. *Pilot and Feasibility Studies*, *7*(1). https://doi.org/10.1186/s40814-021-00875-3

Yang, C. C., & Hsu, Y. L. (2010). A review of accelerometry-based wearable motion detectors for physical activity monitoring. In *Sensors* (Vol. 10, Issue 8, pp. 7772–7788). https://doi.org/10.3390/s100807772

YARROW, L. J., & GOODWIN, M. S. (1965). SOME CONCEPTUAL ISSUES IN THE STUDY OF MOTHER-INFANT INTERACTION. *American Journal of Orthopsychiatry*, *35*(3), 473–481. https://doi.org/10.1111/J.1939-0025.1965.TB00407.X

Yousafzai, A. K., Obradović, J., Rasheed, M. A., Rizvi, A., Portilla, X. A., Tirado-Strayer, N., Siyal, S., & Memon, U. (2016). Effects of responsive stimulation and nutrition interventions on children's development and growth at age 4 years in a disadvantaged population in Pakistan: a longitudinal follow-up of a cluster-randomised factorial effectiveness trial. *The Lancet Global Health*, *4*(8), e548–e558. https://doi.org/10.1016/S2214-109X(16)30100-0

Yu, C., & Smith, L. B. (2013a). Joint attention without gaze following: Human infants and their parents coordinate visual attention to objects through eye-hand coordination. *PLoS ONE*, *8*(11). https://doi.org/10.1371/journal.pone.0079659

Yu, C., & Smith, L. B. (2013b). Joint attention without gaze following: Human infants and their parents coordinate visual attention to objects through eye-hand coordination. *PLoS ONE*, *8*(11). https://doi.org/10.1371/journal.pone.0079659

CHAPTER SIX: APPENDICES

Appendix 1: PLAY Study CAG – Participant Information Sheet (Mothers)

University of the Witwatersrand, Johannesburg

Developmental Pathways for Health Research Unit

Department of Paediatrics and Child Health

Play Love and You (PLAY) study: Information Sheet for the Community Advisory Group (Mothers)

Hello, my name is Dr Alessandra Prioreschi, and I am a Researcher in the Department of Paediatrics at the University of Witwatersrand. I work in the Developmental Pathways for Health Research Unit (DPHRU) at Chris Hani Baragwanath Academic Hospital. Together with other colleagues from the University we are conducting research to understand how to support mothers in Soweto in caring for their babies. We are interested in understanding what the home environment is like in Soweto, who helps look after babies, and how we can support mothers in breastfeeding, and teaching them how to play and bond with their babies.

We would like to invite you to be part of this study because

a) you have a baby aged between 0 months and 3 months

b) you are a Soweto community member

c) you are the primary caregiver for your baby

What is involved in the study?

We will first ask you to read this information sheet. If you are happy to participate in the research we will ask you to sign a consent form. You will then become one of our Community Advisors.

In the first few months:

At first, a member from the research team will contact you by telephone to invite you to take part in a small discussion (called a Focus Group) with the other Community Advisors (12-15 mothers from Soweto) to answer some questions and discuss your ideas about parenting in Soweto. This will include answering questions about your home, your ideas about parenting and other caregivers, and about living in Soweto. These discussions will take place at the DPHRU research unit, within Baragwanath Hospital, in the first few months of 2022. This first discussion session should not last longer than two hours. We cannot guarantee anonymity, as some participants may

recognize one another. We will ask participants not to repeat the content of the discussions outside of the Group, but we cannot enforce this.

We will then use the information you give us to design a study to help women in Soweto with breastfeeding, and caring for their baby. Once we have designed the study (about 1-2 months later), we would like to speak with you again, in a focus group at Baragwanath Hospital, to show you what we have developed, and get your feedback on whether you think it is helpful, and whether you think it will work. Your advice will be important for us to get the study right, and make sure we can help other mothers like you! We may ask you to test out some of the tools, either by using them with us at DPHRU, or taking the tools home to use with your baby. This may include you and your baby wearing a device on your wrist for a few days (like a watch) to measure how much you move, and how much your baby plays. We may also ask you and your baby to wear small cameras on a headband so that we can see how you play together, and show you important moments of you and your baby together. None of these measurements are harmful to you or your baby.

For the next 20 months:

After testing the study we have designed, you may also be asked to attend more discussions over the course of the next 2 years as our study continues, so that we keep developing tools that will be useful for mothers in Soweto as their babies get older. You will be our experts on what it is like to be a mother in Soweto, and so we would like to keep having discussions with you about things that you find important, or things that we are not sure about. We will use the information you give us to make sure we design studies that are helpful for women in your community.

Benefits:

There is no direct benefit to you from participating in the study. You will, however, contribute to what we know about caring for, playing with and breastfeeding infants and toddlers, and how we may be able to help develop these behaviours in the Soweto community.

Risks:

There is a small risk that your child may become upset by the head camera or by the device used to measure play. If this happens you can just remove the device. You can try again another day or simply return the devices to us. These devices are made of hard plastic and so there is a small risk of your child injuring themselves in some way. Although this is unlikely we ask that you do not leave your child unattended with the devices.

With your permission, our discussions will be audio recorded so that we can transcribe your responses in your own words. Therefore, your information and feelings shared will not be anonymous at first; However the tapes will only be heard by the researchers, and only for the purposes of this study, and will be kept in the strictest confidence. The recordings will be stored on the researcher's computer (password protected) and destroyed after five years following the

completion of the project. Direct quotes from you may be used in a published paper, however, your name and other identifying information will always be kept anonymous.

Some of the questions may cause psychological distress. If this is noticed by the interviewer or reported to us by yourself, we will assign you an appointment within the next week with a registered psychologist at the research unit at Baragwanath hospital in order to receive counseling as required. The psychologist will be able to talk to you to try to address the causes of your distress and also has a network of referral bodies for further management of any issues that may arise. You will be free to choose not to respond to any questions, or to stop the interview at any time.

Participation is voluntary:

Participation in this study is completely voluntary, and lack of participation will not have any negative consequences. You can choose not to answer any question(s) or complete any measurements which make you feel uncomfortable. You are able to withdraw at any point during the study.

Reimbursement:

You will not be paid to be part of this study, however we will provide you with R200 to cover your transport expenses for your travel to the research unit.

Confidentiality:

Personal information will be handled with strictest confidentiality. Due to the nature of these focus groups, it is not possible to keep your responses completely anonymous when analysing the results. The note-takers and interviewers will be present in the focus group, and a research assistant will transcribe the information from the voice recordings and notes taken. We will use the name you give us for our own notes, and your voice will appear on our recording, but only the research team has access to these notes and recordings. We like to record because we can't write fast enough to capture the whole conversation. In our analysis, we give each person a number that is in no way linked to your name. We are only looking at general trends, and we will not be reporting on or publishing about individual opinions. Your answers will therefore be linked to your name (using your initials), but only the researchers and the research team will have access to this data. If results are published, they will not include any names or personal details that can lead to individual identification, and all published data will be completely anonymous.

For this study we may be making video recordings, as mentioned above and we ask that you only use the cameras in your own home and when only your immediate family is present. This will prevent us seeing anyone who has not consented to be involved. As part of the consent process we will ask your permission to record yourself, and your child. As soon as the cameras are returned to us the recordings matching the dates and times on your schedule will be downloaded

and stored securely, the cameras will then be erased to protect confidentiality. The videos can only be viewed using special software, so if you do lose your cameras other people would not be able to view the footage.

Your video recordings will be seen by the researcher who will code what they see; this researcher will have no other information about you while they are coding. All information will be identified by your unique code at all times. There may be more than one researcher viewing different videos from you. We also need to send the videos to our study partners in Bristol University in the United Kingdom for coding. These videos will be sent in a protected format, or hand delivered, and will always be anonymous using only your unique study ID. All researchers are bound by ethical guidelines when analysis your videos, and will not break your confidentiality.

Data sharing

The data that we collect as part of this study may be shared with other researchers, including researchers in the United Kingdom, for analysis of the data. In all cases, confidentiality will be maintained as per the processes outlined in this information sheet. All data we collect from you is stored with a unique ID number. Researchers do not need, and will never be given access to your name, address or date of birth. We will never share your details with anyone else except in exceptional circumstances where we feel there is a risk to the safety of your child or someone related to them.We are required by law to report any instance of child abuse which may come to our attention to the authorities.

Results

Upon completion, we will be pleased to provide a summary of the study results on request, free of charge.

Further information:

If you require any further information or have any questions/complaints about the study please contact:

- The Human Ethics Committee of Witwatersrand - 011 717 71234 or zanele.ndolvu@wits.ac.za
- Dr Alessandra Prioreschi - alessandra.prioreschi@wits.ac.za or tel no. 083 989 0070

If you are happy to take part in the study please read and sign the attached consent form.

This study has been approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg ("Committee"). A principal function of this

Committee is to safeguard the rights and dignity of all human subjects who agree to participate in a research project and the integrity of the research.
If you have any concern over the way the study is being conducted, please contact the Chairperson of this Committee who is Dr Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za

Thank you for your time and attention

Kind regards

Dr Alessandra Prioreschi

January 2022

Appendix 2: PLAY Study CAG – Informed Consent Form (Mothers)





University of the Witwatersrand, Johannesburg

Developmental Pathways for Health Research Unit

Department of Paediatrics and Child Health

Play Love and You (PLAY) study: Consent form for the Community Advisory Group (Mothers)

I agree to be a participant in the PLAY study Community Advisory Group. The goals and methods of the study are clear to me. I understand that the study will involve being part of focus group discussions, answering questions, and giving feedback on study tools. All the details and purposes of this study have been explained to me. I understand that my data will not be anonymous to the researchers involved. I understand that my data will be shared with researchers at the University of Bristol in the United Kingdom. I understand that I may be asked to participate in more focus group discussions over the course of the next two years. I understand that I have the right to refuse to participate in the study.

I agree to participation in the Community Advisory Group on condition that:

1. I can withdraw from the study at any time voluntarily and that no adverse consequences will follow on withdrawal from the study.
2. I have the right not to answer any or all questions posed in the interviews and not to participate in any or all of the procedures / assessments.
3. The University of the Witwatersrand Human Ethics committee has approved the study protocol and procedures.
4. All results will be treated with the strictest confidentiality.
5. Only group results, and not my individual results, will be published in scientific journals and in the media.
6. The study scientific team are committed to treating participants with respect and privacy through interviews conducted in private and follow-up counselling available on request.

PARTICIPANT CONSENT SHEET

Play Love and You (PLAY) study (Community Advisory Group – Mothers)

1. I have been given a Participant Information Sheet which explains the nature and processes involved in this study, which is attached hereto;
2. I was given time to read it, or had it read to me, in the language I best understand;
3. I was given time to ask any questions I wanted to and found any answers given to me to be reasonable and satisfactory;
4. I believe I fully understand why the study is being conducted and what the intended outcomes will be;
5. I understand that there will be no immediate benefit to me, should I agree to participate, nor will I receive any payment; conversely, participation will not cost me anything but my time;
6. I understand that, even if I initially consent to take part in the study, I may subsequently withdraw at any time and would not be required to give any reasons; if that happened, any data collected about me for the purposes of the study would immediately be destroyed, unless I give consent for it to be retained
7. I have been given a range of contact details, listed below. If I require further information or become concerned about any aspect of this study I am free to speak to any of these contacts.

Contact details:

Dr Alessandra Prioreschi, Principal Investigator, telephone no. 083 989 0070, or by e-mail at Alessandra.Prioreschi@wits.ac.za,

Professor CB Penny, Chairperson of the Human Research Ethics Committee (Medical) at the University of Witwatersrand, on telephone no. 011 717 2301, or by e-mail at Clement.Penny@wits.ac.za.
Ms. Z Ndlovu or Mr Rhulani Mkansi, Committee Secretariat, telephone nos.: 011 717 2700 or 1234, or by e-mail at: Zanele.Ndlovu@wits.ac.za or Rhulani.Mkansi@wits.ac.za

Name of Participant: _____
Date: _____
Place: _____
Signature or mark _____

Witnessed by:
Name of Witness: _____
Signature: _____
Date: _____

CONSENT FORM FOR AUDIO RECORDING OF STUDY PARTICIPATION

I have read and understood the project information sheet, and I understand that it is up to me whether or not the interview is audio or video recorded. I understand that if I do not wish to be recorded, it will not in any way affect how the interviewer treats me.. I understand that my recordings will be shared with researchers at the University of Bristol in the United Kingdom. I understand that I can ask the person interviewing me to stop recording, and to stop the interview completely at any time. I understand that the information that I give will be treated in the strictest of confidence, and that my name will not be used when the interviews are typed up.

Play Love and You (PLAY) study (Community Advisory Group – Mothers)

I hereby consent to audio recording of the interview, or focus group discussion.

I understand that:

- The recording will be stored in a secure location (a locked cupboard or password protected computer) with restricted access to the researcher and the research supervisor.
- The recording will be transcribed and any information that could identify me will be removed,
- The recordings will be erased within either (a) two (2) years of the publication of the research findings, or (b) six (6) years, if no publications arise from this research or five (5) years after the study.
- Anyone wishing to access this information in the future will first have to obtain the approval of the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg
- Direct quotes from my interview, without any information that could identify me, may be cited in the research report or other write-ups of research.

