DESCRIBING THE ENDURANCE INDEX FOR AUTOMOTIVE WORKERS. A RETROSPECTIVE STUDY.

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Medicine in the field of Biokinetics.

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DECLARATION

I, Thulani Khumalo, declare that this research report is my own work. It is being submitted in partial fulfilment of the degree of Master of Science in Medicine in the field of Biokinetics at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

____(Signature of Candidate)

21 June 2018

DEDICATION

In Memory of my late father

James Muziwandile Khumalo

1948 - 2017

ABSTRACT

Introduction: The purpose of this study was to describe the Endurance Index of automotive workers to determine aerobic capacity to sustain an 8 hour shift. The Endurance Index is the product of Work (in Joules) performed by muscles divided by Peak Heart Rate (in beats per minute). Since there is no clear method for determining full work tolerance (8 hour sustenance) for job specific endurance activities, a new scientific method is warranted.

Methods: This was a retrospective study and 44 jobs were randomly selected. In those jobs there was a sample of 101 automotive workers (n = 94 males and n = 6 females). From the 44 jobs, there were 220 endurance activities/tests and peak heart rates and total work performed by muscles was described then these variables were used to calculate Endurance Index which was described for each endurance activity.

Results: Peak HR had a mean of 139.85 ±20.96 (100 – 184bpm), total work had a mean of 9224.73 ±5826.04 (897.20 – 33 055) and EI had a mean of 67.14 ±42.88 (8 – 243.10). Total work and EI had significant ($p < 0.00$) and good positive correlation ($r = 0.97$). Peak HR and EI had significant ($p < 0.01$) and poor negative correlation ($r = -0.18$).

Conclusion: The scientific rationale for using Endurance Index as an indicator for aerobic capacity is that the better conditioned an individual the more work that can be produced at lower relative heart rates compared to individuals who are poorly conditioned. So the more the work value and the lower the heart rate value, the better the index. In this study it was found that Endurance index is a good indicator of aerobic capacity since a positive correlation was found between total work and Endurance index and a negative correlation was found between peak heart rate during an endurance activity and Endurance Index.

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Abbreviations

ATP: Adenosine Triphosphate

BF%: Body Fat%

BMI: Body Mass Index

Bpm: Beats per minute

d: distance

EI: Endurance Index

F: Force

FCE: Functional Capacity Evaluations

HR: Heart Rate

IGF-1: Insulin-like growth factor-1

KG: Kilograms

LV: Left Ventricle

NAD: Nicotinamide adenine dinucleotide

NADH: Nicotinamide adenine dinucleotide hydride

RPE: Rate of Perceived Exertion

RV: Right Ventricle

TCA: Tricarboxylic acid

W: Total Work

CHAPTER ONE

1. INTRODUCTION

Functional Capacity Evaluations (FCE) are standardised and systematic performance tests administered to determine functional abilities, readiness to return to work or the need for modified work duties (1). Functional Capacity Evaluations include a series of tests/assessments which are used to measure if an individual has the physical or functional abilities to meet the requirements of a specific job (2). Insurers and employers are starting to rely more heavily on FCEs to make decisions with regards to workers (2). Functional Capacity Evaluations allow a comparison between a workers' physical/demonstrated ability and the physical requirements of their specific occupation so they are now commonly used to make decisions (1). Functional Capacity Evaluations can be used to: identify a worker's current injuries or restrictions in movement for appropriate management; determine a worker's ability to safely meet the inherent requirements of the job placement; establish a worker's baseline for health monitoring and to identify the value of wellness and conditioning programs and the effectiveness of rehabilitation programs (3). Functional Capacity Evaluations assist in the pre-employment screening/evaluation and they facilitate the reasoning process for clinicians (4). In rehabilitation, FCEs can assist in making a diagnosis, making recommendations regarding a worker's ability to work, planning and constructing appropriate rehabilitation programmes, and evaluating the efficacy of prescribed programmes (4).

Although FCEs are reliable tests for determining if an individual has the strength requirements of a job, they still lack the ability to predict if an individual can sustain 8 hour work / a full shift. Theodore *et al.* mentioned in a critical review that the challenge with FCEs is that there are currently no scientific methods to predict 8 hour work tolerance (5). In addition, King *et al.* (2) found that there is little reference in the literature for the inclusion of fitness evaluations in FCEs. In the critical review by King *et al.* (2) it was also mentioned that fitness assessments are usually conducted as “stand-alone” evaluations rather than part of an FCE.

Cardiovascular fitness/endurance is a good indicator for determining aerobic capacity and one of the methods for assessing cardiovascular endurance is using submaximal protocols which have predetermined termination points based on a percentage of the client’s estimated heart rate (2). The main barriers to progress in work physiology are a lack of understanding of the inherent differences between exercise testing and work physiology testing (5). Theodore *et al*. pointed out the need for work specific testing to predict prolonged work related to physical exertion which is independent of exercise fitness tests (5). A number of researchers endorse heart rate as the primary measurement to estimate full work tolerance (5). Heart rate can be easily measured without interfering with the assessment in progress (5).

Increased cardiovascular fitness / endurance is associated with lower relative HR at the same work load compared to unfit or sedentary individuals (6). There are a number of mechanisms for this and Dikhuth *et al.* (6) mentioned that chronic endurance training increases aerobic capacity which results in improved cardiocirculatory work economy, maximum performance, and enhanced oxygen uptake. Carrick *et al*. (7) found that endurance activities were correlated with improved heart rate control. Favourable effects on heart rate control during and after work or physical activity result from higher frequencies of lifelong physical activity (7). The heart rate of endurance-trained subjects / those that have adapted to endurance activities is lower than in untrained individuals on a sub-maximal level, despite a comparable cardiac output (6). There are favourable effects on aerobic exercise / work capacity which result from years of physical activity (8).

Changes in skeletal muscle tissue also play a role in aerobic capacity and Dikhuth *et al.* (6) explained that regular exercise / work leads to adaptations in skeletal muscles, and an increase work-related sympathetic activity that occurs later in endurance trained athletes. Izquierdo *et al.* (9) also found that endurance trained athletes have greater maximal aerobic power and oxidative capacity. The increased maximal aerobic power and work is because of mitochondrial biogenesis, increases in capillary density and enzymes leading to enhanced skeletal muscle oxygen utilisation (10). Individuals who can cope with more work show smaller disturbances in blood homeostasis, as they have lower post exercise blood lactate concentrations resulting in delayed fatigue (11). The ability of muscle to regulate H+ and lactate homeostasis during work/exercise has an important role in delaying fatigue (11). Hoyt (12) proposed that a decrease in lactate levels may account for an ability to perform more work at the same relative intensity. Individuals who have adapted to endurance type activities have skeletal muscle adaptations that modify their muscle metabolism resulting in an improved work capacity and physical performance (12).

Izquierdo and colleagues showed in their study that endurance trained athletes could perform more workload at lower heart rates compared to strength trained and sedentary individuals (9). Trappe and colleagues found that the cardiovascular and skeletal muscle profiles of active individuals was approximately double compared with sedentary individuals (13).

The determination of an individual to handle loads repetitively then requires methods that use or combine both the measurements of the weight lifted and heart rate (2). Therefore, this study will address the gap of most FCE protocols, by proposing a new method of predicting endurance capabilities of individuals. The new method is based on the hypothesis that fitter individuals that are adapted to a task will produce more work (in joules) at lower relative heart rates (6, 7, 9, 13). This relationship is shown in the calculation **W/HR** (where W = Work and HR = Heart Rate).

The product of **W/HR** is referred to as Endurance Index (EI) and is a good indicator of aerobic capability since more work will be achieved at relative lower HR by fitter individuals (6, 7, 9, 13). The greater the difference the better the index because as discussed previously fitter individuals will perform greater workloads but at lower heart rate values (6, 7, 9, 13).

Assessing EI is important in order to predict if workers returning to work from injury or sickness will be able to cope with the demands of the job, workers who are being migrated to other jobs can be assessed to see if they will cope with the demands of the job that they are moved to. It will also be possible to recommend to which jobs restricted workers can be moved to and pre-employments can be conducted to determine if the individual will meet the requirements and have a chance to “feel the job” before signing a contract.

1.1. Problem Statement

Functional Capacity Evaluations have numerous benefits for clinicians, employers, insurance companies and the employees that undergo them. Although the benefits are there, FCEs still lack the ability to predict if an individual can sustain work specific activities for an 8 hour work period. Introducing a method of predicting full shift work tolerance will make the FCE a complete tool that not only evaluates strength requirements but endurance capabilities which are specific for the demands of the job.

1.2. Research Aim

The aim of this study was to describe EI values for automotive workers.

1.3. Research Objectives

1.3.1. To describe HR readings during job-specific tasks in automotive workers.

1.3.2. To describe Work (in Joules) for each job-specific task in automotive workers.

1.3.3. To describe job-specific EI's by dividing Work by HR (**W/HR**) for each task.
1.3.4. To assess various factors associated with EI in automotive workers.

CHAPTER TWO

2. LITERATURE REVIEW

The purpose of this literature review will be to explain what FCEs are, their need and applications. It will also look at the scientific rationale of using the product of Work (W) divided by Heart Rate (HR) to determine an individual's job specific endurance levels and the physiology behind the calculation.

2.1. Functional Capacity Evaluations

Functional Capacity Evaluations are standardised batteries of performance based tests (14) and they quantify an individual's capacity to perform activities related to a job/occupation (15). They are a systematic assessment of an individual's ability to perform a series of tasks safely (16). The main purpose of an FCE is to objectively determine an individual's functional limitations and physical capacities to perform work (17) as they allow a comparison between a workers' physical/demonstrated ability and the physical requirements of their specific occupation so they are now commonly used to make decisions (14). For the purpose of this study tasks within FCEs contain an array of physical abilities/tests that are used to assess performance in strength, endurance, range of motion and the ability to sustain different body positions (15).

2.1.1. History of FCEs

It was always the responsibility/task of the physician to determine a worker's physical capability (17). The recommendations were however not detailed and the FCE process emerged due to the requirement of detailed physical capacity of a worker (17). Owen and Wilkins state that Leonard Matheson was the first to develop an FCE in response to a change in the California Workers' Compensation Law, which required physicians to state work capacities for workers involved in compensation (17). This led physicians to rely more on physical and occupational therapists to provide worker capability information (17).

From a South African perspective research on work assessment started in the 1960s by occupational therapy work practice services (18). In the 1970s and 1980s there was a concern from South African occupational therapists as their disabled clients struggled to get formal employment. Access College, was then established in 1983 for disabled individuals so that they can be empowered with business and life skills for them to be able to enter the open labour markets (18). South African occupational therapists offered a number of services which included work preparation programs (18). In 1996 there was an acceptance of the first democratic Constitution of South Africa which firmly rooted the right of people with disabilities to work in a society exclusive of discrimination (18). Guidelines for employers were given through the Labour Relations Act of 1995 as well as the Employment Equity Act of 1988 with regards to recruitment, selection, training, retention and placement of disabled employees (18).

Functional Capacity Evaluations showed to be an important instrument in assisting Human Resource managers, Occupational Health practitioners, medical practitioners, lawyers, employers, Insurers and pension fund administrators with regards to the physical capabilities of disabled employees (18). Functional Capacity Evaluations also played an important role even in fully abled employees

2.1.2. Importance of FCEs

Increased work demands and pressures of today have now increased the likelihood for workers to suffer one or more of a range of occupational related conditions, repetitive injuries and disorders (19). The centre for Disease Control report estimates that 47% of carpal tunnel syndromes are caused by occupation (20). Repetitive injuries can affect absenteeism, productivity levels (of individuals and business), and motivation levels of employees (19, 21). Schultz *et al.* stated that in Britain there was an estimated number of 538 000 people who worked between 2008/2009 and presented with repetitive strain injuries, this resulted in 7.3 million lost work days (19). Shultz *et al.* (19) also mentioned that the estimated costs from compensation claims were 215 billion dollars in the United States in 1995, 26 billion Canadian dollars in Canada in 1998 and 350 million New Zealand dollars annually in New Zealand. Bhattacharya (21) mentioned that musculoskeletal disorders may be caused by bodily reactions such as bending, climbing, crawling, reaching, twisting, overexertion, or repetition. Thus it is imperative that job specific test batteries are performed on workers so that those workers who do not meet the job demands can be identified so as to not expose them to possible injury.

Between 1992 and 2010, musculoskeletal disorders accounted for 29 – 35% of all occupational injuries in the United States of America (21). Shoulder and neck disorders have been reported in sitting assembly work, and it has been stated the manual lifting of loads is a risk factor for low back pain (20). Schierhout and colleagues studied musculoskeletal pain in the manufacturing industry in South Africa (food production, metal products, pharmaceutical processing and motor vehicle assembly) and they found that low back pain was associated with driving motor vehicles, prolonged sitting, whole body vibration and sudden, frequent or heavy lifting (20). Musculoskeletal and repetitive injuries affect the employer and employee negatively (19, 20, 21), they also affect the economy as they shorten the quality and duration of an employees work life (19). Functional Capacity Evaluations are thus crucial not only as they can identify individuals at risk but can also test individuals who are already affected if they are fit to return to their jobs without affecting production quality (as these tests are done in a lab environment) and the health of the associate as the basis of FCEs is safety (14, 16).

2.1.3. Usefulness of FCEs

Research on FCEs has evolved in the recent years and reliable protocols have been developed with certain aspects of validity confirmed (22). Physicians, employers, insurers and benefit adjudicators rely on FCEs with regards to giving objective answers in a variety of situations involving work (23). Functional Capacity Evaluations are used extensively in workers' compensation claims and other insurance systems to assist in making Return-To-Work (RTW) and case management decisions (1). Functional Capacity Evaluations are quite common and it is reported that in the USA over a half a million formal evaluations are conducted each year (23). Measurement of capacity specific to job demands is one of the most important aspects of an FCE (23). Performance-based tests are considered to be more accurate than self-reporting from workers about their abilities (24). Recommendations made from FCEs are used to determine the worker's physical capacity, employability, rehabilitation needs, and compensation awarded in common law personal injury cases settled by the courts (25).

2.2. Endurance Index (EI)

Individuals who have adapted to specific physical activities tend to have certain physiological changes that allow them to be able to cope with the energy requirements of those tasks. Fitter individuals / individuals who have adapted to work specific activities tend to perform more work at lower relative heart rates (6, 7, 9, 13). The relationship between these two variables can be expressed by using the following calculation **W/HR** (where W = Work and HR = Heart Rate). The product of **W/HR** is referred to as Endurance Index (EI) and is a good indicator of aerobic capability since more work will be achieved at relative lower HR by fitter individuals (6, 7, 9, 13). The following section will look at how more work is achieved at lower relative HR's.

2.2.1. Increased Work Output/Muscle work output

Muscles of humans that have adapted to prolonged work take longer to fatigue. There are a number of anatomical and physiologic mechanisms that make it possible for the muscle to perform work for longer periods and they are discussed below.

2.2.1.1. Muscle Fibre Types

Human muscle has a mixture of 3 different fibre types. There are fast-twitch white fibres (Type 2b), and they have a low respiratory capacity and a high myosin ATPase activity (26); then there are fast-twitch red fibres (Type 2a), and they have a moderately high respiratory capacity and a high glycogenolytic capacity and high myosin ATPase activity (26) and finally there are the slow twitch red fibres (Type 1), which have a high respiratory capacity, low glycogenolytic capacity, low myosin ATPase activity and are fatigue resistant (26).

To perform work over a long period of time the Type 1 muscle fibres tend to dominate as they have the highest respiratory capacity (26). Type 1 muscle fibres have more content and activity of oxidative enzymes that are involved in aerobic metabolism and are fatigue resistance (27). Type 1 muscle fibres also have the highest content of mitochondria which is why they have a high respiratory capacity (12, 26, 27). Majority of people tend to have roughly 50% of Type 1 and 50% of Type 2 fibres (27) but Izquierdo *et. al.* (9) found that individuals who can perform prolonged work have a higher percentage of Type 1 muscle fibres compared to those that cannot sustain work for longer periods. Prolonged work was also found to increase mitochondrial content in not only the Type 1 fibres but also in the Type 2a muscle fibres. Muscles with a higher content of Type 1 muscle fibres relative to Type 2a and Type 2b would be more fatigue resistant and therefore perform more work (12, 27).

2.2.1.2. Mitochondria

Mitochondrial content in skeletal muscle has a big impact on fuel usage and endurance capacity (10). The energy molecule Adenosine Triphosphate (ATP), is supplied predominantly by oxidative metabolism in the mitochondria during prolonged work (12). Decades of performing work / exercise stimulate mitochondrial biogenesis which results in a larger content of mitochondria in muscle (10, 12, 26, 27, 28). It was found that not only is there an increase in number of mitochondria in individuals that can sustain prolonged work but there is also an increase in mitochondrial size (12, 26, 27). Not only is there an increase in size and number of skeletal muscle mitochondria but there is also an alteration in the composition of mitochondria in people that have adapted to prolonged activity (26). It has been found that the mitochondria of muscle that has high respiratory capacity resembles heart mitochondria (12). The total protein content of the mitochondrial fraction was found to increase by about 60% due to prolonged work / exercise adaptation in a study by Holloszy and Coyle (27).

Increased mitochondrial content has found to be stimulated by muscle contraction (12, 27). The magnitude of the increase is a function of the total amount of contractile activity, which is increased by either performing more contractions in a given time period or by maintaining the same frequency of contraction for a longer period of time (27). Another probable mechanism by which mitochondrial content is increased in the muscle is that when work rates exceed the capacity of some of the muscle fibres for aerobic generation of energy in a non-adapted state results in an adaptation towards an increased ability to generate energy in an adapted state (27). Hoyt (12) stated that many of the newly formed mitochondria through prolonged work adaptation or exercise are located near the contractile proteins of muscle, this results in less diffusion space between ATP-synthesizing and ATP-utilisation sites thereby lessening the disturbance to homeostasis during periods of physical activity.

Holloszy and Booth mentioned that mitochondrial content of muscle that has adapted to endurance activities has up to twice as many mitochondrial cristae per gram as skeletal muscle that has no endurance adaptations (26).

2.2.1.3. Mitochondrial Enzymes

Endurance activities also result in adaptation of the mitochondrial enzymes resulting in an increase in respiratory capacity (10, 12, 26, 27). The enzymes that adapt to endurance activities are those in the Kreb's cycle, electron transport chain and those involved in fatty acid oxidation (12). Mitochondrial enzymes also play a role in decreasing the amount of lactate which can also cause fatigue at high levels (12, 26, 27). Lower concentrations of blood lactate during submaximal work for individuals who have adapted to prolonged activities are secondary to lower lactate levels in the working muscles due to mitochondrial enzymes (12). The increase in respiratory capacity is due to increases of enzyme levels which are responsible for the activation, transport, and β-oxidation of long-chain fatty acids; the enzymes that are involved in ketone oxidation, the enzymes of the tricarboxylic acid (TCA), enzymes of the citric acid cycle, components of the respiratory chain involved in NADH and succinate, and mitochondrial coupling factor (26, 27).

Some of the enzymes increase two-to-threefold in response to endurance adaptations and others have a 30%-60% increase and some don't increase at all (27). Holloszy and Booth found that a number of TCA cycle enzymes increased (26), and these include citrate synthase, aconitase, NAD-specific iscitrate dehydrogenase and succinate dehydrogenase increased twofold inresponse to endurance activities. A-ketoglutarate dehydrogenase and malate dehydrogenase increased about 30% and acetoacetyl-CoA thiolsae increased by about 50% (26). Holloszy and Coyle mentioned that succinate dehydrogenase, NADH-cytochrome c reductase, NADH dehydrogenase, NADH and cytochrome oxidase activity per gram muscle were found to have increased two-fold in response to an endurance program (27). Some mitochondrial enzymes do not increase at all in response to years of endurance activity when expressed per gram of muscle and due to the increase in mitochondrial protein they are decreased when expressed per milligram of mitochondrial protein. These enzymes include mitochondrial creatine kinase, adenylate kinase and α-glycerophosphate dehydrogenase (26). Years of endurance activities tend to have an impact in increasing the mitochondrial enzymes which are important for oxidative metabolism thereby improving fatigue resistance (12, 26, 27, 29).

2.2.1.4. Capillary Supply

Individuals who can perform more work or who have adapted to endurance activities tend to have a proliferation of capillary supply to the muscle and this also improves fatigue resistance in a number of ways (27). An increased capillary supply enhances the removal of metabolic by-products such as H+ and lactate from the muscle (26, 27). Muscles of individuals who can tolerate prolonged work appear to produce less lactate than those of people who don't have the same adaptations, even at comparable rates of glycogenolysis (26).

In a paper by Hoyt (12), he states that Holloszy and Coyle propose that decreased lactate accumulation may help account for 1) greater endurance at the same relative work intensity and 2) the ability of individuals who have adapted to endurance activities to work at higher relative intensities for a designated period of time. There are mechanisms within the muscle which transport lactate and H+ out of the muscle but increased perfusion contributes to increased release of by-products from the muscle to the blood (27).