Name of Participant: _____
Date: _____
Place: _____
Signature or mark _____

Witnessed by:
Name of Witness: _____
Signature: _____
Date: _____

CONSENT FORM FOR VISUAL RECORDING OF STUDY PARTICIPATION

I have read and understood the project information sheet, and I understand that it is up to me whether or not my videos are viewed by the research team. I understand that if I do not wish for my videos to be seen, it will not in any way affect how the interviewer treats me. I understand that my data will be shared with researchers at the University of Bristol in the United Kingdom. I understand that I can ask the research team to delete my videos, or any part of my videos at any time. I understand that the information that I give will be treated in the strictest of confidence, and that my name will not be used when the videos are analysed.

Play Love and You (PLAY) study (Community Advisory Group – Mothers)

I hereby consent to visual recording of the interview, or focus group discussion.

I understand that:

- The recording will be stored in a secure location (a locked cupboard or password protected computer) with restricted access to the researcher and the research supervisor.
- The recording will be transcribed and any information that could identify me will be removed
- My face and voice will not be identifiable in any visual recording
- The recordings will normally be erased within either (a) two (2) years of the publication of the research findings, or (b) six (6) years, if no publications arise from this research, or five years after the study.
- The film, with all identifying information directly linked to me removed, will be stored permanently and may be used for future research
- Anyone wishing to access this information in the future will first have to obtain the approval of the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg
- Direct quotes from my interview, without any information that could identify me, may be cited in the research report or other write-ups of research.

Name of Participant: _____
Date: _____
Place: _____
Signature or mark _____

Witnessed by:
Name of Witness: _____
Signature: _____
Date: _____

Appendix 3: PLAY Study – Participant Information Sheet

V1.2_07/02/2022

Play Love And You (PLAY) Study: Information Sheet for Participants

Hello, my name is Dr Alessandra Prioreschi, and I am a Researcher in the Department of Paediatrics at the University of Witwatersrand. I work in the Developmental Pathways for Health Research Unit (DPHRU) at Chris Hani Baragwanath Academic Hospital. Together with other colleagues from the University, we are conducting research to support new mothers in caring for their babies. We are going to be providing support for breastfeeding, mental health, bonding with your baby, and playing with your baby so that your baby can grow and develop to their full potential.

Before you decide if you want to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

What is The PLAY Study?
The PLAY Study is a study designed to support women in Soweto with caring for their baby from when the baby is born, until they are 2 years old. The support we are providing is about being a mother and caring for your baby, helping your baby learn, breastfeeding, and your own mental health. The aim of The PLAY Study is to see if the support we provide to you can assist with your baby's growth and development.

What is involved if I decide to take part in The PLAY Study?
We will first ask you to finish reading this information sheet. If you are happy to participate in the research, we will ask you to sign a consent form.

There are two different programmes designed to support mothers in Soweto. Both programmes involve having regular (at least every 2 months) contact with our research team in which you will receive information and material designed specifically to support mothers in Soweto. The material and the way this material is delivered to you will be different in the two groups.

Group A – will receive material through face-to-face meetings when we first enroll you, mobile phone conversations and messages from a trained health helper.

Group B – will receive material through face-to-face meetings when we first enroll you, mobile phone conversations, messages, a mobile app, and in-person assessments from a trained health helper.

How will it be decided which group you go into?

You will randomly be placed in Group A or B and you will have an equal chance of going into Group A or Group B. You will not be able to decide which group you want to go into and will stay in the same group for the full study period. We will give each person a unique identifying number, and will use a computer system to randomly link your identifying numbers into either Group A or Group B.

What is involved for Group A and Group B?

For everyone (both groups)

- Everyone who enrolls in this study will receive the standard Road to Health booklet as well as the Side-by-Side services which are provided for all mothers who have had a baby, whether they are in the study or not.
- Additionally, a trained health helper will spend time explaining the Road-to-Health book to you and teach you about some of the important things to know as a new mother.
- You will also be contacted telephonically every 2 months to check in on how you and baby are doing, and if you need extra support, you will be referred to the required health care facilities.
- You will be expected to fill in a few questionnaires when you enroll in the study, after 12 months and again after 24 months.

Group A

If you are assigned to Group A, you will additionally receive:

- Access to a mobile App which will provide you with information and resources to help you care for your baby and will allow you to communicate with us and receive extra information from us.

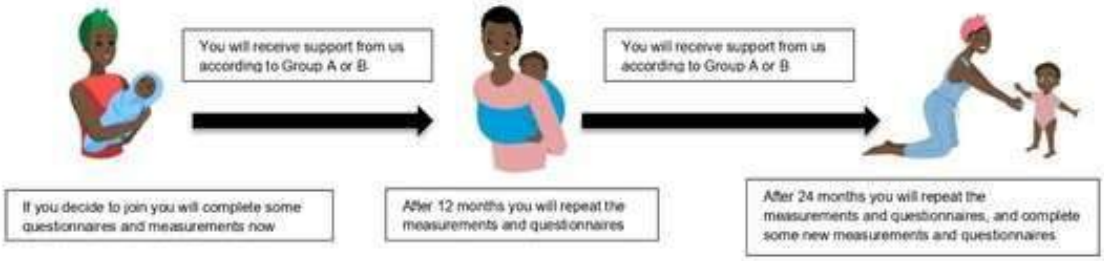
Group B

If you are assigned to Group B, you will additionally receive:

- Access to a mobile App which will provide you with information and resources to help you care for your baby and will allow you to communicate with us and receive extra information from us.
- Every 4 months we will measure your baby's movement and play, and their development. We will share this information and explain it to you, as well as provide recommendation on how to improve your baby's growth and development.
- When we enroll you, we will ask you to fill out some questions to assess your mental health after having your baby. If you need further support, we will provide you with a free assessment with a trained counselling psychologist on our team, who will support you and refer you if necessary.

When and where will measurements take place?

Besides the programme material we will be providing you with, everyone will also have certain measurements done at the beginning of the study, after 12 months, and again after 24 months. When possible, we will come to do assessments at your home, or telephonically. For some measurements after 12 months and after 24 months, you may need to come to our offices (DPHRU) at the Baragwanath Hospital and you will always be reimbursed (R200) for your transport to our offices. To summarise when we will do measurements see the figure below:



What measurements will be taken?

Basic measurements

When you join the study, and again after 12 and 24 months, we will be measuring your height and weight, and the circumference of your waist and hips with a same-sex research assistant in a private setting. We will also measure your baby's weight and height and the circumference of their head and arms. This will take about 10 minutes.

Questionnaires

When you join the study, and again after 12 and 24 months, one of our interviewers will ask you a series of questions, which will take about 60 minutes to complete. These are the questionnaires we would like to go through with you:

- Questionnaires about your home environment
- Questionnaires about your general health
- Questionnaires about your mental health
- Questionnaires about food, and how you feed your baby
- Questionnaires about how confident you feel about looking after and breastfeeding your baby
- Questionnaires about sleep, screen time, and activity
- Questionnaires about your baby's development

Headcam videos

After 12 and 24 months (and after 4 months, 8 months, 16 months, and 20 months if you are in Group B), we will ask you and your baby to wear a small camera on an elastic headband while at home together. You will be asked to take the cameras away with you for a week and use them at least 5 times for a few minutes each whilst interacting with your baby (playing or feeding). We

will give you a sheet to record what days and times you used the cameras. We will then collect them back approximately one week later.

These cameras will record video footage which will be used to understand your behaviours when playing and interacting with your baby. We will watch the video second by second and record what is happening. We will always use a study ID code when looking at your videos, and never your personal information (such as your name). We are only interested in looking at the behaviours between you and your baby and will ignore anything else.

Play and physical activity

After 12 and 24 months (and after 4 months, 8 months, 16 months, and 20 months if you are in Group B), we will measure how much movement you and your baby do using a small device called an accelerometer. You will both wear the device on your wrist for one week, and then we will collect it from you. It will be placed within a strap to prevent swallowing and should not be removed for any reason. You will be asked to record any time that you remove the device.

Body composition

After 24 months, we will be measuring body fat, muscle and bone health on you and your baby using a special x-ray machine called DXA. The whole-body scan takes 10 minutes to complete and has very low radiation exposure and is not thought to cause any health risks. A trained technician will explain what you need to do during the procedure. Briefly, you will need to lie very still on a bed while your whole body is scanned. Before the scan you will be asked whether you are pregnant. If there is any possibility that you may be pregnant, please inform the technician so that we do not expose you to the scan. We have urine pregnancy tests available onsite to confirm pregnancy status.

What are the benefits of being involved in the study?

Your participation may enable you to obtain knowledge about healthy behaviours for yourself and the healthy growth of your baby and will also provide you with extra support and information that you would not normally receive from the clinic. This study will also contribute to a better understanding of healthy childhood growth and development in South Africa and will help us understand how to help more babies and mothers in the future. There will be no financial compensation for your participation to the trial.

What are the risks of being involved in the study?

There is a small risk that your child may become upset by the head camera or by the device used to measure play. If this happens you can just remove the device. You can try again another day or simply return the devices to us. These devices are made of hard plastic and so there is a small risk of your child injuring themselves in some way. Although this is unlikely, we ask that you do not leave your child unattended with the devices.

Some of the questions may cause psychological distress. If this is noticed by the interviewer or if you report any experience of distress to us, you will be offered an appointment within the next week with a professional registered Psychologist at the research unit at Baragwanath hospital to receive counseling as required. The Psychologist will be able to talk to you to try to address the causes of your distress and has a network of referral bodies for further management of any issues that may arise. You will be free to choose not to respond to any questions, or to stop the interview at any time.

Headcams, photos and videos:

Confidentiality cannot be completely maintained due to the nature of the photos, and headcam video recording. A number of preventative measures have thus been put in place to ensure that confidentiality is maintained as much as possible, and that you have complete control over your footage:

1. All photos and videos will be labelled using a study ID only, and the footage will only be used for the behaviour coding described in the methods.
2. You will be given the option to request that any portion of a recording (or an entire recording) or photo be deleted, and this will be done without investigators viewing the photo or video beforehand and without any question.
3. It is a possibility that other family members or visitors to the home may appear in the photos and footage. We ask that you alert any people in the home to the fact that you will be recording or taking photos at certain times, and obtain permission if family members may be in the room at the same time. If there are any other family members in the home who appear in any of the recordings, you will have the option to delete any portion of the video, or the entire video. If family members do not request their data to be deleted, we will still ignore any portions of video where they appear. All faces in photos will be blurred out. Recordings will only be done at home, and so external parties will not be recorded.
4. You will be able to take photos and turn the cameras on and off as you wish, and so you can choose when you would like to record or not.
5. The photos and videos are viewed on special software, so that if devices are lost other people will not be able to view your videos.
6. Your images will not be published (unless separate consent is obtained).
7. The Principal Investigator will keep all footage, and de-linked files on a password protected computer and encrypted university server.

Do I have to participate in this study?

Participation in this study is completely voluntary, and lack of participation will not have any negative consequences. You can choose to not complete any activities and assessments, fill in any questionnaires or talk to anyone on the phone if it will make you feel uncomfortable. You are able to withdraw at any point during the study and without giving a reason. Withdrawing from the study at any stage will not affect the standard of care you receive from your clinic or hospital.

Will I be paid to take part in this study?
You will not be paid to be part of this study, however we will provide you with R200 to cover your transport expenses for your travel to the research unit.

Will my taking part in this study be kept confidential?
Personal information will be handled with strictest confidentiality. For this study we may be making video recordings, as mentioned above and we ask that you only use the cameras in your own home and when only your immediate family is present. This will prevent us seeing anyone who has not consented to be involved. As part of the consent process, we will ask your permission to record yourself, and your child. As soon as the cameras are returned to us the recordings matching the dates and times on your schedule will be downloaded and stored securely, the camera footage will then be erased to protect confidentiality. The videos can only be viewed using special software, so if you do lose your cameras other people would not be able to view the footage.

Your video recordings will be seen by the researcher who will code what they see; this researcher will have no other information about you while they are coding. All information will be identified by your unique code at all times. There may be more than one researcher viewing different videos from you. We also need to send the videos to our study partners in the United Kingdom for coding. These videos will be sent in a protected format, or hand delivered, and will always be anonymous using only your unique study ID. All researchers are bound by ethical guidelines when analysing your videos and will not break your confidentiality.

Data sharing
The data that we collect as part of this study may be shared with other researchers, including researchers in the United Kingdom, for analysis of the data. In all cases, confidentiality will be maintained as per the processes outlined in this information sheet. All of your data will be anonymous except for the video data, which will show your face and your baby's face but will not be linked to your name or other personal details. All data we collect from you is stored with a unique ID number. Researchers do not need, and will never be given access to your name, address or date of birth. We will never share your details with anyone else except in exceptional circumstances where we feel there is a risk to the safety of your child or someone related to them. We are required by law to report any instance of child abuse which may come to our attention to the authorities.

What if I change my mind?
Participating in this study is entirely voluntary. You may change your mind about taking part in this study at any point in time. If you change your mind, you must contact the research staff to let them know that you no longer want to participate in the study. Changing your mind and

withdrawing from the study will not affect the standard of care you receive at your hospital or clinic.

What will happen with the results of this study?

The results of this study will be published in medical journals and may be presented at scientific meetings. You may also view the results of this study on our website after the study is finished (www.theplaystudy.co.za). No individuals will be specifically identified in any one of our publications or in any one of our presentations. Upon completion, we will be pleased to provide a summary of the study results on request, free of charge.

Who has reviewed this study?

This study has been approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg ("Committee"). A principal function of this Committee is to safeguard the rights and dignity of all human subjects who agree to participate in a research project and the integrity of the research.

If you have any concern over the way the study is being conducted, please contact the Chairperson of this Committee who is Dr Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za

If you are happy to take part in the study, please read and sign the attached consent form.

Thank you for your time and attention.
Kind regards
Dr Alessandra Prioreschi
February 2022

Appendix 4: PLAY Study – Informed Consent Form





Play Love And You (PLAY) Study: Consent form

1. I have been given a Participant Information Sheet which explains the nature and processes involved in this study, which is attached hereto;
2. I was given time to read it, or had it read to me, in the language I best understand;
3. I was given time to ask any questions I wanted to and found any answers given to me to be reasonable and satisfactory;
4. I believe I fully understand why the study is being conducted and what the intended outcomes will be;
5. I understand that there will be no immediate benefit to me, should I agree to participate, nor will I receive any payment; conversely, participation will not cost me anything but my time;
6. I understand that, even if I initially consent to take part in the study, I may subsequently withdraw at any time and would not be required to give any reasons; if that happened, any data collected about me for the purposes of the study would immediately be destroyed, unless I give consent for it to be retained
7. I have been given a range of contact details, listed below. If I require further information or become concerned about any aspect of this study, I am free to speak to any of these contacts.

Contact details:

- Dr Alessandra Prioreschi, Principal Investigator, telephone no. 083 989 0070, or by e-mail at Alessandra.Prioreschi@wits.ac.za,
- Professor CB Penny, Chairperson of the Human Research Ethics Committee (Medical) at the University of Witwatersrand, on telephone no. 011 717 2301, or by e-mail at Clement.Penny@wits.ac.za.
- Ms. Z Ndlovu or Mr Rhulani Mkansi, Committee Secretariat, telephone nos.: 011 717 2700 or 1234, or by e-mail at: Zanele.Ndlovu@wits.ac.za or Rhulani.Mkansi@wits.ac.za

Name of Participant: _____
Date: _____
Place: _____
Signature or mark _____

Witnessed by:
Name of Witness: _____
Signature: _____
Date: _____

CONSENT FORM FOR VISUAL RECORDING OF STUDY PARTICIPATION

I have read and understood the project information sheet, and I understand that it is up to me whether or not my videos are viewed by the research team. I understand that if I do not wish for my videos to be seen, it will not in any way affect how the interviewer treats me. I understand that my data will be shared with researchers in the United Kingdom. I understand that I can ask the research team to delete my videos, or any part of my videos at any time. I understand that the information that I give will be treated in the strictest of confidence, and that my name will not be used when the videos are analysed.

I hereby consent to visual recording of my interactions with my baby using the Headcam devices.

I understand that:

- The recording will be stored in a secure location (a locked cupboard or password protected computer) with restricted access by the researcher and the research supervisor.
- The recording will be transcribed and any information that could identify me will be removed from the transcription.
- My face and voice, and my baby's face and voice will be visible and audible in the recordings.
- The recordings will normally be erased within either (a) two (2) years of the publication of the research findings, or (b) six (6) years, if no publications arise from this research, or five years after the study.
- The film, with all identifying information directly linked to me removed, will be stored permanently and may be used for future research.
- Anyone wishing to access this information in the future will first have to obtain the approval of the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg.

Name of Participant: _____
Date: _____
Place: _____
Signature or mark _____

Witnessed by:
Name of Witness: _____
Signature: _____
Date: _____

Appendix 5: Data Collection Questionnaires (Compiled)

ANNEX 4

Play Love And You (PLAY) Study

CONTACT DETAILS

Cell number 1: _____ Cell number 2: _____

Other contact number: _____

Home address: _____

Contact details of a relative or a friend who will **always** know where you live (different to information on contact sheet):

Name: _____ Landline number Work number: _____

Address: _____ Relationship: _____ Cell number: _____

Other: _____

DATA COLLECTION TABLE

Timepoints	0 months	4 months	8 months	12 months
Infant Factors				
Age	X			X
Infant gestation age (Pre-term/full term baby)	X			
Birth Order	X			
Weight	X			X
Height	X			X
Infant's general health	X			X
Accelerometry		X	X	X
Headcam		X	X	X
Mother Factors				

1 | Page

ANNEX 4

Age	X			X
Weight	X			X
Height	X			X
Ethnicity	X			
Marital status,	X			X
Socio-economic status,	X			X
Education	X			X
Employment	X			X
Mental health	X			X
Mother's general health	X			X
Accelerometry		X	X	X
Headcam		X	X	X

SCREENING QUESTIONS

Are you older than 18?	(0) No (1) Yes	If No, EXCLUDE
Do you currently live in Soweto?	(0) No (1) Yes	If No, EXCLUDE
Are you planning on staying on Soweto for the next two years?	(0) No (1) Yes (7) Don't know	If No, EXCLUDE
Are you going to be the primary caregiver for your baby?	(0) No (1) Yes (7) Don't know	If No, EXCLUDE
Did you deliver a single baby (not twins)?	(0) No (1) Yes	If No, EXCLUDE
Is APGAR score >= 7?	(0) No (1) Yes (7) Don't know	If No, EXCLUDE
Was baby born at term?	(0) No (1) Yes (7) Don't know	If No, EXCLUDE
Has a doctor ever told you or other health professional that you have type 1 diabetes?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable	If yes, EXCLUDE

ANNEX 4

If yes, are you currently taking medication for your diabetes, either pills or insulin?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable	If yes, EXCLUDE
Have you ever been told by a doctor or other health professional that you have epilepsy?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable	If yes, EXCLUDE
If yes, are you currently taking medication for your epilepsy?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable	If yes, EXCLUDE

If screening criteria are passed – move on to the rest of the questions

A. SOCIO-DEMOGRAPHICS

Mother

Name:_____

Date of birth (calculate Age):_____

Ethnicity: _____

Marital Status: _____

Infant

Date of birth (calculate Age):_____

Birth order (first time mother or not): _____

Infant gestation age (from birth records): _____

Infant birth weight (from birth records): _____

Infant birth length (from birth records): _____

Mode of delivery (vaginal vs caesarean): _____

Infant Sex:_____

ANNEX 4

B. INFANT VARIABLES

Measurements

Length (cm):

			.	
			.	

Weight (kg):

			.	
			.	

Operator: **Date:**

QUALITY CHECKED BY: **DATE:**

ANNEX 4

C. Accelerometry INFANT	
Serial number	
Date issued	
Date returned	

D. Headcam INFANT	
Serial number	
Date issued	
Date returned	

ANNEX 4

E. MATERNAL VARIABLES

Measurements

Height (cm):

			.	
			.	

Weight (kg):

			.	
			.	

Operator: | **Date:**

QUALITY CHECKED BY: | **DATE:**

ANNEX 4

F. SOCIOECONOMIC STATUS:

Which of the following do you have in your current home (place where you spent most nights in the past three months)? It does not matter who owns/pays for these things. (*Answer all questions*)

	Item	**In current home**	
		Yes	**No**
a.	Electricity		
b.	Fridge		
c.	Stove		
d.	Vacuum cleaner		
e.	Washing machine		
f.	MNet/DSTV/Satellite		
g.	DVD Player		
h.	Motorcar		
i.	Television		
j.	Telephone (landline)		
k.	Cell phone		

l.	Computer/laptop		
m.	Internet access		

- How many people currently (in the last 3 months) live in the home with you (spend most nights in the home per week)?
- How many rooms for sleeping are there in your current home (include outside rooms/cottages)?
- How many of the people currently living in your home are children (<18 years)?

G. EDUCATION

The first few questions ask about your experiences with schooling and education.

Question	Responses
Do you have a matric?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable
If no, what is the last grade you successfully completed?	(1) Grade 5 or lower (2) Grade 6 (3) Grade 7 (4) Grade 8 (5) Grade 9 (6) Grade 10 (7) Grade 11 (77) Don't know (88) Refuse to answer (99) Not applicable
Since leaving formal full-time schooling, have you **ever** done any training or been registered with any training institution (including any training through employment and correspondence)?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable

V1.2_04/02/2022

Are you currently enrolled in a training institute?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable
Have you ever attended university or another post-matric college?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable
If yes, did you graduate?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable
If yes, what is the highest degree you have attained?	(1) Diploma (2) Bachelors (3 years) (3) Honors (4th year) (4) Masters (5) PhD
Are you currently enrolled in a university degree or college diploma program?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable
If yes, what is the level you are enrolled in?	(1) Diploma (2) Bachelors (3 years) (3) Honors (4th year) (4) Masters (5) PhD

ANNEX 4

H. OCCUPATION/ EMPLOYMENT

1. Have you **ever** had a job? By job we mean any work done to earn money or to gain skills. This includes casual/informal work & volunteer work.

Yes	No (Skip to Q3)

2. Do you currently have a job? By job we mean any work done to earn money or to gain skills. This includes casual/informal work & volunteer work.

Yes	No

3. Are you currently looking for a job?

Yes	No

4. If no, what is the main reason? (tick **one**)

Reason	**Tick one**	**Code**
I am at school / studying		1
I am too busy or don't have time		2
Family responsibilities (i.e. Pregnant or Looking after children/family/relatives)		3
I don't need money		4
I am not skilled or experienced enough/ my level of education is not high enough		5
It's too expensive to look		6
I am sick / disabled		7
Other (specify)		8

5. Have you been unemployed and seeking work for a month or more during the past 6 months?

yes	**no**

ANNEX 4

I. MENTAL HEALTH

Antenatal Stress Questionnaire (16)

Sometimes one's life and that of one's close family goes through periods of being very stressful. I'd like to ask you some questions about any stresses you might have experienced in the last few months.

1. During the last 6 months have you or a member of your close family been in real danger of being killed, in one of the following ways?

1 = By criminals
2 = By police, army or other 'officials'
3 = During political activities
4 = This has not happened at all

2. During the last 6 months did you witness a violent crime (e.g. murder, robbery, assault, rape)?

Yes = 1	No = 2

3. During the last 6 months have you found that you are in so much debt that you don't know how you will repay the money?

Yes = 1	No = 2

4. During the last 6 months have you or your close family ever had too little money for basics, such as food, rent, and clothes?

Yes = 1	No = 2

5. Have you or one of your close family not been able to find a job for more than 6 months?

Yes = 1	No = 2

6. During the last 6 months have you or anyone in your close family been seriously ill?

Yes = 1	No = 2

7. During the last 6 months did any member of your close family die?

Yes = 1	No = 2

ANNEX 4

8. Is there anyone in your close family with a serious disability (e.g. epilepsy, mental retardation, deafness, blindness, mental illness)

Yes = 1	No = 2

9. Is there anyone in your close family who has a problem with drugs or alcohol?

Yes = 1	No = 2

10. During the last 6 months have you had a break-up with your husband or partner?

Yes = 1	No = 2

11. During the last 6 months has your husband or partner hit or beaten you?

Yes = 1	No = 2

12. During the last 6 months have you had any serious fight or alienation from members of your family or your close neighbours?

Yes = 1	No = 2

13. During the last 6 months have you or any member of your close family been arrested, had to go to court or consulted a lawyer on a non-routine matter?

Yes = 1	No = 2

14. During the last 6 months have you given help (money, accommodation etc.) to close family or friends in need?

Yes = 1	No = 2

15. During the last 6 months have you been separated unwillingly from any of your children (excluding holidays)?

Yes = 1	No = 2

16. During the last 6 months have you experienced any problems with your other children (such as schools closing, failure at school, problem behaviour, drugs, etc.)?