An increase capillary supply also plays a major role with regards to supplying oxygen to the working muscle (26, 27).

2.2.1.5. Oxygen delivery and extraction

Muscles of people who can perform large amounts of total work by the muscles have the ability to extract more oxygen from the blood than those who perform lower levels of work (26, 27). Blood flow per gram of working muscle is lower in individuals who have adapted to endurance activities than those who have not at the same absolute work levels (26), working muscles of those who have adapted compensate for this by extracting more oxygen and this is reflected by a greater arteriovenous oxygen difference (26). Myoglobin also improves oxygen extraction and utilisation as it increases the rate of oxygen diffusion through a fluid layer and it also improves oxygen utilisation in the muscle by increasing the rate of oxygen diffusion through the cytoplasm to the mitochondria (26).Physical work and exercise also brings about vasodilation in the vascular bed of working muscle and this improves delivery of oxygen (28), and it seems that this effect is initiated by local factors, including substances released from skeletal muscle, endothelial cells and red blood cells (28).

2.2.1.6. Energy utilisation

Muscle of adapted individuals tend to derive a greater percentage of energy from fat oxidation during submaximal work (16) and there is also a sparring effect on glycogen stores (10, 12, 26, 27). They have an increased in systemic release of amino acids which is accompanied by a simultaneous increase of fat oxidation (10). There is decreased utilisation of carbohydrates by muscle which has adapted to prolonged work and this decrease is compensated for by a proportional increase in fat oxidation (26, 27). This increase is reflected by a lower respiratory exchange ratio at both the same absolute and the same relative intensities (27). There seems to be an increased expression of genes that stimulate fat catabolism and mitochondrial biogenesis which results in improved oxidative capacity in the adapted state (10). Capacity of tissue to oxidise fat also plays a role in how much work can be produced and rate of fatty acid oxidation is highest in the Type 1 muscle fibres than in Type 2a and Type 2b (26). Glycogen depletion has been shown to increase fatigue during prolonged work, so the glycogen-sparring effect of increased fat oxidation may play a big role in increasing work output (26, 27).

2.2.2. Mechanisms and physiology of why HR is lower

The cardiovascular system is responsible for delivering oxygen-rich blood from the lungs to the working muscles (30). There are certain anatomical and physiological changes that occur in the heart of individuals who have adapted to years of prolonged work. This section will describe these mechanisms and how they contribute to a lower heart rate for adapted individuals at same absolute intensities relative to those who do not have these adaptations.

2.2.2.1. Cardiac Structure

The cardiac structure re-models as an adaptation to years of physical activity so that more work can be achieved, there seems to be dilatation of all the cardiac chambers and an increase in maximal wall thickness (6, 31). The Left Ventricle (LV) has been shown to have increased hypertrophy and dilation (6, 30, 31), wall thickness increases and there is an increase in end-diastolic diameter resulting from an increased/dilated LV chamber (6, 30, 31). It has also been found that the LV tends to undergo eccentric hypertrophy in individuals adapted to prolonged work (30). The hypertrophy may be due to an increased volume load for years and this is associated with high plasma volumes (6). Wilson et al. (31) mentioned that absolute and indexed LV end-systolic volumes and stroke volumes were higher in people adapted to prolonged work than those who were not.

Prolonged work requires that both the LV and Right Ventricle (RV) eject a large quantity of blood (30). The RV tends to have larger cavities, thicker walls, end-diastolic and end-systolic volumes and increased stroke volumes in individuals who have adapted to prolonged work (6, 30, 31). Enlargement of the left atrium has also been shown specifically to people who perform endurance type of activities (30). Structural changes to the heart make it more efficient, so the heart does not to work as hard to deliver nutrients thereby lowering HR.

2.2.2.2. Cellular and molecular mechanisms for cardiac remodelling

Prolonged work causes increased myocardial mass and this is mainly due to cardiomyocyte hypertrophy and new cardiomyocte and capillary formation (31). Signals for cardiac hypertrophy can either be biomechanical (stretch sensitive) or can be through neurohumoral mechanisms (30). Biomechanical stress due to volume or pressure overload triggers cardiac hypertrophy by activating integrin cell adhesion complexes, myocardial sarcomeric Z-discs and transmembrane receptors (6, 30). It has been found that increased cardiac insulin-like growth factor-1 (IGF-1) expression and activation of the PI3K (p110α) pathway can be also responsible for cardiomyocyte hypertrophy (31). There are several neurohumoral agents which are up-regulated during physical activity and these can include catecholamines, natriuretic peptides and fibroblast growth factor which have also been implicated as possible mediators of ventricular hypertrophy (30).

2.2.2.3. Causes for a lower HR

Individuals who have adapted to prolonged work have lower submaximal HR relative to those that have not adapted (6, 7, 8, 9, 13, 30, 32). It seems that sympathetic drive to the heart is less when people have adapted to endurance/prolonged work (6, 32). There is also an increased parasympathetic tone (6, 7, 8, 32) a reduction in the sensitivity of the heart to catecholamines which may cause a reduced HR but there may also be intrinsic factors in the heart (32). There is also some evidence that implies that the adapted heart becomes less sensitive to sympathetic stimulation (32). Reduction in HR also has been attributed to intramuscular adaptations, as Winder et al. (32) mentioned reduced HR from arm training does not carry over to work performed by non-trained legs and this is also true for unilateral leg training.

CHAPTER THREE

3. METHODS

3.1. Study Design

The study design is a retrospective document review to describe the relationship between Work and HR as an indicator for endurance of work-specific physical demands. As this is a retrospective document review study, data was gathered for the 2014 and 2015 periods for analysis.

3.2. Sampling/Recruitment

There was 283 jobs/documents in total and for convenience of the study 15% (44 jobs) of the total job titles/documents were selected. Each job title was assigned a number from 1 to 44. The job titles were selected using a random number generator from www.random.org. Out of the 44 job titles, there was a total of 101 records of participants that were tested between the 2014 and 2015 time period from 44 job titles. Each participant's record/data set was assigned a number from 1 to 101. Recording the participant's identities as numbers ensured that anonymity was kept.

3.3. Study population

The study population consisted of 101 records of automotive workers (94 males and 6 females).

3.3.1. Inclusion criteria

Inclusion criteria included the following:

- Complete data set in document without any missing variables.

- Record must include physical activities that describe Work and HR values.

3.3.2. Exclusion criteria

- Incomplete records.
- Physical demands/activities that do not include Work and HR measures.

3.4. Measuring tools

Measuring tool for this study was a data collection sheet which collected related to the objectives of this study (refer to Appendix C).

3.5. Data collection

The following section will explain how the data was collected for this study by the researcher for this report.

3.5.1. Data Gathering

Ethics approval for the study was given by the University of the Witwatersrand's Human Research and Ethics Committee (Appendix E) and the company Human Resources Director (Appendix F). The record of each participant was retrieved from their medical files at the plant clinic. To do this their company identification number was identified and this number was used to locate the participant's file. The order of the file location was based on their randomly allocated number (1 – 101) as previously described. The data of the total work achieved during the job-specific endurance tasks was printed out and is in the medical file. The HR data was then retrieved from the Firstbeat software as this is where the data was stored in a HP laptop. Each participant was then assigned a number to ensure anonymity. Human Resource systems were used to determine how long each participant had worked for the organisation. Job title, total work achieved, baseline HR, peak HR, age, height, weight, BMI, endurance test type, resistance, number of years were all captured on the data collection sheet refer to Appendix D).

3.6. Data Analysis

Statistica v.13.2.92.1 was used in the analysis of the data. For the first 2 objectives descriptive analysis was done on variables. For the 3rd objective, the formula W/HR was used to calculate the EI values and descriptive analyses was done on the data. Pearson's correlations coefficient matrices were done to assess the various predictors of EI. For pearson's correlation categories if a value was near ±1 then that would be considered a perfect correlation; between ±0.7 and ±1 strong correlation; between ±0.3 and ±0.69 moderate correlation; ±0.1 and ±0.29 weak correlation and no correlation if value is 0.

CHAPTER FOUR

4. RESULTS

4.1. Study Population

The records consisted of 101 participant's data set (94 males and 6 females). The mean age was 33.15 years ±8.3 (21 – 58 years). Mean height was 1.72 m ±0.08 (1.52 – 1.90 m). Mean weight was 74 kg ±14.8 (49 – 127 kg). Mean BMI 25kg/m^2 ±4.37 (18.1 – 39.2 kg/m^2). Mean of working experience was 4.59 years ±5.18 (2 – 31 years).

4.2. Descriptive statistics for Peak HR, Total work and EI.

A total of 220 endurance tests (refer to Appendix F) was recorded out of the 44 jobs and each was grouped in the following 12 categories: 12 Ankle plantar flexion, 29 Bilateral above waist lift, 44 Bilateral below waist lift, 15 Bilateral pulling, 28 Bilateral pushing, 13 Bilateral pulling and pushing, 12 Steering, 3 Unilateral above waist lifting, 7 Unilateral below waist lifting, 34 Unilateral pulling, 9 Unilateral pulling and pushing, and 14 Unilateral push. Refer to appendix F for the detailed breakdown of the different endurance activities.

Refer to Appendix E for the peak HR, Total work and EI of each specific endurance activity recorded. Descriptive statistics for Peak HR, total work and EI are as shown in Table 1. Out of the 44 job titles, there were 220 endurance activities so this resulted in 220 peak HR's, total work values and EI's. Peak HR had a mean of 139.85 ±20.96 (100 – 184bpm), total work had a mean of 9224.73 ±5826.04 (897.20 – 33 055) and EI had a mean of 67.14 ±42.88 (8 – 243.10).

Table 1. Descriptive Statistics for peak HR, Total Work & EI

Variable	n	Mean ±SD	Minimum	Maximum
Peak HR	220	139.85 ±20.96	89	184
Total Work	220	9224.73 ±5826.04	897.20	33 055
EI	220	67.14 ±42.88	8	243.10

For the data on each of the endurance groups/categories for peak HR, work, EI and resistance please refer to Table 9 – 20. Peak HR mean was lowest for the unilateral below waist lift at 114 ±18 bpm and the minimum peak HR value was found in the unilateral below waist lift as well at 89bpm. The highest peak HR mean was for unilateral above waist lift at 167±15 bpm and the highest HR value was also for the unilateral above waist lift as well at 184bpm. Lowest mean for work was with unilateral below waist lift at 3583.7 ±1949.3 J and the lowest total work was with ankle plantar flexion at 897.2 J. Highest mean total work was with bilateral pulling at 15467.1 ±8588.3 J and the highest total work was also found in bilateral pulling at 33 055J. Highest mean for EI was with bilateral pulling at 113.9 ±62.9 and highest value was also with bilateral pulling at 243.10. Lowest mean resistance was with the ankle plantar flexion at 2.8 ±0.0 kg, and the lowest resistance was with the bilateral above waist lift activity at 2.2kg. Bilateral pulling had the highest value of mean resistance at 13.7 ±8.9kg and the highest resistance at 27.2kg.