ANNEX 4

Yes = 1	No = 2	No other child = 3

If YES, specify problem _____

ANNEX 4

J. GENERAL HEALTH

Questions	Responses
Do you think you get ill more often than other people?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have high blood pressure?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
If yes, are you currently taking blood pressure medication?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have high cholesterol?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
If yes, are you currently taking a cholesterol lowering medication?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have asthma or wheeze?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
If yes, are you currently taking medication for your asthma?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have allergies?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable

ANNEX 4

If yes, are you currently taking medication for your allergies?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have tuberculosis?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
If yes, are you currently taking medication for tuberculosis?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have HIV?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
If yes, are you currently taking medication for HIV?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable

ANNEX 4

K. Accelerometry MOTHER	
Serial number	
Date issued	
Date returned	

L. Headcam MOTHER	
Serial number	
Date issued	
Date returned	

Appendix 6: PhD Ethics Approval – M220785 Submission

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R14/49 Ms Dumsile Nontokozo Maduna

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M220785

NAME: (Principal Investigator)	Ms Dumsile Nontokozo Maduna
DEPARTMENT:	School of Clinical Medicine
PROJECT TITLE:	*Determining synchrony of mother-infant non-verbal and movement behaviours using first-person observation and accelerometer data*
DATE CONSIDERED:	Ad hoc
DECISION:	Approved unconditionally
CONDITIONS:	Sub-study under M220217 and M210846
SUPERVISOR:	Dr A. Prioreschi
APPROVED BY:	Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	11/08/2022

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on the Third Floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions.Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. I **agree to submit a yearly progress report.** The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed in **August** and will therefore be due in the month of **August** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix 7: Main Study Ethical Clearance

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

Office of the Deputy Vice-Chancellor (Research and Innovation)

TO:	Dr A Prioreschi School of Clinical Medicine Department of Paediatrics and Child Health Developmental Pathways for Health Research Unit Chris Hani Baragwanath Academic Hospital E-mail: Alessandra.Prioreschi@uct.ac.za
CC:	Supervisor: Not applicable <> and <HREC-Medical Research Office@wits.ac.za>
FROM:	Mr Iain Burns Human Research Ethics Committee (Medical) Tel: 011 717 1252 E-mail: Iain.Burns@wits.ac.za
DATE:	2022/05/05
REF:	R14/49
PROTOCOL NO:	**M220217** (This is your ethics application reference number. Please quote it in all enquiries, oral or written, relating to this study.)
PROJECT TITLE:	*The PLAY study trial protocol: an intervention to improve infant growth and development by encouraging responsive caregiving through interactive play*

Please find attached the Clearance Certificate for the above project. I hope it goes well and that an article in a recognized publication comes out of it. This will reflect well on your professional standing and contribute to Government funding of the University.

MSWorks2000/Iain0007/Clearscan.wps

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

R49 Dr A Prioreschi

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M220217

NAME: (Principal Investigator)	Dr A Prioreschi
DEPARTMENT:	School of Clinical Medicine Department of Paediatrics and Child Health Developmental Pathways for Health Research Unit Chris Hani Baragwanath Academic Hospital
PROJECT TITLE:	*The PLAY study trial protocol: an intervention to improve infant growth and development by encouraging responsive caregiving through interactive play*
DATE CONSIDERED:	2022/02/25
DECISION:	Approved unconditionally
CONDITIONS:	
NOTE:	If contact information regarding student study participants is required, please contact the Registrar's office - <Nicoleen.Potgieter@wits.ac.za>
SUPERVISOR:	Not applicable
APPROVED BY:	Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	2022/05/05

This Clearance Certificate is valid for 5 years from the date of approval. An extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office secretariat on the 3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated from the research protocol as approved, I/we undertake to submit details to the Committee. **I agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date when the study was initially reviewed. In this case, the study was initially reviewed in **February** and therefore reports and re-certification will be due in the month of **February** each year. Unreported changes to the study may invalidate the clearance given by the HREC (Medical).

Signature of Principal Investigator _____ Date _____

Appendix 8: PhD Study Protocol

Title: Determining synchrony of mother-infant non-verbal and movement behaviors using first-person observation and accelerometer data

Dumsile Maduna (1694184)

PhD Clinical Medicine

University of Witwatersrand

Supervisor:

Dr Alessandra Prioreschi (PhD)

SAMRC-Wits Developmental Pathways for Health Research Unit (DPHRU)

Department of Pediatrics and Child health,

School of Clinical Medicine, Faculty of Health Sciences

University of the Witwatersrand, Johannesburg

Co-Supervisor:

Professor Ian Thomas Nabney

Professor and Head of School of Computer Science,

Electrical and Electronic Engineering, and Engineering Maths,

University of Bristol. United Kingdom

18 February 2022

Glossary of Terms

Term	Definition
Accelerometers	Small electronic gadgets that measure body movement acceleration and provide an objective estimate of locomotion time and intensity.
Synchrony	The ability of the mother and the infant to respond to each other in a short period of time by performing matched actions, resulting in the formation of a single relational unit (dyad)
Behavioral Synchrony	Occurs when, micro-level relational actions are coordinated into patterned configurations that get incorporated into the infant's life Over time and with repeated experience and influences its development.
Nonverbal synchrony	The temporal, unconscious, spontaneous and mutual nonverbal behaviors between interacting partners in a dyad that is associated with the quality of the interaction
Movement Synchrony	The time-based relationship between the gestures of the partner in a dyadic interaction, regardless of a specific body part or direction.
Time delay	When one partner in a dyadic relationship produces a specified behavior that is reciprocated by the other partner's coordinated conduct within a specific time frame.

Simultaneous	When there is no temporal time gap between a dyad's movements
Converging	When the movements of a pair become more identical over time, this is known as convergent synchrony.
Leader-follower relationship	One individual leads the conversation and sets the tempo, while the other follows suit.
Pseudo synchrony	Randomly occurring synchrony
Responsive caregiving	The ability of the caregiver to recognize, comprehend, and respond appropriately to the child's signs.

18 February 2022

RESEARCH PROTOCOL

Background/Introduction

In recent years non-verbal synchrony has received considerable attention from many disciplines especially studies investigating mother-infants' interactions[1]. Synchrony has been greatly recognized for its role in the formation of social, emotional and cognitive foundations in early childhood which are critical in achieving health and wellbeing milestones during child growth and development[2]. However, many children in low and middle-income countries are still at risk of poor development due to their exposure to adversities that impair their optimal development from conception and through early childhood[3]. The WHO has emphasized the urgent need to integrate responsive caregiving into early life interventions to strengthen the caregiver's responsiveness to the child's behaviors and cues appropriately[4].

Considered to be at the heart of mother-infants' interactions, studying and understanding non-verbal synchrony is crucial in early childhood development[5,6]. Improvements in assessment of synchrony have been made, and advancements in technology have made it possible to objectively record synchrony behaviors through the use of motion sensors and videos applications[7]. Although a number of methods have been developed to measure behavioral and movement synchrony, their validity and reliability remains to be tested[8]. The World Health Organization (WHO) has highlighted the need for more research into reliable tools to assess child and caregiving outcomes[4].

Role of synchrony in infant-caregiver interactions

Synchrony involves the mutual capacity and emotional ability of both the mother and the infant to respond each other, hence collectively creating a single relational unit (dyad)[9,10]. It encompasses matching dyadic biological rhythms, emotional states, and behaviors[11] that happen during early

childhood development. Behavioral synchrony as a distinctive level of synchrony found in infant-caregiver interactions, is the most regularly examined due to its accessibility for testing[2].

Scientific findings show that positive infant-caregiver interactions have many health benefits early in the infant's life which may have lasting effects on childhood developmental outcomes[12]. As a child grows, they grow their skills (i.e., relational or communicative abilities) on the foundations they learnt and developed in early childhood which do not only survive a lifetime, but also have an impact on the human development of future generations[13]. Communicative abilities, for instance enable infants to actively and increasingly interact with their mothers and other people [14]. Understanding infant-caregiver behaviors and interactions is therefore at the center of early infant development[2], and synchrony is a critical component of these interactions.

Synchrony has a significant impact on the formation of relationships and interpersonal rapport[1]. Interactional synchrony is one of the key components that make up rapport, along with positivity and mutual attention[15]. For example, before young children learn to speak, early bonding with their caregivers is facilitated by physical contact and shown through cuddling, eye contact, smiles, vocalizations and gestures[16]. These mutual mother-infant engagements establish an emotional bond and that triggers brain connections[4], which enables the infant to recognize and appreciate the world around them, including learning about people, relationships and language[17]. Starting from the first months of life, quality interactions between infants and caregivers – including touching and engaging in play, creates neural connections that strengthen the infant's brain[18,19].

Synchrony provides opportunities for early learning, which is a critical requirement for children to reach their full developmental potential[16]. In human beings, learning is an intrinsic mechanism, which enables one to adjust to life changing situations[4]. Responsive caregiving encompasses enriched learning that facilitates the building of trust and social relationships through caregiver's

observation and response to children's movements and gestures[4]. In the early childhood, interpersonal relationships with other people play a critical role in the acquisition of basic learning, social skills and capacities through nonverbal behaviors that provide a foundation for subsequent abilities[4]. These interactions enable the infant to learn about interacting with other people, build their confidence, and create their motivation to learn more. Children therefore need a family environment filled with affection and security, including daily life guidance from adults which nurture their relationship skills[4].

Movement behaviors and synchrony

Behavioral synchrony includes the time-based linking of motions of the mother-infant dyads, regardless of the body part involved or direction[8,20] known as movement synchrony. Movement synchrony is a specific type of nonverbal synchrony which comprises of nonverbal behaviors such as gaze, gestures, facial expressions, body postures and other movements[21]. Throughout life, body movements during an interaction, and how these motions are coordinated by interacting partners are an important part of social interactions[22]. These coordinated bodily movements reveal information about the quality of the relationship[23],personality and emotional states[24]. In mother-infant interactions, body movement plays an important role in infant stimulation[25]. For example, when a mother coordinates her motions with her infant, she shows the infant that she is aware of him and wants to be a part of his experience[22]. However, there has not been much focus on the importance of synchronous movement in early mother-infant connection in the scientific literature[22].

Literature supports the need to develop healthy movement habits early childhood in order to support long-term child development[26]. Movement behaviors including physical activity, sitting, screen time, and sleep are linked to healthy growth and physical development, as well as cognitive,

social, and emotional development in children under five years old[27,28]. Physical activity behaviors formed early in life tend to persist throughout later childhood and adolescence[26], hence it should be encouraged from an early age. Physical movement has numerous advantages in early childhood, including enhanced cardiometabolic biomarkers [29,30], improved mental health, cognitive[31] and social[29] development [31]. Physical activity is linked to improved motor skill development and adiposity measurements in infants younger than 12 months[29], and to better bone and skeletal health in toddlers[26].

Considering these health benefits of movement behaviors in early childhood [32], age-specific guidelines such as, *"The South African 24-hour movement guidelines for birth to 5 years"*[27], have been produced to assist various cohorts in achieving their health's ideal mobility profiles. These guidelines emphasize on the importance of encouraging children to be physically active through participating in a variety of age-specific and ability appropriate play or planned physical activities that are entertaining and safe[27]. Sedentary behaviors such as screen-based sitting activities should be discouraged or reduced as much as possible whilst ensuring good quality sleep in these age groups[27]. A balance of activities is necessary a typical 24 hr. daily routine[28].

The involvement of caregivers and or other children in playing and conversing with the infants[27] serves as a source of stimulation and motivation for children. According to a study that measured activity levels in children, infants are more physically active when the mother is the primary caregiver[33]. Infant's physical movement was found to be directly linked to the mother's physical activity levels[33], and infants copy and reciprocate their mother's movement behaviors during these engagements. This mutual behavioral interaction requires investigation and nurturing so that infants are provided as much chance to be as active as possible[33].

How is synchrony measured?

The assessment of infant-caregiver interactions is a critical concern in the early years of an infant's life development[2] due to its role in supporting infants' wellbeing and development[34]. Although crucial, there is no commonly acceptable method for detecting and assessing synchrony between interactive partners during early childhood development[35]. The Guideline Development Group (GDG) mentioned that a large variety of tools are used to assess synchrony of behaviors in infancy, however their reliability and validity requires further research as many are unstandardized[36].

Manual ratings of behavior and movement synchrony by trained observers, also known as the 'judgement method', have been previously used to measure synchrony, and this involved subjective ratings on some aspects of synchrony on a 9-point Likert scale[37]. This technique measured simultaneous movement, similarities of tempo, or rhythm, as well as the coordination and smoothness of behaviors between interacting partners[1]. Alternatively, discrete movements such as touch of the face and pose shift were measured and then their occurrences were correlated over time[38]. However, these non-computational methods proved to be time-consuming, unreliable and subjective to the judges' assessing synchrony[1]. These drawbacks are exaggerated by the lack of an acceptable general framework for investigating synchrony to date[35].

Nowadays, improved methods for measuring synchrony which utilizes operational coding systems have been developed, and these have been classified into three categories: global, specific synchrony scales of dyadic interaction, and micro-coded time-series analyses[2]. Although behavioral coding is still required during the creation of algorithms for these new computational methods, after completion their outputs are deterministic by nature and manual ratings become unnecessary[39].

Global interaction scales generally measure mother-infant dyadic behaviors during interactions by providing an overall assessment and qualitative description of interaction[1]. These video-based assessments, grades mother-infant behaviors in dimensions that describe how well a mother's actions are adjusted to her infant's, describes the infant's positive participation in the interaction and measure the overall quality of the engagement[40]. Synchrony scales are more specific and include various assessment designs. Although most synchrony scales are still global and qualitative, some have a list of behaviors that can be measured statistically to determine synchrony (e.g., frequency, duration, cooccurrence)[2]. In the assessment instrument, both the global and specific scales do not always use the term synchronization. Micro-coded time-series analyses are statistical tools used to measure synchrony of specific behaviors focusing on the time component of parent-child interactions using a pre-determined list of behaviors and mother-infant observations which are divided into short time units for assessment by coders[2].

Measurement of behavioral synchrony

There is no tool that is accepted as the gold standard for measuring mother–infant interaction, and this makes the selection of an objective synchrony assessment method from the many tools that exist more difficult[2]. It is therefore important to consider the dynamic, reciprocal, time-delayed and temporal nature of synchrony when selecting measurement methods[1]. To improve the quality of synchrony analysis, a consolidative approach integrating clinical observation and engineering tools is recommended[22].