Table 2. Descriptive Statistics for ankle plantar flexion

Variable	Ankle Plantar Flexion			
	N	Mean	Minimum	Maximum
Peak HR	12	132 ±21	94	160
Work	12	6930.5 ±6593.9	897.2	21786.5
EI	12	53.5 ±49.6	8.0	155.6
Resistance/Weight (KG)	12	2.8 ±0.0	2.8	2.8

Table 3. Descriptive Statistics for bilateral above waist lift

Variable	Bilateral above waist lift			
	N	Mean	Minimum	Maximum
Peak HR	29	145 ±16	114	174
Work	29	4767.2 ±1579.7	2375.5	8037.1
EI	29	33.7 ±13.5	15.2	70.5
Resistance/Weight (KG)	29	8.9 ±5.6	2.2	20.5

Table 4. Descriptive Statistics for bilateral below waist lift

Variable	Bilateral below waist lift			
	N	Mean	Minimum	Maximum
Peak HR	44	148 ±17	116	173
Work	44	7374.6 ±3509.9	2807.5	20470.1
EI	44	50.2 ±24.6	18.3	137.4
Resistance/Weight (KG)	44	10.6 ±4.2	2.6	15.8

Table 5. Descriptive Statistics for bilateral pulling

Variable	Bilateral Pulling			
	N	Mean	Minimum	Maximum
Peak HR	15	136 ±19	99	169
Work	15	15467.1 ±8588.3	4359.9	33055.0
EI	15	113.9 ±62.9	34.0	243.1
Resistance/Weight (KG)	15	13.7 ±8.9	3.4	27.2

Table 6. Descriptive Statistics for bilateral pushing

Variable	Bilateral pushing			
	N	Mean	Minimum	Maximum
Peak HR	28	134 ±22	90	172
Work	28	11507.0 ±5927.0	3773.3	22651.6
Resistance/Weight (KG)	28	10.8 ±7.4	3.3	25.0
EI	28	83.3 ±37.6	31.4	172.9

Table 7. Descriptive Statistics for bilateral pulling/pushing

Variable	Bilateral Pulling/Pushing			
	N	Mean	Minimum	Maximum
Peak HR	13	139 ±25	97	170
Work	13	14137.2 ±6785.4	4113.1	23490.1
EI	13	101.4 ±48.7	42.4	205.7
Resistance/Weight (KG)	13	6.5 ±1.5	4.2	8.8

Table 8. Descriptive Statistics for steering

Variable	Steering			
	N	Mean	Minimum	Maximum
Peak HR	12	157 ±13	125	168
Work	12	7552.4 ±4320.1	4061.2	17364.5
EI	12	49.5 ±30.4	26.2	115.0
Resistance/Weight (KG)	12	3.6 ±0.0	3.6	3.6

Table 9. Descriptive Statistics for unilateral above wait lift

Variable	Unilateral above waist lift			
	N	Mean	Minimum	Maximum
Peak HR	3	167 ±15	155	184
Work	3	5155.8 ±3962.9	1287.8	9207.2
EI	3	31.5 ±26.0	8.0	59.4
Resistance/Weight (KG)	3	4.3 ±0.0	4.3	4.3

Table 10. Descriptive Statistics for unilateral below waist lift

Variable	Unilateral below waist lift			
	N	Mean	Minimum	Maximum
Peak HR	7	114 ±18	89	149
Work	7	3583.7 ±1949.3	1569.4	6779.2
EI	7	33.3 ±21.0	12.5	64.0
Resistance/Weight (KG)	7	4.0 ±1.8	2.0	5.8

Table 11. Descriptive Statistics for unilateral pulling

Variable	Unilateral Pulling			
	N	Mean	Minimum	Maximum
Peak HR	34	137 ±19	107	165
Work	34	11593.8 ±5149.6	4499.9	24824.2
EI	34	87.4 ±42.3	30.6	203.4
Resistance/Weight (KG)	34	10.0 ±6.1	2.6	22.0

Table 12. Descriptive Statistics for unilateral pushing/pulling

Variable	Unilateral Pulling/Pushing			
	N	Mean	Minimum	Maximum
Peak HR	9	130 ±24	100	165
Work	9	9425.5 ±3487.8	3619.0	13520.0
EI	9	71.8 ±22.8	32.0	105.3
Resistance/Weight (KG)	9	5.8 ±0.9	4.2	6.2

Table 13. Descriptive Statistics for unilateral pushing

Variable	Unilateral Pushing			
	N	Mean	Minimum	Maximum
Peak HR	14	127 ±17	98	158
Work	14	9668.2 ±4437.8	1524.4	18122.9
EI	14	77.4 ±36.0	12.2	138.3
Resistance/Weight (KG)	14	7.7 ±3.9	6.0	17.0

4.3. Correlations between the various factors of EI.

All the correlations between the different predictors are as shown in Table 2 – 8. There was significant ($p < 0.00$) weak positive correlation between Age and BMI ($r = 0.23$). Age and number of years in company showed significant ($p < 0.00$) moderate positive correlation ($r = 0.57$). Age and total work showed a significant ($p < 0.04$) weak negative correlation ($r = -0.13$). Age and peak HR also showed significant ($p < 0.00$) but weak negative correlation ($r = -0.24$). Baseline HR and number of years in company had a significant ($p < 0.01$) but weak negative correlation ($r = -0.18$). There was significant ($p < 0.04$) but weak negative correlation ($r = -0.13$) between Baseline HR and EI. BMI and total work had significant ($p < 0.02$) but weak negative correlation ($r = -0.15$). BMI and EI showed significant ($p < 0.03$) but weak negative correlation ($r = -0.15$). Number of years and Peak HR had significant ($p < 0.00$) but moderate negative correlation ($r = -0.34$). There was also significant ($p < 0.00$) but weak positive correlation ($r = 0.28$) between KG and total work. KG and peak HR showed significant ($p < 0.00$) moderate positive correlation ($r = 0.32$). KG and EI had significant ($p < 0.00$) but weak positive correlation ($r = 0.20$). Total work and EI had significant ($p < 0.00$) and strong positive correlation ($r = 0.97$). Peak HR and EI had significant ($p < 0.01$) and weak negative correlation ($r = -0.18$).

Table 14. Age correlations

Correlations with age n = 220 r (p value)	
	Age
Baseline HR	0.11 (0.12)
BMI	0.23 (<0.00)*
No. of years in company	0.57 (<0.00)*
KG	0.02 (0.75)
Total Work	-0.13 (0.04)*
Peak HR	-0.24 (<0.00)*
EI	-0.08 (0.23)

HR = Heart Rate, BMI = Body Mass Index, KG = Kilograms, EI = Endurance Index
* Significant at p<0.05

Table 15. Baseline HR correlations

Correlations with Baseline HR n = 220 r (p value)	
	Baseline HR
Age	0.11 (0.12)
BMI	0.12 (0.08)
No. of years in company	-0.18 (<0.01)*
KG	0.1 (0.16)
Total Work	-0.1 (0.14)
Peak HR	0.13 (0.06)
EI	-0.13 (0.04)*

HR = Heart Rate, BMI = Body Mass Index, KG = Kilograms, EI = Endurance Index

* Significant at p<0.05

Table 16. BMI correlations

Correlations with BMI n = 220 r (p value)	
	BMI
Age	0.23 (<0.00)*
Baseline HR	0.12 (0.08)
No. of years in company	0.05 (0.50)
KG	-0.03 (0.63)
Total Work	-0.15 (0.02)*
Peak HR	-0.03 (0.68)
EI	-0.15 (0.03)*

HR = Heart Rate, BMI = Body Mass Index, KG = Kilograms, EI = Endurance Index

* Significant at p<0.05

Table 17. Number of years in company correlations

Correlations with No. of years in company n = 220 r (p value)	
	No. of years in company
Age	0.57 (<0.00)*
Baseline HR	-0.18 (<0.01)*
BMI	0.05 (0.50)
KG	-0.5 (0.57)
Total Work	-0.09 (0.17)
Peak HR	-0.34 (<0.00)*
EI	-0.03 (0.71)
HR = Heart Rate, BMI = Body Mass Index, KG = Kilograms, EI = Endurance Index * Significant at p<0.05	

Table 18. KG correlations

Correlations with KG n = 220 r (p value)	
	KG
Age	0.02 (0.75)
Baseline HR	0.1 (0.16)
BMI	-0.03 (0.63)
No. of years in company	-0.5 (0.57)
Total Work	0.28 (<0.00)*
Peak HR	0.32 (<0.00)*
EI	0.2 (<0.00)*
HR = Heart Rate, BMI = Body Mass Index, KG = Kilograms, EI = Endurance Index * Significant at p<0.05	

Table 19. Total Work correlations

Correlations with Total Work n = 220 r (p value)	
	Total Work
Age	-0.13 (0.04)*
Baseline HR	-0.1 (0.14)
BMI	-0.15 (0.02)*
No. of years in company	-0.09 (0.17)
KG	0.28 (<0.00)*
Peak HR	0.04 (0.51)
EI	0.97 (<0.00)*

HR = Heart Rate, BMI = Body Mass Index, KG = Kilograms, EI = Endurance Index
* Significant at p<0.05

Table 20. Peak HR correlations

Correlations with Peak HR n = 220 r (p value)	
	Peak HR
Age	-0.24 (<0.01)*
Baseline HR	0.13 (0.06)
BMI	-0.03 (0.68)
No. of years in company	-0.34 (<0.00)*
KG	0.32 (<0.00)*
Total Work	0.04 (0.51)
EI	-0.18 (<0.01)*

HR = Heart Rate, BMI = Body Mass Index, KG = Kilograms, EI = Endurance Index
* Significant at p<0.05

CHAPTER FIVE

5. Discussion

Determining whether work can be sustained for 8 hours using FCEs has always been a challenge. In a previous study it was mentioned that there are currently no scientific methods to predict 8 hour work tolerance (5). For this reason the aim of this study was to describe EI values for automotive workers in a car manufacturing company. And to determine which factors were associated with EI in this population. To the authors knowledge this is the first study of its kind and the novel EI values presented serve as a good guideline with regards to full work tolerance.