Mother-infant behaviors and movements during dyadic interactions are most objectively measured by observation[39]. Observational tools of mother-infant interactions exist, and these provide more reliable measures compared to self-reports such as parent-report questionnaires which could be misleading due to inherent biases of the respondent[39]. Observational tools are capable of measuring

synchrony in dyadic interactions, although an extensive knowledge of this construct is needed when selecting a tool and trainings on the technical aspects of equipment are a must[41,42]. Therefore, researchers or clinicians should evaluate the strengths and limitations of available tools to measure their behaviors of interest[42,43]. This information, however, may not be available as most observational tools remains unpublished[39].

Generally, the third-person point of view has been used to measure synchrony whereby the mother-infant interactions were observed or filmed by a trained researcher in a clinical, research, or home setting[44]. However, this technique can be intrusive, and burdensome to both the researcher and the participant[44]. More recently, a first-person viewpoint has been investigated, whereby small cameras are attached to specially-designed headbands worn by both mothers and infants while interacting[16,44,45]. These cameras face outward to capture each person's perspective during that interaction period and have proved to be effective to objectively record mother–child visual behaviors.

On the other hand, bodily movement behaviors are complex and challenging to measure[36]. A wide range of techniques to measure movement exist, and these include behavioral observations, and motion sensors, such as heart rate monitors, combined heart rate and accelerometry devices and pedometers[46]. These are expensive, time-consuming, prone to recall-bias and require supply and return of equipment. Also, the subjectivity of these methods may over- or underestimate participants' movements information[47,48].

Today, advances in motion capture technology have allowed for more precise measurement of movement, and wearables[7] such as body-worn accelerometers provide an opportunity to study movement synchrony outside the lab setting[49]. Accelerometry has become a popular data collection tool in recent studies[50] and is considered by some researchers, as the gold standard to

objectively measure infants' and toddlers' physical activity[26]. These small battery-operated gadgets measure acceleration allowing for "real-time" evaluation of exercise intensity, duration, and frequency[51,52]. A variety of accelerometers are available on the market[46]. A wearable band that fits an accelerometer on the infants' wrist, has been designed to measure infant 24-hour movement[16]. Such advancements applied in the assessment of infant-caregiver interactions provide detailed measures of first-person observation in a free-living home setting[45]. Therefore, this study aims to determine the synchrony of mother-infant non-verbal and movement behaviors using first-person observation and accelerometer data in a group of mother-infant dyads.

Hypothesis

Based on the literature, it is hypothesized that:

- Within the dataset mother-infants' dyads are more synchronous compared to randomly assigned pairs of women and infants.
- Changes in the mothers and infants' behaviors occur over time form patterns that get incorporated into the infant's life, thereby shaping its development across time, and repeated experience. Examining these temporal patterns is the best way of investigating synchrony.
- Mother and infant characteristics predicts synchrony in a mother-infant's dyadic interaction and these include age, education, ethnicity, socio-economic status, marital status, first time mother, pre-term/full term baby, mother/infant's health, mothers depression/anxiety/stress.

Study Aim and Objectives

Aim

This study aims to determine the synchrony of mother-infant non-verbal and movement behaviors using first-person observation and accelerometer data in a group of mother-infant dyads from Soweto, South Africa

Objectives

1. **To assess synchrony of mother-infant (aged 0-2 years) micro-behaviors such as touch, hand movement and gaze, during free play using first person observation**
2. **To assess synchrony in diurnal movement behaviors of mother-infant dyads using accelerometry**
3. **To assess longitudinal patterns of synchrony of movement- and interaction behaviors between mother-infant dyads in the first year of life**

Methods

Objective 1

Study Design

As a first step, this study involves secondary data analysis from a cross-sectional study that tested the acceptability and feasibility of the headcam devices in the Soweto context.

Study Site

This study will be conducted in Soweto (SAMRC/Wits Developmental Pathways for Health Research Unit (DPHRU)

Study population

Secondary data of participants from the study titled, *"The headcam mother-infant interaction assessment tool: testing the feasibility and acceptability in Soweto, South Africa, using participatory engagement"* will be used in the proposed study. The original study is described in detail elsewhere[16] and included a total of 19 mother-infant (6–24 months) dyads who were recruited from existing studies at the SAMRC/Wits Developmental Pathways for Health Research Unit (DPHRU). Women were >18 years old, had a child aged between 6 and 24 months and lived in the Soweto area. Participants agreed to take part in the study and for their footage from the headcams to be collected and shared with colleagues for analysis by signing a written consent form[16].

Data collection

Primary outcome data: Headcam

Headcam data were collected between May and July 2019, whereby mother-infant dyads were requested to participate in group and individual activities while wearing headcams affixed to a soft fabric headband to record first-person observation[16]. Activities done in groups included free play, play circles, and mother-infant dance movement. Data was also collected at the dyads home, in at least three, 5-minutes mother-infant interaction sessions that were spread over a 1-week period to provide context for the interactions[16].

Demographic data:

In the current analysis I will use all available demographic factors such as the age of the child and gender and maternal age, socioeconomic status, employment status, education, A csv. file will be downloaded from RedCap and variables will be extracted for analysis. Information extraction

sheets will be used to record each variable. All data will be de-identified. These variables will be summarized and controlled for during data analysis.

Data Processing and outcome measures

Video footage from the headcam mother-infant assessment tool has been downloaded successfully and viewed for each mother-infant dyad. These videos will be coded using the Noldus Observer XT software. A second-by-second manual coding of mother-infant behaviors, such as touch, hand movement and gaze will be done by the researcher using an event-based coding framework developed specifically for mother-infant interactions[16]. After coding, pairs of video sequences in frames, for each behavior of interest, with and without behavioral synchrony will be generated[53] (see Annex 1 in Appendices). Sequences of frames with behavioral synchrony will be extracted from those without behavioral synchrony[53] to generate pairs of behaviors' time series.

Each extracted time series will have a window of 75 or 125 frames (3 or 5 seconds, respectively)[53] and an R^2 cut-off of 0.25 will be used[53] to distinguish and separate genuine synchrony from pseudosynchrony[37,54]. These configurations are considered the best identifiers of body-movement synchrony according to Schoenherr et al (2019)[55].

Each behavior will be treated separately such that the generated time series for the mothers' play, touch, and gaze behaviors will be independent from the infants' time series. A logarithm transformation will be applied to each behavior's time series to control for spurious correlations caused by non-stationarity which has a potential to overidentify the synchronization intervals[56]. Variables such as the time when the synchrony of touch, synchrony of gaze and synchrony of play occurs in mothers and infants, strength of the association, maximum synchrony, frequency of

synchrony and the leader-follower relationships, e.g., which behavior precedes another during free play, will be determined and described.



Figure 1 An example of a second by second coding of behaviors for mothers and infants

Data Analysis

The methods to be used to locally identify synchrony of touch, synchrony of gaze and synchrony of play for the mother-infant dyads are the window cross-lagged correlation (WCLC-frequency) and window cross-lagged regression (WCLR), which will be applied to the paired behaviors time series[20,56,5755]. The algorithms for these methods are available for public use at GitHub: https://github.com/10101-00001/sync_ident. We will scrutinize the results to understand whether regime changes (i.e., temporal changes in the relationships between signals from mother and infant) or non-linearity is present and adjust our modelling accordingly if so.

This method will generate an R^2 matrix, which displays the time points when the infant's behavior is significantly related with the simultaneous or time-lagged event. mothers' behaviour[55]. A modification of Boker et al.'s (2002) peak-picking algorithm will then be applied whereby the

matrix will be analyzed to produce a global synchrony score[56]. The means and standard deviations of the synchrony output scores, and time lags will be investigated.

The associations of different synchrony output scores will be investigated such that the strength of the associations will be averaged across time and different time lags[58], and frequency of synchrony will be calculated as the ratio between synchronized time and total time[59]. Maximum synchrony and directionality, such as the leader-follower relationship, will also be determined.

Table 1 shows a summary of data processing and analysis methods (See Annex 1 in Appendices), including a list of variables to be assessed

OBJECTIVE 2 and 3

Study Design

This study is nested in a Randomized Controlled Trial (RCT), the Play Love and You (PLAY) study, which aims to implement and test the efficacy of an intervention designed to promote growth and development through responsive caregiving and interactive play. PLAY study participants (mothers with infants aged 0-3 months) will be individually randomized into either a control or intervention group (n=75 each). The intervention will last 24 months, and assessments will be made when the infants are 6, 12- and 24-months of age. The trial will consist of a standard of care package (control group), and an intervention package – including standard of care as well as the intervention content (intervention group). Mothers assigned to the control group will receive the standard Road to Health booklet as well as the Side-by-Side services provided as routine postpartum care. They will also be contacted every 2 months to check in, and to provide referrals to health care facilities if necessary. The intervention group will receive the standard of care

package, as well as the intervention content comprising of a number of micro-interventions supporting the following themes: 1) exclusive breastfeeding for first 6 months 2) play and promotion of early learning, 3) responsive caregiving and 4) maternal mental health. The intervention will be delivered using an interactive App with content and resources, rapid feedback on infant's movement behaviors and the dyad's interaction styles, and mental health screening and support. The intervention will be delivered in three phases according to Figure 1 below. Data collection for my PhD will occur between baseline and 12 months and will include all participants of the PLAY study.

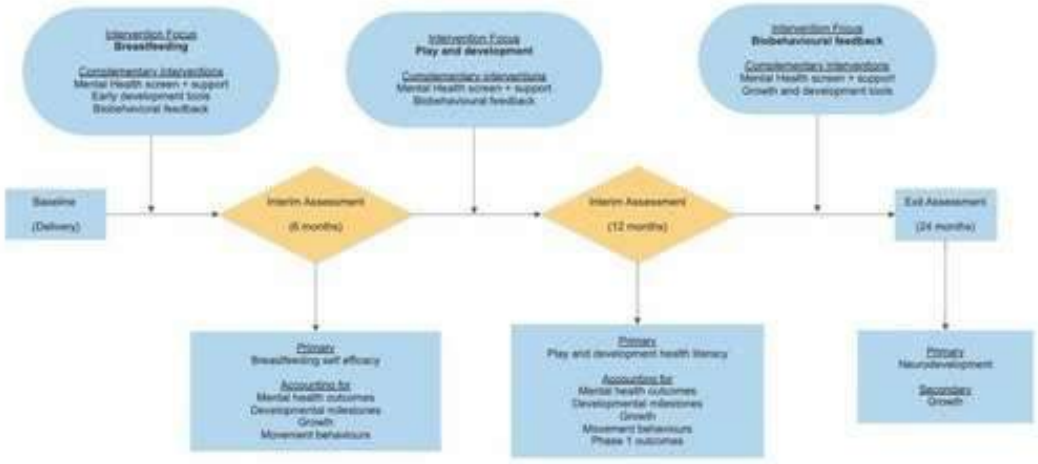


Figure 2 PLAY Study flow chart diagram showing where this study will be nested.

Study Site

This study will be conducted in Soweto (SAMRC/Wits Developmental Pathways for Health Research Unit (DPHRU)

Study population

Mother-infant dyads will be recruited from the community clinics in Soweto. A total of 150 mother-infant dyads will be recruited at delivery and followed up for a 12-month period. The study will include mother-infant dyads who meet the following criteria: Mothers aged ≥18 years who, are the primary caregivers and agree to participate for the duration of the study, and who reside in, and intend to remain in Soweto for the study duration. Mother-infant dyads will be excluded if they have any disabilities, impairments or disease that could restrict movement or limit common behavior as shown by the Road to Health book and medical records[45].

Sample size

This study will use the entire sample of 150 mother-infant pairs recruited by the PLAY study from community clinics in Soweto. In order to achieve this target, the PLAY study has already accounted for an expected 30% loss to follow up across the two-year study period recruiting 210 mother-infant dyads[45]. The churn rate will be minimized by enforcing strict inclusion criteria at recruitment, keeping contact with participants at regular basis and by ensuring flexibility and versatility in the study delivery.

OBJECTIVE 2

Data collection

Primary outcome data: Accelerometry

Both mothers and infants will be asked to wear an Axivity-AX3 on their wrist for seven-days, 24-hours per day when the infant is baseline, 4 months, 8 months, and 12 months old. Data will be downloaded from devices to tablets for a quick onsite quality control (QC) monitoring by study staff members and subsequently transferred to a computer for further processing and analysis.

Demographic data:

Mother-infant's demographic information will be collected by study staff using standardized procedures at enrollment and at each study visit. The demographics and socio-economic questionnaires will be used to collect mother and infant's child's age and sex; and mother's education, employment status, socioeconomic status and household density (see Annex 4 in appendices). These variables will also be summarized and controlled for during data analysis.

Data Processing and outcome measures

At each visit, axivity-AX3 data will be collected, downloaded in raw. cwa format, auto-calibrated, and then converted to .wav format using OmGui open-source software (Omgui Version 1.0.0.28; Open Movement, Newcastle, UK)[45]. Acceleration data will be captured and stored at 100 Hz, their maximum sampling frequency[60].

Axivity files will be processed with the Wave package https://github.com/MRC-Epid/Wave/releases/tag/v1.0.0-Beta and analyzed in Python[36]. Processing will include data quality checks, removal of noise and gravity, vector magnitude processing and removing periods of non-wear[61].

Individual wrist acceleration signals for mother and infants' hourly movement data will be generated and these will be combined into an overall acceleration measure for each individual[49]. Movement data variables outputs such as the frequency, average acceleration and the intensity of movement synchrony will be assessed for both mother-and infant at each time point[49,62].

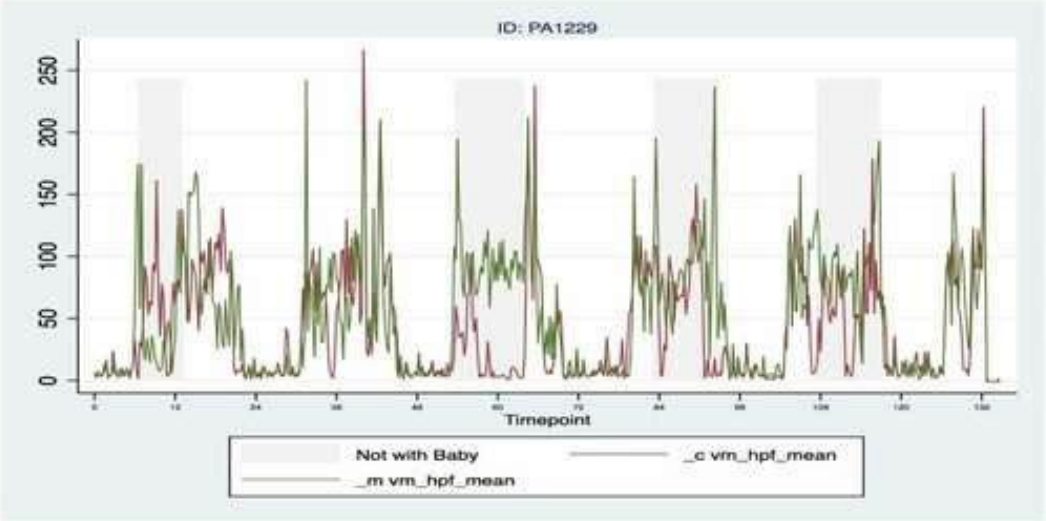


Figure 3 An example of movement time series for mother and infant[64]

Data Analysis

To determine the synchrony of movement between mother and infant, wavelet analysis adopted from the PyCWT module in Python[49] will be applied on the dyads' time series signals. To account for non-stationarity, acceleration data from both mother-infant time series signals will be compared to produce a cross-wavelet transform in the time-frequency domain[49]. This will reveal a temporal-frequency response common to both signals without requiring a sliding window. The cross-wavelet transform will then be averaged across frequencies to provide a measure of likeness at any frequency[49].

The average cross-wavelet power (AWC) will provide a good measurement of likeness between two time series, showing similarities at any frequency if found, and by how much. To determine the level of similarity in movement between mother-infant dyadic time series signals two comparison algorithms: time-based cross-correlation (CC) over a sliding window of 5s, and the frequency-averaged cross-wavelet transform (ACW) will be used[49].

OBJECTIVE 3

Data collection

Primary outcome data: Synchrony of interaction and movement behaviors

Mother-infant dyads will be provided with headcams to collect first-person observation measures during free play at home when the infant is baseline, 4 months, 8 months, and 12 months. The aim is to have at least five, 3–5-minute-long mother-infant play interactions recorded over the course of a week for each measurement period.

Furthermore, mother-infants' accelerometry data will be used from objective 2.

Exposure variables

Based on literature potential predictors of synchrony will also be assessed whereby the mother and infant characteristics such as: age, education, ethnicity, employment, socio-economic status, marital status, first time mom, pre-term/full term baby, mother/infant's health, mothers' depression/anxiety/stress[2] will be collected. Data collection will be conducted by independent, trained research assistants[45] at first visit after delivery (baseline), 4 months, 8 months and 124 months using demographics, socio-economic questionnaires and mother/infant' health forms (see Annexes 4 in appendices).

Data Processing and outcome measures

The Noldus Observer XT software will be used to code headcam observations, following the same procedure as in Objective 1. Mother-infants' accelerometry data will be processed following the same procedures as in objective 2. Longitudinal patterns of synchrony of movement- and interaction behaviors between mother-infant dyads in the first year of life will be determined using

both the headcam and accelerometry data. This will include assessing the predictors of synchrony over time.

Data Analysis

Headcam and accelerometry synchrony time-series generated from objective 2 will be used to determine synchrony changes and patterns the first year of life (12 months period). Synchrony time series for each behavior (headcam synchrony) or movement (accelerometry synchrony) will be analyzed separately.

Summary statistics of each synchrony outcome will be described i.e., percentage of time of synchrony, degree, and directionality of synchrony. Univariate and multivariate analysis will be applied to the identified potential predictors of each synchrony behavior such as age, education, ethnicity, socio-economic status, marital status, first time mother, pre-term/full term baby, mother/infant's health, mothers depression/anxiety/stress.

Time series models such as the Vector autoregressive models (VAR) will be used to describe time trends or seasonality of synchrony (mother-infant synchrony of touch, synchrony of gaze, synchrony of play and synchrony of hand movement) and changes occurring at the 4 months, 8 months and 12 months' time points will be compared. Mixed effects models will be used on data that was aggregated at these time points to control for confounders and risk factors i.e., Poisson mixed will be applied to determine how these longitudinal factors affect time series data. Confounding variables to be considered includes time, type of behavior or movement as well as the predictors of synchrony etc.

Data Management

Data will be managed using REDCap (https://www.project-redcap.org)[16,45], whereby only authorized people have access to this secured system. The Wits University servers host RedCap and an external hard drive will also back up data files daily, during and after study completion.

Ethics

I will apply for ethical approval, which will be considered by the Human Ethics Research Committee of the University of the Witwatersrand, Johannesburg. The work will not commence until ethical approval has been given.

The PLAY study will also be considered by the Human Ethics Research Committee of the University of the Witwatersrand, Johannesburg, South Africa.

Funding

The proposed work is nested in the PLAY study which is supported by the National Institute for Health Research (NIHR) through the UK's Official Development Assistance (ODA) Funding and Wellcome under the NIHR-Wellcome Partnership for Global Health Research[35]. Hence, research costs related to the proposed study such as human resource, transport, and equipment are already accounted for and budgeted for in the trial.

The PhD is also funded through the project funds (See Annex 3 in Appendices). However, supplementary funding for living expenses is still being applied for from the Wits internal funding and NFR

Potential Problems

- Unforeseen delays or changes in the timelines of the study due to the dynamic nature of the COVID-19 pandemic may be possible. The study will concentrate attention on data

collection when the project begins adapting to changes, when necessary, as guided by the Ministry of Health and the University.

- COVID-19 infection: All COVID-19 protocols as stated by the Ministry of Health, and by the University, shall be strictly followed at all times (PLAY Study COVID-19 Plan)
- Data Quality Challenges: Data collectors and participants will be trained on the use and care of headcams and accelerometers.
- Loss of equipment: Participants will be trained on how to take care of the devices, and these will be collected timeously as necessary.
- Attrition: Study staff shall conduct follow-ups on missed appointments, set reminders and conduct home visits where necessary for study participants.

References

1. Luehof S. Automatic Analysis of Synchrony in Dyadic Interviews. 2019.
2. Leclè Re C, Viaux S, Avril M, Achard C, Chetouani M, Missonnier S, et al. Why Synchrony Matters during Mother-Child Interactions: A Systematic Review.
3. Lo S, Das P, Horton R. A good start in life will ensure a sustainable future for all. Vol. 389, The Lancet. Lancet Publishing Group; 2017. p. 8–9.
4. NURTURING CARE FOR EARLY CHILDHOOD DEVELOPMENT IN SUPPORT OF.
5. Feldman R. Parent–Infant Synchrony: Biological Foundations and Developmental Outcomes. https://doi.org/101111/j1467-8721200700532.x [Internet]. 2016 Jun 24 [cited 2022 Feb 10];16(6):340–5. Available from: https://journals.sagepub.com/doi/abs/10.1111/j.1467-8721.2007.00532.x
6. Cohen D. The developmental being. Modeling a probabilistic approach to child development and psychopathology. Neuropsychiatrie de l'Enfance et de l'Adolescence. 2012 Jul;60(5):S25–6.
7. An Q, Ishikawa Y, Nakagawa J, Kuroda A, Oka H, Yamakawa H, et al. Evaluation of Wearable Gyroscope and Accelerometer Sensor (PocketIMU2) during Walking and Sit-to-Stand Motions.
8. Chetouani M, Delaherche E, Dumas G, Cohen D, Burgoon JK. Interpersonal synchrony: from social perception to social interaction. Social Signal Processing [Internet]. 2017;9781316676202. Available from: https://hal.sorbonne-universite.fr/hal-02422930
9. Bell MA. Mother-child behavioral and physiological synchrony. Advances in Child Development and Behavior. 2020 Jan 1;58:163–88.
10. Mcleod S. Attachment A-level Revision Notes AQA(A).

11. Feldman R. Parent–infant synchrony and the construction of shared timing; physiological precursors, developmental outcomes, and risk conditions. Journal of Child Psychology and Psychiatry [Internet]. 2007 Mar 1 [cited 2022 Jan 17];48(3–4):329–54. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1469-7610.2006.01701.x

12. Tomlinson M, Cooper P, Murray L. The Mother–Infant Relationship and Infant Attachment in a South African Peri-Urban Settlement. Child Development [Internet]. 2005 Sep 1 [cited 2022 Jan 16];76(5):1044–54. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1467-8624.2005.00896.x

13. Wrottesley S v., Pearson R, Prioreschi A. The headcam mother-infant interaction assessment tool: testing the feasibility and acceptability in Soweto, South Africa, using participatory engagement. Pilot and Feasibility Studies. 2021 Dec 1;7(1).

14. Bigelow AE, Power M, McQuaid N, Ward A, Rochat P. Distinguishing mother-infant interaction from stranger-infant interaction at 2, 4, and 6 months of age. Infancy. 2008 Mar;13(2):158–71.

15. Tickle-Degnen L, Rosenthal R. The Nature of Rapport and Its Nonverbal Correlates. http://dx.doi.org/101207/s15327965pli0104_1 [Internet]. 2009 Jan 1 [cited 2022 Jan 17];1(4):285–93. Available from: https://www.tandfonline.com/doi/abs/10.1207/s15327965pli0104_1

16. Wrottesley S v., Pearson R, Prioreschi A. The headcam mother-infant interaction assessment tool: testing the feasibility and acceptability in Soweto, South Africa, using participatory engagement. Pilot and Feasibility Studies. 2021 Dec 1;7(1).

17. SocialBaby_May04_English.

18. Lagercrantz H. Infant brain development : formation of the mind and the emergence of consciousness.

19. Vally Z, Murray L, Tomlinson M, Cooper PJ. The impact of dialogic book-sharing training on infant language and attention: a randomized controlled trial in a deprived South African community. Journal of child psychology and psychiatry, and allied disciplines [Internet]. 2015 Aug 1 [cited 2022 Jan 17];56(8):865–73. Available from: https://pubmed.ncbi.nlm.nih.gov/25399699/

20. Altmann U. Synchronisation nonverbalen Verhaltens. Synchronisation nonverbalen Verhaltens. Springer Fachmedien Wiesbaden; 2013.

21. Tonti M, Gelo OCG. Rate of speech and emotional-cognitive regulation in the psychotherapeutic process: A pilot study. Research in Psychotherapy: Psychopathology, Process and Outcome. 2016;19(2):102–12.

22. Egmose I, Varni G, Cordes K, Smith-Nielsen J, Væver MS, Køppe S, et al. Relations between automatically extracted motion features and the quality of mother-infant interactions at 4 and 13 months. Frontiers in Psychology. 2017 Dec 13;8(DEC).

23. Ramseyer F, Tschacher W. Nonverbal synchrony of head- and body-movement in psychotherapy: Different signals have different associations with outcome. Frontiers in Psychology. 2014;5(AUG).

24. Kleinsmith A, Bianchi-Berthouze N. Affective Body Expression Perception and Recognition: A Survey.

25. Beebe B. Mother-infant research informs mother-infant treatment. Clinical Social Work Journal. 2010 Feb;38(1):17–36.

26. Bruijns BA, Truelove S, Johnson AM, Gilliland J, Tucker P. Infants' and toddlers' physical activity and sedentary time as measured by accelerometry: A systematic review and meta-analysis. Vol. 17, International Journal of Behavioral Nutrition and Physical Activity. BioMed Central Ltd.; 2020.

27. Why are 24-hour movement guidelines important for children from birth to 5 years? [Internet]. Available from: www.laureus.co.za.

28. Draper CE, Tomaz SA, Biersteker L, Cook CJ, Couper J, de Milander M, et al. The South African 24-hour movement guidelines for birth to 5 years: An integration of physical activity, sitting behavior, screen time, and sleep. Journal of Physical Activity and Health. 2020;17(1):109–19.