5.1. HR readings during job-specific endurance tasks in automotive workers.

Reduction in HR also has been attributed to intramuscular adaptations, usually due to sustained exposure to a workload or physical training (32). Therefore, individuals that have adapted to prolonged work are expected to have lower submaximal HR relative to those who are not trained (6, 7, 8, 9, 13, 30, 32). The current study assessed the peak heart rate for 220 endurance tests within the automotive industry. Mean peak HR for all the tests was 139.85 ±20.96bpm.The peak HR values ranged from 89bpm to 184bpm, indicating the high variation in the demands of the different tasks performed. The lowest HR value was with the BS 25 – Boot Hinge fitment job and the endurance activity that was performed was a Unilateral below waist lift activity. Although literature regarding HR and automotive industry workers is scarce, within sports research Reilly (33) found that soccer players playing at lower intensity had lower peak heart rates as when they played at highly competitive games. Indeed, based on the current findings it would be expected that the lowest HR reading should be found during the lowest resistance value and the highest should be found in the activity with the highest resistance. The job with the lowest resistance was the BS 28 – Bonnet Hinge Fitment job with 2kg of resistance for Unilateral below waist lift endurance activity. However, this was not the job with the lowest peak HR (116bpm), but in fact the BS 25 – Boot Hinge Fitment had the lowest peak HR (89bpm). It should be noted that the difference between the forces for these two jobs was only 0.2kg, which may explain the findings.

The highest peak HR recording was found in the BS18RE – Rear end carrier job with the Unilateral above waist lift endurance activity (184bpm), despite the fact that the resistance was 4.3kg for the endurance activity (job with the highest resistance was BS24 – Rear door fitment with 27.2kg resistance). However, due to the fact that there were both males and females completing this task, the females may have caused the increase in HR. Males in general perform better in physical tasks than females due to physiological differences (34, 35, 36). Therefore, the reason that the highest peak HR value was not with the most demanding resistance might be that females struggled to execute the test relative to the male. This is also evident in the amount of work that was performed as the male performed higher workloads compared to the females yet at a lower peak HR value (34, 35, 36). Although the highest HR value was not associated with the highest resistance, overall Peak HR and resistance (KG) had a significant moderate positive correlation ($r = 0.32$, $p = 0.00$). The more the resistance the higher the HR should be in order to meet steady state or the physiological requirements of the activity. Higher resistance is equivalent to higher intensity.

As people age maximal HR decreases (6, 7, 37, 38). In a study by Tanaka and colleagues, they found that maximal HR was strongly and inversely related to age in both males and females (38). The current study found a significant negative correlation between age and peak HR ($r = -0.24$, $p=0.00$). Younger individuals are in general better conditioned than older individuals and they would work at lower relative heart rates compared to the older individuals (6, 7, 9, 13). However, this study found the opposite of that, peak HR didn’t increase with increasing age. Heart rate is not only affected by age but also deconditioning or disease (37). The participants in this study are in physically demanding jobs, so they may be more physically active. The reason why peak HR was not higher during tasks with increasing age could be that the individuals regardless of age are not in a deconditioned state and may not have poor fitness levels. The other reason could be that the older individuals have been working for a long time, which means they have been physically active for years and could have adapted to the workloads. On the contrary, Kostis *et.al.* (37) found that during exercise testing older individuals achieved lower exercise heart rates ($r = 0.27$, $p = 0.05$) and that they had lower exercise tolerance ($r = 0.41$, $p = 0.01$) and they also had a steeper increase in heart rate during the testing. The lower heart rates were attributed to a decline in the capacity of the sinus node to increase the heart rate (37). It was also mentioned that aging is also associated with changes in pacemaker tissue, decrease in the responsiveness of the autonomic cardiovascular reflexes, a decline in intrinsic heart rate and decreased adrenergic receptor sensitivity (37). Sinus node decreased capacity is believed to be caused by decreased responsiveness to catecholamines as it has been shown that older individuals may have increased plasma norepinephrine levels but without dramatic changes in heart rate (37).

Cardiorespiratory fitness is a good indicator of aerobic capacity and during submaximal tests/protocols HR can be used to determine an individual's fitness levels (2). In this study it was found that peak HR and EI had an inverse relationship and this confirms the notion that fitter individuals will perform more work at lower relative HR values (6, 7, 8, 9, 13).

5.2. Work for each job-specific endurance task in automotive workers.

Changes in skeletal muscle tissue also play a role in aerobic capacity and Dikhuth *et al.* (6) explained that regular exercise / work leads to adaptations in skeletal muscles, and an increase work-related sympathetic activity that occurs later in endurance trained athletes. Thus, it would be expected that individuals who have adapted to years of prolonged work would have muscle adaptations that modify their muscle metabolism resulting in an improved work capacity and physical performance (6, 9, 12, 27).

In this study 220 total work outputs were assessed for different endurance activities. The mean total work was 9224.73 ±5826.04. Total worked performed ranged from 897.20 to a maximum of 33055J and this is reflective of the variability within the demands of the different tasks. The job with the lowest total work was the Dispatch – Cushman Driver with a total work of 897.20J for ankle plantar flexion which is a simulation of stepping on a pedal. As previously stated, literature in the automotive industry and work outputs is scarce but research in sport has found that the higher the resistance the higher the total work required to overcome that force (33). In this study this was not the case as the lowest work output was not found in the lowest resistance (2kg). The range for the Dispatch – Cushman Driver job was high though, as the total work ranged from 897.20 – 21786.5J (Range = 20889.3J) although the resistance was the same (2.8kg) and the mean was 6930.5J ±6593.9 meaning that there was high variability. This difference could be attributed to a number of factors which cannot be confirmed in this study, such as high variability in fitness levels of the participants, gender differences, unreported pain responses or participant stopping before they had reached fatigue.

In contrast the highest total work which was found in the BS24 – Rear door fitment job at 33055J for bilateral pulling had the highest resistance (27.2kg) which is in agreement with previous studies in sport research (33). Unlike the ankle plantar flexion endurance task, bilateral pulling had a variety of different forces for the different jobs (8 of the jobs required bilateral pulling), ranging from 3.4kg to a maximum of 27.2kg. Based on this fact it would be expected that the total amount of work performed will have high variability due to the different resistance levels that the participants had to work against. The mean of the total work for the bilateral pulling endurance task was 15467.1J ±8588.3 and the range was 4359.9 – 33055J (28695.1J). This variance is due to the differences in resistance because Work is the product of Force x Distance. Based on this direct relationship between the two variables (work and force) as force goes up so will the amount of work required to handle the load. This notion was found to be true in this study as there was a significant positive correlation ($r = 0.28$, $p = 0.00$) between total work and resistance (KG).

There was significant negative correlation between age and total work ($r = -0.13$, $p < 0.04$). So this finding implies that the older an individual, the less total work or endurance that can be achieved. This has been reported in other studies as well, where the same relationship has been reported (39, 40). The reasons for this may be due to sarcopenia which is age-related decrease in lean body mass (39). It has been reported that with advancing age, there is a loss of relative and absolute muscle mass (39). Metabolic changes that come with aging are a significant contributor to loss of muscle mass and there is also decreased muscle protein synthesis (39). Siparsky *et.al.* (39) found that endurance capacity of muscle declines by 10% per decade and this may be due to enzymatic changes in energy production which occur with age as anaerobic enzymes seem to remain constant, but aerobic energy production is decreased with age (39, 41). It was found that reduced endurance was due to a decrease in the number of mitochondria and the reduction of mitochondrial-based enzymes (39).

There are also age-related changes in the cardiovascular system and because muscle is a highly vascularised and metabolically active tissue it is also affected by oxygen delivery throughout the body (8, 13). With increasing aging there is a decrease in LV compliance and this is due to stiffening of the LV (8). There are structural and functional changes which come with aging on the cardiovascular system and some of these are a reduction in the number of cardiomyocytes and slight increases in the size of residual cells, there is increase of the connective tissue volume due to degeneration of matrix proteins and this can result in reduced functionality of the LV thereby decreasing oxygen delivery capabilities (8).

The ability of muscle to perform more work is because it has greater maximal aerobic power and oxidative capacity (9). Intrinsic muscle adaptation also has an effect on lowering HR (32), in this study it was found that higher total work performed by muscles was related to higher EI and so total work is a good indicator of aerobic capacity.

5.3. Job-specific EI's for each endurance task.

The product of **W/HR** is referred to as Endurance Index (EI) and is a good indicator of aerobic capability since more work will be achieved at relative lower HR by fitter individuals (6, 7, 9, 13). According to the knowledge of the author no study has looked at the product of **W/HR** and this is novel.

Endurance Index had a mean of 67.14 ±42.88 and ranged from a minimum of 8 – 243.10 (range = 235.10). As with total work, it was found that the job with the lowest EI was the Dispatch – Cushman Driver for plantar flexion endurance task with an EI value of 8. The job with the highest EI at 243.10 was the BS24 – Rear door fitment for bilateral pulling endurance task which also was found to have the highest total work value. The Dispatch – Cushman Driver job had a mean of 53.5 ±49.6 and range was from 8 – 155.6 (Range = 147.6) which also suggests high variability although the resistance/force was the same (2.8kg).

BS24 – Rear door fitment job had a mean of 113.9 ±62.9 and range was from 34 – 243.1 (range = 209.1) for bilateral pulling endurance task which also had a high variability, and as previously explained this variability would be expected since the force values have large differences. Thus it is quite evident that EI values seem to be closely related to total work as the data follows a similar trend. This then seems to suggest that total work is the biggest determinant of EI relative to peak HR. This finding could then be due to the notion that the fitter an individual, the higher work that can be achieved at a lower peak HR relative to a less fit individual (6, 7, 9, 13). So it would be expected that total work should have a direct relationship with EI and peak HR should have an inverse relationship.

In this study the relationship between total work and EI was found to be direct as there was a strong positive correlation ($r = 0.97$, $p = 0.00$). This could suggest that work performed by contracting muscles is the strongest predictor for endurance when using EI to determine performance. As discussed in an earlier chapter endurance trained athletes have greater maximal aerobic power and oxidative capacity (9). The increased maximal aerobic power and work is because of mitochondrial biogenesis, increases in capillary density and enzymes leading to enhanced skeletal muscle oxygen utilisation (10, 12, 26, 27, 28). There is also improved blood flow distribution to the working muscle because of enhanced skeletal muscle capillarisation (42). Individuals who can cope with more work show smaller disturbances in blood homeostasis, as they have lower post exercise blood lactate concentrations resulting in delayed fatigue (27). The ability of muscle to regulate H^+ and lactate homeostasis during work/exercise has an important role in delaying fatigue (27). Hoyt (12) proposed that a decrease in lactate levels may account for an ability to perform more work at the same relative intensity. Individuals who have adapted to endurance type activities have skeletal muscle adaptations that modify their muscle metabolism resulting in an improved work capacity and physical performance (12).