29. Timmons BW, Leblanc AG, Carson V, Gorber SC, Dillman C, Janssen I, et al. Systematic review of physical activity and health in the early years (aged 0-4 years). Applied Physiology, Nutrition and Metabolism. 2012 Aug;37(4):773–92.

30. Müller I, Walter C, du Randt R, Aerts A, Adams L, Degen J, et al. Association between physical activity, cardiorespiratory fitness and clustered cardiovascular risk in South African children from disadvantaged communities: results from a cross-sectional study. BMJ Open Sport & Exercise Medicine [Internet]. 2020 Sep 1 [cited 2022 Feb 18];6(1):e000823. Available from: https://bmjopensem.bmj.com/content/6/1/e000823

31. Carson V, Lee EY, Hewitt L, Jennings C, Hunter S, Kuzik N, et al. Systematic review of the relationships between physical activity and health indicators in the early years (0-4 years). BMC Public Health. 2017 Nov 20;17.

32. Chaput JP, Carson V, Gray CE, Tremblay MS. Importance of all movement behaviors in a 24 hour period for overall health. International Journal of Environmental Research and Public Health. 2014 Dec 4;11(12):12575–81.

33. Prioreschi A, Brage S, Westgate K, Micklesfield LK. Describing the diurnal relationships between objectively measured mother and infant physical activity. International Journal of Behavioral Nutrition and Physical Activity [Internet]. 2018 Jun 25 [cited 2022 Feb 18];15(1):1–10. Available from: https://ijbnpa.biomedcentral.com/articles/10.1186/s12966-018-0692-2

34. Ragni B, Boldrini F, Buonomo I, Benevene P, Grimaldi Capitello T, Berenguer C, et al. Intervention programs to promote the quality of caregiver–child interactions in childcare: A systematic literature review. Vol. 18, International Journal of Environmental Research and Public Health. MDPI; 2021.

35. Delaherche E, Chetouani M, Mahdhaoui A, Saint-Georges C, Viaux S, Cohen D. Interpersonal Synchrony : A Survey Of Evaluation Methods Across Disciplines.

36. Albinali F, Goodwin MS, Intille SS. Recognizing stereotypical motor movements in the laboratory and classroom: A case study with children on the autism spectrum. ACM International Conference Proceeding Series. 2009;71–80.

37. Bernieri FJ, Reznick JS, Rosenthal R. Synchrony, Pseudosynchrony, and Dissynchrony: Measuring the Entrainment Process in Mother-Infant Interactions. Journal of Personality and Social Psychology [Internet]. 1988 [cited 2022 Jan 8];54(2):243–53. Available from: /doiLanding?doi=10.1037%2F0022-3514.54.2.243

38. Stel M, van Dijk E, Olivier E. You want to know the truth? Then don't mimic! Psychological science [Internet]. 2009 Jun [cited 2022 Jan 30];20(6):693–9. Available from: https://pubmed.ncbi.nlm.nih.gov/19422628/

39. Lotzin A, Lu X, Kriston L, Schiborr J, Musal T, Romer G, et al. Observational Tools for Measuring Parent–Infant Interaction: A Systematic Review. Clinical Child and Family Psychology Review. 2015 Jun 15;18(2):99–132.

40. div-class-title-measurement-of.

41. Mahoney G, Spiker D, Boyce G. Clinical Assessments of Parent-Child Interaction: Are Professionals Ready To Implement This Practice? http://dx.doi.org/101177/027112149601600105 [Internet]. 2016 Aug 17 [cited 2022 Feb 10];16(1):26–50. Available from: https://journals.sagepub.com/doi/10.1177/027112149601600105

42. Early Head Start National Resource Center [Internet]. Available from: http://www.

43. Margolin G, Oliver PH, Gordis EB, O'Hearn HG, Medina AM, Ghosh CM, et al. The Nuts and Bolts of Behavioral Observation of Marital and Family Interaction. Clinical Child and Family Psychology Review 1998 1:4 [Internet]. 1998 [cited 2022 Feb 10];1(4):195–213. Available from: https://link.springer.com/article/10.1023/A:1022608117322

44. Lee R, Skinner A, Bornstein MH, Radford AN, Campbell A, Graham K, et al. Through babies' eyes: Practical and theoretical considerations of using wearable technology to measure parent-infant behaviour from the mothers' and infants' view points. Infant behavior & development [Internet]. 2017 May 1 [cited 2022 Feb 9];47:62–71. Available from: https://pubmed.ncbi.nlm.nih.gov/28347907/

45. Prioreschi A, Pearson R, Richter L, Bennin F, Theunissen H, Cantrell SJ, et al. The PLAY study trialtrail protocol: an intervention to improve infant growth and development by encouraging responsive caregiving through interactive play [Internet]. Available from: https://www.who.int/clinical-trials-

46. Skender S, Ose J, Chang-Claude J, Paskow M, Brühmann B, Siegel EM, et al. Accelerometry and physical activity questionnaires - A systematic review. BMC Public Health [Internet]. 2016 Jun 16 [cited 2022 Feb 9];16(1):1–10. Available from: https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-016-3172-0

47. Ferrari P, Friedenreich C, Matthews CE. The role of measurement error in estimating levels of physical activity. American journal of epidemiology [Internet]. 2007 Oct [cited 2022 Feb 10];166(7):832–40. Available from: https://pubmed.ncbi.nlm.nih.gov/17670910/

48. Neilson HK, Robson PJ, Friedenreich CM, Csizmadi I. Estimating activity energy expenditure: how valid are physical activity questionnaires? The American journal of clinical nutrition [Internet]. 2008 Jan 2 [cited 2022 Feb 10];87(2):279–91. Available from: https://pubmed.ncbi.nlm.nih.gov/18258615/

49. Ward JA, Hunter K, Richardson D, Orgs G. Sensing interpersonal synchrony between actors and autistic children in theatre using wrist-worn accelerometers [Internet]. Vol. 9, ACM Trans. Graph. 2010. Available from: https://doi.org/0000001.0000001_2

50. Troiano RP. A timely meeting: objective measurement of physical activity. Medicine and science in sports and exercise [Internet]. 2005 Nov [cited 2022 Feb 10];37(11 Suppl). Available from: https://pubmed.ncbi.nlm.nih.gov/16294111/

51. Yang CC, Hsu YL. A review of accelerometry-based wearable motion detectors for physical activity monitoring. Vol. 10, Sensors. 2010. p. 7772–88.

52. Taffoni F, Rivera D, Camera A la, Nicolò A, Velasco JR, Massaroni C. A wearable system for real-time continuous monitoring of physical activity. Journal of Healthcare Engineering. 2018;2018.

53. Box GEP, Cox ; D R. An Analysis of Transformations. Vol. 26, Journal of the Royal Statistical Society. Series B (Methodological). 1964.

54. Ramseyer F, Tschacher W. Nonverbal Synchrony or Random Coincidence? How to Tell the Difference. Vol. 5967, Training School. 2009.

55. Schoenherr D, Paulick J, Strauss BM, Deisenhofer AK, Schwartz B, Rubel JA, et al. Identification of movement synchrony: Validation of windowed cross-lagged correlation and -regression with peak-picking algorithm. PLoS ONE. 2019 Feb 1;14(2).

56. Altmann U. Investigation of movement synchrony using windowed cross-lagged regression. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). 2011;6800 LNCS:335–45.

57. Boker SM, Xu M, Rotondo JL, King K. Windowed cross-correlation and peak picking for the analysis of variability in the association between behavioral time series. Psychological methods [Internet]. 2002 [cited 2022 Jan 8];7(3):338–55. Available from: https://pubmed.ncbi.nlm.nih.gov/12243305/

58. Ramseyer F, Tschacher W. Nonverbal synchrony in psychotherapy: coordinated body movement reflects relationship quality and outcome. Journal of consulting and clinical psychology [Internet].

2011 Jun [cited 2022 Jan 8];79(3):284–95. Available from: https://pubmed.ncbi.nlm.nih.gov/21639608/

59. Schoenherr D, Paulick J, Worrack S, Strauss BM, Rubel JA, Schwartz B, et al. Quantification of nonverbal synchrony using linear time series analysis methods: Lack of convergent validity and evidence for facets of synchrony. Behavior Research Methods [Internet]. 2019 Feb 15 [cited 2022 Jan 8];51(1):361–83. Available from: https://link.springer.com/article/10.3758/s13428-018-1139-z

60. Rowlands A v., Mirkes EM, Yates T, Clemes S, Davies M, Khunti K, et al. Accelerometer-assessed Physical Activity in Epidemiology. Medicine & Science in Sports & Exercise [Internet]. 2018 [cited 2022 Jan 27];50(2):257–65. Available from: https://www.academia.edu/48679568/Accelerometer_assessed_Physical_Activity_in_Epidemiology

61. ACFrOgDhQLILk8gy.

62. Kunze K, Lukowicz P, Junker H, Tröster G. Where am I: Recognizing On-Body Positions of Wearable Sensors. [cited 2022 Jan 28]; Available from: www.wearable.ethz.ch

63. Gao F, Philip Miller J, Xiong C, Luo J, Beiser JA, Chen L, et al. Estimating correlation between multivariate longitudinal data in the presence of heterogeneity. BMC Medical Research Methodology. 2017 Aug 17;17(1).

64. Prioreschi A, Brage S, Westgate K, Micklesfield LK. Describing the diurnal relationships between objectively measured mother and infant physical activity. IJBNPA. 2018:15;59

APPENDICES

ANNEX 1

Table 1 **Summary table for data processing and analysis methods and variables to be assessed**

Input	Data Processing	Output	Analysis	Variables	Outcome
Objective 1					
Headcam Data	Coding of behaviors (second by second) Pairs of video sequences with/without synchrony (behaviors time series) logarithm transformation (control errors by non-stationarity) Determine bandwith & cut-off points (75/125 frames	Pairs of behaviors time series	Window cross-lagged correlation (WCLC-frequency) and window cross-lagged regression (WCLR) R^2 Matrix Peak-picking algorithm (analyze matrix)	Time of synchrony Average strength synchrony Frequency of synchrony Maximum synchrony Directionality	Synchrony time series - Synchrony of touch - Synchrony of gaze - Synchrony of play

	& R^2 of 0.25) ↓ Extract frames showing synchrony ↓ ↓ ↓		Global synchrony score		
Objective 2					
Accelerometry data		Acceleration signals (time series)	Wavelet analysis & time-based cross-correlation Cross-wavelet transform temporal-frequency response	Time of synchrony Average acceleration of synchrony Frequency of synchrony Intensity/degree of synchrony	Synchrony time series - Synchrony of movement
Objective 3					

Headcam Synchrony time series		Mother-infant synchrony time series (each behavior i.e. (touch, hand movement and gaze treated separately)	Mixed Effect Regression (REM)	Percentage synchrony Time of synchrony Intensity/degree of synchrony **Potential Predictors;** age, education, ethnicity, socio-economic status, marital status, first time mom, pre-term/full term baby, mother/infant's health, mothers depression/anxiety/stress.	Longitudinal behavioural synchrony patterns
Accelerometry synchrony time series		Movement synchrony time series (mother and infant independently)			Longitudinal movement synchrony patterns

**These are variables currently considered for analyses and may be modified, removed or added when necessary*

ANNEX 2 PhD TIMELINES

	YEAR 1				YEAR 2				YEAR 3				YEAR 4			
Activities	**July - Sept**	**Oct - Dec**	**Jan-March**	**April - June**	**July - Sept**	**Oct - Dec**	**Jan-March**	**April - June**	**July - Sept**	**Oct - Dec**	**Jan-March**	**April - June**	**July - Sept**	**Oct - Dec**	**Jan-March**	**April - June**
Registration																
Protocol																
Coding Data																
Paper 2 Data Analysis																
Paper 1 writing																
Review																
Publishing																
Recruitment of Participants																
Data Collection																
Paper 2 Data Analysis																
Paper 2 writing																
Review																
Publishing																

Paper 3 Data Collection																
Paper 3 Data Analysis																
Paper 3 writing																
Review																
Publishing																
Graduation																

ANNEX 3 Table 2 PhD Budget

Items	**Quantity**	**Amount**	**Status**
Equipment:			
- Laptop	1 unit	R25285.05	Funded
- Tablets and accessories	2 units	R5943.40	Funded
- Accelerometers	20		Funded
- Headcams	20		Funded
Softwares:			
- RedCap	3 years		Free from Wits
- Observer XT	3 years		Funded

- Stata	3 years		Free from Wits
Human Resource			
- Transport	24 months	R7000/monthly car rental	Funded
Participants costs:			
- Reimbursement	6 visits*108	R200/dyad	Funded
- Refreshments (snacks)	6 visits*108	R50/dyad	Funded
Researcher's School fees			
- Tuition and international costs	3 years	R22280	Funded
Living costs			
- Accommodation & Subsistence costs	3 years	R100,000.00/annum	Funded
- Medical Aid	3 years	R6000/annum	Not funded
- Visa	1	R500	Not funded
- Trainings & Conferences	1 per year		Not funded

P
lay Love And You

CONTACT DETAILS

Cell number 1: Cell number 2: _____

Other contact number: _____

Home address: _____

Contact details of a relative or a friend who will **always** know where you live (different to information on contact sheet):

Name:_____ Landline number Work number: _____

Address: _____Relationship:_____Cell number: _____

Other: _____

DATA COLLECTION TABLE

Timepoints	0 months	4 months	8 months	12 months
Infant Factors				
Age	X			X
Infant gestation age (Pre-term/full term baby)	X			
Birth Order	X			
Weight	X			X

Height	X			X
Infant's general health	X			X
Accelerometry		X	X	X
Headcam		X	X	X
Mother Factors				
Age	X			X
Weight	X			X
Height	X			X
Ethnicity	X			
Marital status,	X			X
Socio-economic status,	X			X
Education	X			X
Employment	X			X
Mental health	X			X
Mother's general health	X			X
Accelerometry		X	X	X
Headcam		X	X	X

SCREENING QUESTIONS

Are you older than 18?	(0) No (1) Yes	If No, EXCLUDE
Do you currently live in Soweto?	(0) No (1) Yes	If No, EXCLUDE
Are you planning on staying on Soweto for the next two years?	(0) No (1) Yes (7) Don't know	If No, EXCLUDE
Are you going to be the primary caregiver for your baby?	(0) No (1) Yes (7) Don't know	If No, EXCLUDE
Did you deliver a single baby (not twins)?	(0) No (1) Yes	If No, EXCLUDE
Is APGAR score >= 7?	(0) No (1) Yes (7) Don't know	If No, EXCLUDE
Was baby born at term?	(0) No (1) Yes (7) Don't know	If No, EXCLUDE

Has a doctor ever told you or other health professional that you have type 1 diabetes?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable	If yes, EXCLUDE
If yes, are you currently taking medication for your diabetes, either pills or insulin?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable	If yes, EXCLUDE
Have you ever been told by a doctor or other health professional that you have epilepsy?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable	If yes, EXCLUDE
If yes, are you currently taking medication for your epilepsy?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable	If yes, EXCLUDE

If screening criteria are passed – move on to the rest of the questions

A. SOCIO-DEMOGRAPHICS

Mother

Name:_____

Date of birth (calculate Age):_____

Ethnicity:_____

Marital Status:_____

Infant

Date of birth (calculate Age):_____

Birth order (first time mother or not):_____

Infant gestation age (from birth records): _____

Infant birth weight (from birth records): _____

Infant birth length (from birth records): _____

Mode of delivery (vaginal vs caesarean): _____

Infant Sex:_____

B. INFANT VARIABLES

Measurements

Length (cm):

			.	
			.	

Weight (kg):

			.	
			.	

Operator: | **Date:**

QUALITY CHECKED BY: | **DATE:**

C. Accelerometry INFANT	
Serial number	
Date issued	
Date returned	

D. Headcam INFANT	
Serial number	
Date issued	
Date returned	

E. MATERNAL VARIABLES

Measurements

Height (cm):

			.	
			.	

Weight (kg):

			.	
			.	

Operator: | **Date:**

QUALITY CHECKED BY: | **DATE:**

F. SOCIOECONOMIC STATUS:

Which of the following do you have in your current home (place where you spent most nights in the past three months)? It does not matter who owns/pays for these things. (*Answer all questions*)

	Item	**In current home**	
		Yes	**No**
a.	Electricity		
b.	Fridge		
c.	Stove		
d.	Vacuum cleaner		
e.	Washing machine		
f.	MNet/DSTV/Satellite		
g.	DVD Player		
h.	Motorcar		
i.	Television		
j.	Telephone (landline)		
k.	Cell phone		

l.	Computer/laptop		
m.	Internet access		

- How many people currently (in the last 3 months) live in the home with you (spend most nights in the home per week)?
- How many rooms for sleeping are there in your current home (include outside rooms/cottages)?
- How many of the people currently living in your home are children (<18 years)?

G. EDUCATION

The first few questions ask about your experiences with schooling and education.

Question	Responses
Do you have a matric?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable
If no, what is the last grade you successfully completed?	(1) Grade 5 or lower (2) Grade 6 (3) Grade 7 (4) Grade 8 (5) Grade 9 (6) Grade 10 (7) Grade 11 (77) Don't know (88) Refuse to answer (99) Not applicable
Since leaving formal full-time schooling, have you **ever** done any training or been registered with any training institution (including any training through employment and correspondence)?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable

V1.2_04/02/2022

Are you currently enrolled in a training institute?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable
Have you ever attended university or another post-matric college?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable
If yes, did you graduate?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable
If yes, what is the highest degree you have attained?	(1) Diploma (2) Bachelors (3 years) (3) Honors (4th year) (4) Masters (5) PhD
Are you currently enrolled in a university degree or college diploma program?	(0) No (1) Yes (7) Don't know (8) Refuse to answer (9) Not applicable
If yes, what is the level you are enrolled in?	(1) Diploma (2) Bachelors (3 years) (3) Honors (4th year) (4) Masters (5) PhD

H. OCCUPATION/ EMPLOYMENT

1. Have you **ever** had a job? By job we mean any work done to earn money or to gain skills. This includes casual/informal work & volunteer work.

Yes	No (Skip to Q3)

2. Do you currently have a job? By job we mean any work done to earn money or to gain skills. This includes casual/informal work & volunteer work.

Yes	No

3. Are you currently looking for a job?

Yes	No

4. If no, what is the main reason? (tick **one**)

Reason	**Tick one**	**Code**
I am at school / studying		1
I am too busy or don't have time		2
Family responsibilities (i.e. Pregnant or Looking after children/family/relatives)		3
I don't need money		4
I am not skilled or experienced enough/ my level of education is not high enough		5
It's too expensive to look		6
I am sick / disabled		7
Other (specify)		8

5. Have you been unemployed and seeking work for a month or more during the past 6 months?

18 February 2022

yes	no

I. MENTAL HEALTH

Antenatal Stress Questionnaire (16)

Sometimes one's life and that of one's close family goes through periods of being very stressful. I'd like to ask you some questions about any stresses you might have experienced in the last few months.

1. During the last 6 months have you or a member of your close family been in real danger of being killed, in one of the following ways?

1 = By criminals
2 = By police, army or other 'officials'
3 = During political activities
4 = This has not happened at all

2. During the last 6 months did you witness a violent crime (e.g. murder, robbery, assault, rape)?

Yes = 1	No = 2

3. During the last 6 months have you found that you are in so much debt that you don't know how you will repay the money?

Yes = 1	No = 2

4. During the last 6 months have you or your close family ever had too little money for basics, such as food, rent, and clothes?

Yes = 1	No = 2

5. Have you or one of your close family not been able to find a job for more than 6 months?

Yes = 1	No = 2

6. During the last 6 months have you or anyone in your close family been seriously ill?

Yes = 1	No = 2

7. During the last 6 months did any member of your close family die?

Yes = 1	No = 2

8. Is there anyone in your close family with a serious disability (e.g. epilepsy, mental retardation, deafness, blindness, mental illness)

Yes = 1	No = 2

9. Is there anyone in your close family who has a problem with drugs or alcohol?

Yes = 1	No = 2

10. During the last 6 months have you had a break-up with your husband or partner?

Yes = 1	No = 2

11. During the last 6 months has your husband or partner hit or beaten you?

Yes = 1	No = 2

12. During the last 6 months have you had any serious fight or alienation from members of your family or your close neighbours?

Yes = 1	No = 2

13. During the last 6 months have you or any member of your close family been arrested, had to go to court or consulted a lawyer on a non-routine matter?

Yes = 1	No = 2

14. During the last 6 months have you given help (money, accommodation etc.) to close family or friends in need?

Yes = 1	No = 2

15. During the last 6 months have you been separated unwillingly from any of your children

(excluding holidays)?

Yes = 1	No = 2

16. During the last 6 months have you experienced any problems with your other children (such as schools closing, failure at school, problem behaviour, drugs, etc.)?

Yes = 1	No = 2	No other child = 3

If YES, specify problem _____

J. GENERAL HEALTH

Questions	Responses
Do you think you get ill more often than other people?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have high blood pressure?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
If yes, are you currently taking blood pressure medication?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have high cholesterol?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
If yes, are you currently taking a cholesterol lowering medication?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have asthma or wheeze?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
If yes, are you currently taking medication for your asthma?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have allergies?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable

If yes, are you currently taking medication for your allergies?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have tuberculosis?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
If yes, are you currently taking medication for tuberculosis?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
Have you ever been told by a doctor or other health professional that you have HIV?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable
If yes, are you currently taking medication for HIV?	(0) No (1) Yes (7) Don't know (8) Refuse (9) Not applicable

18 February 2022

K. Accelerometry MOTHER	
Serial number	
Date issued	
Date returned	

L. Headcam MOTHER	
Serial number	
Date issued	
Date returned	

Appendix 9: Protocol Approval Letter

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Private Bag 3 Wits, 2050
Fax: 027117172119
Tel: 02711 7172076

Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

12 May 2022
Person No: 1694184
PAG

Miss DN Maduna
416 Elton Avenue Ferndale
Randburg
2194
South Africa

Dear Miss Dumsile Maduna

Doctor of Philosophy: Approval of Title

We have pleasure in advising that your proposal entitled *Determining synchrony of mother-infant non-verbal and movement behaviors using first-person observation and accelerometer data* has been approved. Please note that any amendments to this title have to be endorsed by the Faculty's higher degrees committee and formally approved.

Yours sincerely

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

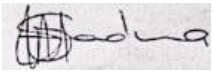
Appendix 10: Author Contributions and Acquiescence

Study 1 - Determining synchrony of mother-infant non-verbal behaviours using first-person observation

	Dumsile	**Alessandra**	**Lukhanyo**	**Ian**	**Rebecca**	**Ansuyah**
Coding of videos	x	x				
Data Collection	x	x				
Data processing and Statistical analysis	x					
Interpretation of data	x		x			
Drafted the Manuscript	x					
Editing the initial Manuscript versions	x		x	x		x
Editing and critiquing the Manuscript for intellectual content	x	x	x	x	x	x

I hereby certify that all co-authors have provided their consent for the inclusion of the paper in the thesis and that the co-authors accept the candidate's contribution to the paper as described in this Statement of Originality.

Candidate (Dumsile Maduna):



Supervisor (Lukhanyo Nyati)

Supervisor (Ian Nabney)

Appendix 11: Statistical Methods Applied

A1. Descriptive and Bivariate Analyses

Across all manuscripts, descriptive statistics formed the foundation for understanding the sample context. Frequencies and percentages were used to summarise categorical variables (e.g., maternal education, employment, infant sex), while medians and interquartile ranges (IQR) were used for skewed continuous data (e.g., infant age, household size).

Example:

In Manuscript 3, at 8 months postpartum, 76.2% of mothers were unemployed, and the median household size was 5 individuals (IQR = 4–6), providing a context for interpreting synchrony dynamics.

A2. Cross-Correlation Analysis

Cross-correlation was used to examine the lagged relationship between mother and infant movement signals recorded via accelerometry. This approach identifies whether one partner typically leads synchronised movement and by how many time steps.

Equation:

$$CCF(k) = E[(x_t - \mu_x)(y_{t+k} - \mu_y)] / (\sigma_x * \sigma_y)$$

Example:

In Manuscript 3, at 4 months, the mean best lag was –1.8 minutes, indicating maternal-led synchrony. At 8 months, this shifted to +1.6 minutes, suggesting infant-led synchrony.

A3. Linear Mixed-Effects Models (LMMs)

LMMs were employed to examine synchrony over time while accounting for repeated measures within mother-infant dyads. Random intercepts were specified to capture intra-dyad variation.

Equation:

$$Y_{ij} = \beta_0 + \beta_1 * X_{ij} + u_j + \varepsilon_{ij}$$

Example:

In Manuscript 3, LMMs revealed that maternal employment was associated with a lower synchrony score ($\beta = -0.131$, $p = 0.004$), even after accounting for timepoint, infant age, and relationship status.

A4. Vector Autoregressive Models (VAR)

VAR models were used to model the temporal dynamics of synchrony in dyads with longitudinal data.

Equation:

$$[X_t, Y_t]' = A1 * [X_{t-1}, Y_{t-1}]' + \varepsilon_t$$

Example:

At 4 months, VAR analysis showed stronger maternal-led movement dynamics ($\beta = 0.15$, $p = 0.02$), while at 8 months, infant-led influence increased ($\beta = 0.18$, $p < 0.01$).

A5. Actor-Partner Interdependence Model (APIM)

The APIM framework was employed to analyse the bidirectional influence between mothers and infants. It models how each partner's behaviour predicts both their own and their partner's outcomes.

Equation:

$$Y_i = b1 * X_i + b2 * X_j + e_i$$

Example:

In the 4-month headcam data (Manuscript 1), both mother and infant touch behaviour significantly predicted partner responses in matched behavioural pairs.

A6. Multilevel Linear Models (MLMs)

MLMs were used to analyse synchrony frequency, probability, and duration in coded video data (Manuscript 1), accounting for nested structures (e.g., behaviours within dyads).

Example:

Matched gaze behaviours increased over time ($\beta = 2.18$, 95% CI: [1.31, 3.06]), while unmatched combinations such as infant gaze and mother play also showed significant co-occurrence.