In this current study the inverse relation between peak HR and EI was found as there was a significant negative correlation ($r = -0.18$, $p < 0.01$). As stated in the introduction, increased cardiovascular fitness / endurance is associated with lower relative HR at the same work load compared to unfit or sedentary individuals (6). This inverse relationship between peak HR reached during the tests and EI is because fitter individuals will perform more workloads at lower submaximal HR relative to less fitter individuals (6, 7, 8, 9, 13). During periods of physical activity the HR of physically active individuals is lower because sympathetic drive is less (32), and there is increased parasympathetic tone and intrinsic cardiac muscle adaptations (6, 32). There is a change in left ventricular structure and function, increased blood volume with a decrease in peripheral resistance and these changes allow the heart to work efficiently by pumping out larger volumes of blood but at lower heart rates as compared to a sedentary state (6, 30, 31). An intrinsic adaptation in skeletal muscle has an effect on the regulation of exercise HR though (32). Winder *et.al.* (32) mentioned that heart rate reduction resulting from arm training does not carry over to physical activity performed with untrained leg muscles. It was further mentioned that there is a lower submaximal HR response when testing a trained unilateral leg compared to when the untrained leg is tested (32). This was attributed to feedback coming from the afferent nerves which in turn determine the magnitude of the sympathoadrenal response during physical activity (32). It was postulated that intramuscular adaptations caused by physical activity (like increased myoglobin and mitochondria) cause a change in the metabolic and ionic environment at the sensory receptor sites in the muscle and this in turn reduces afferent nerve impulses resulting in adrenergic output by the autonomic nervous system (32).

Intrinsic adaptations in the muscle, like increased mitochondrial content, mitochondrial enzymes, and capillary supply improve the aerobic capacity of the muscle (12, 26, 28, 29, 30, 33) and since intrinsic skeletal muscle adaptation plays a significant role in lowering HR during work (32), EI is a good indicator of aerobic capability.

5.4. Correlations of the various factors with the EI values.

Baseline HR and EI showed significant negative correlation ($r = -0.13$, $p < 0.04$). This suggests that if resting/baseline HR is lower, then a higher EI can be achieved, and this may be due to better conditioning (6, 30). It has been shown that resting HR of well-trained endurance athletes can be even lower than 40bpm (30). There is a reduction of sympathetic drive to the heart in fitter individuals (32). It was found that there is increased parasympathetic tone which decreases cardiac excitation, atrioventricular conduction and increased tolerance to orthostatic stress (6, 32). There is also reduced sensitivity to catecholamines and intrinsic cardiac adaptations leading to a lower HR (33).

Body Mass Index and EI had negative correlation which was significant ($r = -0.15$, $p<0.03$) and this relationship was also found between BMI and total work ($r = -0.15$, $p < 0.02$). Numerous studies have shown that individuals with higher BMI have lower endurance capability (43, 44, 45). Lad and colleagues in their study found that handgrip endurance was higher for males and females in the normal BMI ranges relative to those that were above normal (43). They found that there was a negative correlation between endurance and being overweight. They also found that individuals in the underweight category of BMI had lower strength values than overweight individuals but they had better endurance values compared to overweight individuals (43). In a study by Strel (44) it was found that individuals in the normal BMI category performed better in a 600m run. In that study, it was found that the more the body weight the poorer the results in a 600m run. So a negative correlation was found between BMI and endurance which is also the case in this study. Hasan *et.al.* (45) found that there was decreased endurance of quadriceps and abdominal muscles in obese individuals when compared with overweight and normal individuals. There is a higher proportion of fast-twitch fibers in the skeletal muscles of obese people (45) relative to leaner people. This was attributed to the notion that higher levels of muscle power are required for obese individuals to move their heavy mass/bodies and this may reduce their ability to sustain activities for a long time (45). Increased fat mass results in decreased time of activity in aerobic activities (39, 41, 45).

Resistance (KG) and EI also had a significant positive correlation ($r = 0.20$, $p = 0.00$). This is not surprising as EI is closely related to total work. EI and total work seem to follow similar trends and as previously explained that Work (W) is the product of Force (F) multiplied by distance (d) and can be expressed by the following calculation: $W = F \times d$. It would be expected that the higher the resistance the higher the EI value would be (as in the relationship of work and resistance).

5.5. Correlations between the various factors.

It was found that there is a significant positive correlation between age and BMI. This would mean that the older an individual gets, the higher their BMI would be. This finding is in line with other studies that have investigated this relationship (39, 41, 42, 45). As people age, there is an increase in fat mass and a decrease in lean mass and bone mineral density (39, 41, 46, 47). This increase in fat mass could be attributed to the higher BMI values as people age. It could be argued though that BMI as an index does not discriminate between fat% and lean mass, so it is not a good indicator of fat%. In a study by Ranasinghe *et.al.* (47) it was found that there is a strong and significant positive correlation between BMI and Body Fat% (BF%) in males and females. The study consisted of 1114 adults with BMI values representing a large range (14.8 – 41.1kg/m²). They found that the pearson's correlation coefficient was $r = 0.75$ ($p < 0.01$) for males and was $r = 0.82$ ($p <0.01$) for females. Mungreiphy *et.al.* (46) also found that BMI increases with age, and attributed this increase to BF%. Reas *et.al.* (48) found the opposite though, there was a significant negative correlation between age and BMI ($r = -0.30$, $p<0.001$ for males and $r = -0.25$, $p<0.001$ for women). There is discrepancy in their data though as the absolute results show that over an 11 year period, 18% of their study population lost weight, 76.7% gained weight and 5.2% reported no weight change. This would mean that as the participants aged, majority of them gained weight which would result in a higher BMI value. Body weight increases with age until the age of 49, then it decreases slightly after that, but the most significant decreases in weight occur after age 60 (46, 47). This means that BMI decreases after age 60, our study population ages ranged from 21 – 58 years so this effect could not have affected the results. So BMI increases in a curvilinear manner (46, 47) but BF% still increases with increasing age even after age 60. The reason for the lower BMI after age 60 is due to an increase in loss of muscle mass (39, 41, 46, 47). BF% increases with age for a number of physiological reasons; there is an increase in insulin resistance and higher body fat mass in conjunction with a decreasing Basal Metabolic Rate and Resting Metabolic Rate (RMR) (39, 41). Older individuals also have lower basal fat oxidation, and there is a decrease in aerobic energy production as there are decreased mitochondrial-based aerobic enzymes (39, 41).

There was a significant positive correlation between age and number of years in company ($r = 0.57$, $p <0.00$). The most obvious reason would be that the older individuals entered the company while the younger individuals were either still undergoing schooling or some of them not even born at the time, so the number of years would of course be higher for the older individuals. But it was found that individuals stay at a company for long due to job satisfaction (49) and previously job satisfaction was thought to increase linearly (as in this study) with age but this is not the case. It was found that job satisfaction is 'U' shaped in age (49). Younger employees were found to be highly satisfied with their jobs for a number of reasons. Youth unemployment rates are high and there is pleasure in being employed in comparison to unemployed peers (49). First time workers also don't have a lot of information about the job market so they can't compare with other jobs to deduce if whether they are in a good or bad job, this will come with experience and more informed comparisons can be made later in life (49). As workers reach middle age, job satisfaction drops as more of their peers find more attractive jobs and due to the increased experience in the labour market, they may find that the job is not as great when comparing to others (49). As workers approach old age job satisfaction rises again and this could be due to reduced aspirations, there may be few alternative jobs once a career is established and older workers might put less effort on comparison's after realising that their initial expectations have not been met (49). It is possible that a similar trend can be found in the company where this study was done, but this would be not known as this was not the focus of this study and based on the current results, there is a linear relationship between age and number of years in company and it would be misleading to attribute that to job satisfaction.

Baseline HR and number of years in company had a significant negative correlation ($r = -0.18$, $p < 0.01$). No studies were found correlating these two factors. These findings suggest that the higher the baseline HR the lower the number of years would have been spent in the company. Since it was found that there was a direct relationship between number of years in the company and age, it can be deduced that the older the individual the lower the baseline HR would be. A number of studies have shown the opposite of this as older age was associated with higher baseline/resting HR due to a number of physiological reasons (6, 30, 32). Baseline HR and age in this study supports the findings of the other studies although the correlation was not significant ($r = 0.11$, $p < 0.12$).

5.6. Strengths and limitations

The method of assessing aerobic capacity in this study is highly specific which makes it useful in a clinical or industrial setting. The EI values are formulated from performing job-specific movements and this allows clinicians to test against exactly what the worker will do and be able to use the EI values as a guideline as to whether an individual is ready to return to work or not.

On the other hand, the sample sizes are small so the EI's values cannot be used as normative data. Secondly, to acquire the EI value expensive equipment is required so only clinicians/corporations with sufficient resources can be able to utilise this method. Finally using EI as a method to determine aerobic capacity requires measurement of HR, this method would not work if an individual is on HR suppressing medications.

5.7. Recommendations

Future studies in this topic should focus on developing methods which will incorporate the use of Rate of Perceived Exertion (RPE). RPE coupled with total work will allow the estimation of aerobic capacity in individuals who are on HR modifying medications/drugs. Since this study used expensive equipment to determine EI, future studies can investigate cheaper but reliable tools which can allow for the measuring of EI.

5.8. Conclusion

The aim of this study was to describe EI values for automotive workers for different endurance tasks. Endurance Index is the product of Work divided by peak HR. Since an increase in intensity results in higher values of HR (33) it was expected that the job with the highest resistance levels would result in the largest values of peak HR and the job with the lowest resistance levels would result in the lowest peak HR values. That was not the finding in this study, the highest HR values may have been attributed to gender differences since males in general perform better than females with regards to physical activities (34, 35, 36). The job with the lowest peak HR was not the one with the lowest resistance, but it was noted that the difference was only 0.2kg.

Since work has a direct relationship with force, an increase in resistance would result in larger amounts of total work required by muscle to overcome the force and the opposite would also be true. This principle was also found in this present study as the job with the highest resistance value (27.2kg) presented with the highest total work value (33055J). The job with the lowest resistance (2kg) did not present with the lowest total work value. The job which presented with the lowest total work value showed high variability between the sample population which was tested and the reason why there was so much variability could not be determined in this study. There could be reasons such as high variability in fitness levels of the participants, gender differences, unreported pain responses or participant stopping before they had reached fatigue.

Endurance Index values showed a close relationship with total work as there was a strong positive correlation. This then seems to suggest that total work is the biggest determinant of EI relative to peak HR. This finding could then be attributed to the notion that the better conditioned an individual, the higher work that can be achieved at a lower peak HR relative to a lesser conditioned individual (6, 7, 9, 13).

Endurance Index is a good indicator for aerobic capacity but has a number of limitations. It can be used by clinicians as a guideline in the laboratory environment to determine readiness-to-work. Future studies should investigate on the limitations of EI such as incorporating RPE into the formula.

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APPENDICES

Appendix A – Informed Consent

I____ _____________ (Full name and Co.ID) declare that all the information stated about my health is true and correct.

I give my consent that the results may be used for report and research purposes, knowing that all my information will be kept confidential.

I expressly undertake that in the event of any unforeseen injury during the test that I shall not hold either the evaluator or the evaluator's employer, or my employer liable for any claim I may have resulting from such test / injury. I hereby agree to fully comply and conform to each specific instruction provided to me, to ensure the safest implementation of these tests. I am aware that I may experience muscle soreness and discomfort 24 -48hours after the test. I am aware that I can withdraw my consent or discontinue with the assessment at any time. I further undertake to operate equipment and all other amenities associated therewith as prescribed by the Biokineticist or Biokinetic employees. I hereby voluntary consent to undergo the Functional Capacity Evaluation and I confirm that I was fully informed with regards to the purpose and procedure of the physical evaluation.

Signature: ____

Date: __________________________

Appendix B – Data Collection Sheet

Name of Job	Research Identity	Name & Surname	Gender	Company ID	Age	Baseline HR	Peak HR	Height	Weight	BMI	Strength/Endurance Requirements					Start date at BMW	Year	No. of years at BMW until 2015
											Endurance Test Type	Peak HR	Total Work	EI	Resistance/KG			

Appendix C – Peak HR, Total Work and EI Values for each endurance test

Name of Job	Strength/Endurance Requirements				
	Endurance Test Type	Peak HR	Total Work	EI	Resistance/KG
(BS 1) ST04 &ST07	Bilateral below waist lift	118	4533	38.4	3.1
(BS2a&2b) ST21,01,23	Bilateral above waist lift	146	3406.5	23.3	7.15
	Bilateral above waist lift	135	5771.8	42.8	7.15
(BS3) ST30.1-30.4	Bilateral below waist lift	156	6269	40.1	5.4
(BS4) SFO0101	Unilateral Pulling	125	17472	139.8	16
(BS5) SMRL0401	Bilateral below waist lift	164	3024.5	18.4	8.2
	Bilateral above waist lift	159	4012	25.3	8.2
	Bilateral Pushing	156	13176	84.5	10.4
	Bilateral Pulling	157	6176.4	39.3	6.1
	Bilateral below waist lift	163	3944.5	24.2	8.2
	Bilateral above waist lift	143	4762.8	33.3	8.2
	Bilateral Pushing	159	18445	116	10.4
	Bilateral Pulling	136	17270	127	6.1
(BS6) SMR 0101	Bilateral below waist lift	159	4475.3	28.15	7.2
(BS7) ST45.1 - ST50.2 FWA	Bilateral above waist lift	153	5614.5	36.69	3.8
	Unilateral Pulling	116	10549	90.9	8.6
	Bilateral above waist lift	125	5516	44.13	3.8
	Unilateral Pulling	115	7268.1	63.2	8.6
(BS8) ST05 - ST30 FWA	Bilateral above waist lift	156	2375.5	15.2	2.2
	Unilateral Pulling	159	7577.3	47.65	10
	Bilateral above waist lift	145	5816.9	40.1	2.2
	Unilateral Pulling	155	15975	103	10
(BS69FG) ST01 Crossbar	Bilateral below waist lift	146	11696	80.10	15
	Bilateral above waist lift	155	5162.3	33.3	15
(BS17FE) ST35; ST91; ST95: ST60AC Front Wheelhouses	Bilateral below waist lift	123	10654	86.6	5.6
	Bilateral above waist lift	116	2420.8	20.9	3.8
	Unilateral Pulling	122	24824	203.4	6.5
	Unilateral Pushing	123	16149	131.3	6
	Bilateral below waist lift	153	5261.7	34.4	5.6
	Bilateral above waist lift	153	2889.1	18.9	3.8
	Unilateral Pulling	148	20594	139.1	6.5
	Unilateral Pushing	131	18123	138.3	6
(BS16FE) ST40; ST65; ST85.1: ST85.2 Front Wheelhouses	Bilateral below waist lift	145	7006.7	48.3	5.6
	Bilateral above waist lift	140	3255.7	23.3	3.8
	Unilateral Pulling	144	15723	109.2	17
	Bilateral below waist lift	138	5274.6	38.1	5.6
	Bilateral above waist lift	147	3984.9	27.1	3.8
	Unilateral Pulling	146	5463	37.4	17

(BS18RE) 10FX01; 20FX01; 20FX02; 30FX01; 30FX02; 30FX03 Rear End Carrier	Unilateral above waist lift	184	4972.5	27	4.3
	Unilateral Pulling	159	6821.9	42.9	17
	Unilateral above waist lift	161	1287.8	8	4.3
	Unilateral Pulling	161	4932.2	30.6	17
	Unilateral above waist lift	155	9207.2	59.4	4.3
	Unilateral Pulling	165	9097.5	55.1	17
(BS15RE) 50FX01; 60FX01; 60FX02; 60FX03 Rear End Carrier	Bilateral below waist lift	125	8500.3	68	4.8
	Bilateral Pulling	151	12589	83.4	16.6
	Bilateral Pushing	152	13440	88.4	12.2
	Bilateral below waist lift	128	6324.6	49.4	4.8
	Bilateral Pulling	133	29301	220.3	16.6
	Bilateral Pushing	131	22652	172.9	12.2
(BS14RE) 70FX01; 70FX02; 80FX01; 80FX02 Rear End Complete	Bilateral below waist lift	157	5461	34.8	6.8
	Unilateral Pulling	156	9411.1	60.3	13
	Bilateral below waist lift	152	11074	72.9	6.8
	Unilateral Pulling	161	9405.5	58.4	13
(BS10RE) 10FX01; 20FX01; 20FX02; 15FX01; 40FX01; 40FX02 Rear End Complete	Bilateral above waist lift	155	5855.1	37.8	3.5
	Unilateral Pulling	157	14871	94.7	22
	Bilateral above waist lift	148	3439.4	23.2	3.5
	Unilateral Pulling	157	5864.6	37.4	22
(BS20FE) ST10; ST20; ST25: ST30 Front End Complete Firewall	Unilateral Pulling	117	14304	122.3	16.5
	Unilateral Pulling	124	9915.5	80	16.5
(BS64RE) 45FX01; 55FX01; 55FX02; 55FX03; 80FX01; 80FX02 Rear End Carrier	Bilateral above waist lift	152	3559.9	23.4	4.9
	Bilateral above waist lift	114	8037.1	70.5	4.9
(BS63RE) 50FX01 CO2 (Welding) Rear End Complete	Unilateral Pushing	125	1524.4	12.2	17
	Unilateral Pulling	136	4522.8	33.3	14.6
	Unilateral Pushing	136	2492.5	18.3	17
	Unilateral Pulling	136	4499.9	33.1	14.6
BS21 - Defo element bracket attachment	Unilateral below waist lift	103	2620.2	25.4	5.8
	Bilateral Pushing	99	7075	71.5	4.5
	Unilateral below waist lift	149	1867.9	12.5	5.8
	Bilateral Pushing	121	6612.1	54.6	4.5
BS22 - Cleaning & Grinding Booth	Unilateral below waist lift	111	6779.2	61.1	5
	Unilateral below waist lift	117	3279.1	28	5
BS27 - Fender Fitment	Bilateral below waist lift	120	4479.1	37.3	2.6
	Bilateral Pushing	155	19356	124.9	21.3
	Bilateral Pulling	116	13527	116.6	7.7
	Unilateral Pulling	115	9765.2	84.9	2.6
	Bilateral below waist lift	147	6119.2	41.6	2.6
	Bilateral Pushing	147	15653	106.5	21.3
	Bilateral Pulling	131	16495	125.9	7.7
	Unilateral Pulling	138	9432.9	68.3	2.6
	Bilateral below waist lift	139	4676.3	33.6	12.8

BS23 - Rear Door Fitment	Bilateral Pushing	118	14335	121.5	10.2
	Bilateral Pulling	155	10575	68.2	25.8
BS23 - Rear Door Fitment	Bilateral below waist lift	121	6114.8	50.5	12.8
	Bilateral Pushing	126	17743	140.8	10.2
	Bilateral Pulling	142	21449	151	25.8
BS29 & 30 - Bonnet fitment, manipulation & alignment	Bilateral above waist lift	149	6688.2	44.9	20.5
	Bilateral Pushing	150	19591	130.6	15
	Bilateral Pulling	129	20788	161	11.5
	Bilateral above waist lift	173	3732.3	21.6	20.5
	Bilateral Pushing	135	18517	137.2	15
	Bilateral Pulling	159	5400.9	34	11.5
BS31 - Bonnet stay fitment	Bilateral Pushing	164	14630	89.2	20.5
	Bilateral Pushing	152	9648.6	63.5	20.5
BS24 - Front Door Fitment	Bilateral below waist lift	173	6154	35.6	14.1
	Bilateral Pushing	172	20803	120.9	25
	Bilateral Pulling	169	20878	123.5	27.2
	Unilateral Pulling	148	18665	126.1	5
	Bilateral below waist lift	137	6788.1	49.5	14.1
	Bilateral Pushing	141	10478	74.3	25
	Bilateral Pulling	136	33055	243.1	27.2
	Unilateral Pulling	123	17262	140.3	5
BS28 - Bonnet Hinge Fitment	Unilateral below waist lift	116	1569.4	13.5	2
	Bilateral Pulling	120	13879	115.7	8.5
BS26 - Bootlid Fitment	Bilateral above waist lift	174	5320	30.6	8
	Bilateral above waist lift	122	7081.4	58	8
BS25 - Boot Hinge Fitment	Unilateral below waist lift	115	3272.7	28.5	2.2
	Bilateral Pushing	113	6183.3	54.7	3.3
	Bilateral Pulling	113	6263.4	55.4	3.4
	Unilateral below waist lift	89	5697.6	64	2.2
	Bilateral Pushing	101	5842.1	57.8	3.3
	Bilateral Pulling	99	4359.9	44	3.4
BS13 Bonnet Alignment	Bilateral Pulling/Pushing	148	23490	158.7	8.8
(PS27-29) Topcoat Flatting Horizontal	Bilateral Pulling/Pushing	157	17836	113.6	7.2
	Unilateral Pulling/Pushing	158	13520	85.6	6.2
	Bilateral Pulling/Pushing	165	22749	137.9	7.2
	Unilateral Pulling/Pushing	165	13081	79.3	6.2
	Bilateral Pulling/Pushing	110	22631	205.7	7.2
	Unilateral Pulling/Pushing	100	10528	105.3	6.2
	Bilateral Pulling/Pushing	163	16768	102.9	7.2
	Unilateral Pulling/Pushing	156	11782	75.5	6.2
(PS27-29) Topcoat Flatting Vertical	Unilateral Pushing	114	8886.7	78	6.2
	Unilateral Pulling	109	11701	107.4	4.2
	Unilateral Pushing	146	10629	73	6.2
	Unilateral Pulling	135	15117	111.9	4.2

(PS27-29) Topcoat Flatting Vertical	Unilateral Pushing	107	8955.3	84	6.2
	Unilateral Pulling	107	11238	105	4.2
	Unilateral Pushing	145	8702.9	60	6.2
	Unilateral Pulling	137	14623	106.7	4.2
	Unilateral Pushing	158	8097.6	51.3	6.2
	Unilateral Pulling	159	7917.2	49.8	4.2
PS25 - Spray Booth - Clearcoat Manual	Unilateral Pulling/Pushing	113	3619	32	6.2
	Unilateral Pulling/Pushing	124	6095.9	49.2	6.2
	Unilateral Pulling/Pushing	124	11026	88.9	6.2
PS18 - Primer Finish Horizontals	Bilateral Below waist lift	159	12105	76.1	7.2
	Bilateral Below waist lift	164	9401.8	57.3	7.2
PS17 - Primer Finish Vertical / Doors	Unilateral Pushing	98	9644.9	98.4	6.2
	Unilateral Pulling	107	15344	143.4	4.2
	Unilateral Pushing	122	12196	100	6.2
	Unilateral Pulling	135	17017	126.1	4.2
	Unilateral Pushing	143	12138	84.9	6.2
	Unilateral Pulling	156	6020.9	38.6	4.2
PS13 - Primer Tac Rag	Bilateral Pulling/Pushing	157	8425.2	53.7	7.2
	Bilateral Pulling/Pushing	170	7394.7	43.5	7.2
PS32a & 32b Waxing Preparation	Bilateral Pushing	156	13846	88.8	14.4
	Bilateral Pushing	160	12070	75.4	14.4
PS22 Basecoat Manual Bonnet & Boot Lid	Bilateral below waist lift	166	10550	63.6	14.4
	Bilateral below waist lift	170	9927.7	58.4	14.4
PS23 Basecoat Manual Doors	Unilateral Pushing	115	10589	92.1	6.2
	Unilateral Pulling	117	14706	125.7	4.2
	Unilateral Pushing	116	7227.5	62.3	6.2
	Unilateral Pulling	112	6288.7	56.1	4.2
PS21 Basecoat Tac rag	Bilateral Pulling/Pushing	151	17155	113.6	7.2
	Unilateral Pulling/Pushing	110	5812.8	52.8	4.2
	Bilateral Pulling/Pushing	137	17313	126.4	7.2
	Unilateral Pulling/Pushing	120	9364.2	78	4.2
PS44- Offline- polish line-outer surface (station 1 & 2)	Bilateral pulling/pushing	100	8081.4	80.8	4.6
	Bilateral Pulling/Pushing	97	4113.1	42.4	4.2
	Bilateral pulling/pushing	132	11050	83.7	4.6
	Bilateral Pulling/Pushing	123	6778.5	55.1	4.2
Dispatch - Cushman Driver (CKD)	Bilateral below waist lift	162	4913.2	30.3	12.7
	Steering wheel	160	5284	33	3.6
	Ankle Plantar flexion	159	2141.2	13.5	2.8
	Bilateral below waist lift	171	7909.8	46.3	12.7
	Steering wheel	157	14425	91.9	3.6
	Ankle Plantar flexion	94	10838	115.3	2.8
	Bilateral below waist lift	165	9741.8	59	12.7
	Steering wheel	166	5030.9	30.3	3.6
	Ankle Plantar flexion	143	16893	118.1	2.8

Dispatch - Cushman Driver (CKD)	Bilateral below waist lift	159	6781.2	42.6	12.7
	Steering wheel	162	6011.8	37.1	3.6
	Ankle Plantar flexion	135	8877.7	65.7	2.8
	Bilateral below waist lift	155	9320.3	60.1	12.7
	Steering wheel	168	4921.3	29.3	3.6
	Ankle Plantar flexion	160	2496.4	15.6	2.8
	Bilateral below waist lift	156	20470	131.2	12.7
	Steering wheel	151	17365	115	3.6
	Ankle Plantar flexion	140	21787	155.6	2.8
	Bilateral below waist lift	158	5641.5	35.7	12.7
	Steering wheel	158	4217.4	26.7	3.6
	Ankle Plantar flexion	135	4413.4	32.7	2.8
	Bilateral below waist lift	153	2807.5	18.3	12.7
	Steering wheel	155	4061.2	26.2	3.6
	Ankle Plantar flexion	101	3611.8	35.8	2.8
	Bilateral below waist lift	151	5404	35.8	12.7
	Steering wheel	167	5580.1	33.4	3.6
	Ankle Plantar flexion	140	6557.4	46.8	2.8
Dispatch Cushman Driver (Engine)	Bilateral below waist lift	167	5131.9	30.7	15.8
	Steering wheel	168	5252.4	31.3	3.6
	Ankle Plantar flexion	144	2772	19.3	2.8
	Bilateral below waist lift	129	6409.2	49.7	15.8
	Steering wheel	142	8057.2	56.7	3.6
	Ankle Plantar flexion	120	1881.9	15.7	2.8
	Bilateral below waist lift	144	7232.4	50.2	15.8
	Steering wheel	125	10424	83.4	3.6
	Ankle Plantar flexion	112	897.2	8	2.8
CKD Plant 6 Receiving Unboxing	Bilateral below waist lift	168	7282.9	43.4	12.7
	Bilateral above waist lift	168	5361.4	31.9	12.7
	Bilateral Pushing	120	3773.3	31.4	3.5
	Bilateral below waist lift	143	10284	71.9	12.7
	Bilateral above waist lift	139	7689.6	55.3	12.7
	Bilateral Pushing	126	4214.6	33.4	3.5
	Bilateral below waist lift	121	4032.2	33.3	12.7
	Bilateral above waist lift	136	3884.2	28.6	12.7
	Bilateral Pushing	112	5552.4	49.6	3.5
	Bilateral below waist lift	126	17316	137.4	12.7
	Bilateral above waist lift	126	3900.8	31	12.7
	Bilateral Pushing	90	4366.5	48.5	3.5
	Bilateral below waist lift	116	5613.5	48.4	12.7
	Bilateral above waist lift	118	6188.8	52.4	12.7
	Bilateral Pushing	103	6186.6	60.1	3.5
Engine Warehouse Receiving Unboxing	Bilateral below waist lift	159	8935.9	56.2	15.8
	Bilateral above waist lift	163	3917.2	24	15.8

Engine Warehouse Receiving Unboxing	Bilateral Pushing	145	5541.4	38.2	3.5
	Bilateral below waist lift	141	4655.8	33	15.8
	Bilateral above waist lift	145	6191.1	42.7	15.8
	Bilateral Pushing	132	6367.7	48.2	3.5
	Bilateral below waist lift	164	4782.3	29.2	15.8
	Bilateral above waist lift	146	2413.3	16.5	15.8
	Bilateral Pushing	123	6099.9	49.6	3.5

Appendix D – Job names and endurance tests

Job No.	Name of Job	Research Identity of Worker	Endurance Test Type	No. of Test
1	(BS 1) ST04 &ST07	1	Bilateral below waist lift	1
2	(BS2a&2b) ST21,01,23	2	Bilateral above waist lift	2
		3	Bilateral above waist lift	3
3	(BS3) ST30.1-30.4	4	Bilateral below waist lift	4
4	(BS4) SFO0101	5	Unilateral Pulling	5
5	(BS5) SMRL0401	6	Bilateral below waist lift	6
			Bilateral above waist lift	7
			Bilateral Pushing	8
			Bilateral Pulling	9
		7	Bilateral below waist lift	10
			Bilateral above waist lift	11
			Bilateral Pushing	12
			Bilateral Pulling	13
6	(BS6) SMR 0101	8	Bilateral below waist lift	14
7	(BS7) ST45.1 - ST50.2 FWA	9	Bilateral above waist lift	15
			Unilateral Pulling	16
		10	Bilateral above waist lift	17
			Unilateral Pulling	18
8	(BS8) ST05 - ST30 FWA	11	Bilateral above waist lift	19
			Unilateral Pulling	20
		12	Bilateral above waist lift	21
			Unilateral Pulling	22
9	(BS69FG) ST01 Crossbar	13	Bilateral below waist lift	23
			Bilateral above waist lift	24
10	(BS17FE) ST35; ST91; ST95: ST60AC Front Wheelhouses	14	Bilateral below waist lift	25
			Bilateral above waist lift	26
			Unilateral Pulling	27
			Unilateral Pushing	28
		15	Bilateral below waist lift	29
			Bilateral above waist lift	30
			Unilateral Pulling	31
			Unilateral Pushing	32
11	(BS16FE) ST40; ST65; ST85.1: ST85.2 Front Wheelhouses	16	Bilateral below waist lift	33
			Bilateral above waist lift	34
			Unilateral Pulling	35
		17	Bilateral below waist lift	36
			Bilateral above waist lift	37

			Unilateral Pulling	38
12	(BS18RE) 10FX01; 20FX01; 20FX02; 30FX01; 30FX02; 30FX03 Rear End Carrier	18	Unilateral above waist lift	39
			Unilateral Pulling	40
		19	Unilateral above waist lift	41
			Unilateral Pulling	42
		20	Unilateral above waist lift	43
			Unilateral Pulling	44
13	(BS15RE) 50FX01; 60FX01; 60FX02; 60FX03 Rear End Carrier	21	Bilateral below waist lift	45
			Bilateral Pulling	46
			Bilateral Pushing	47
		22	Bilateral below waist lift	48
			Bilateral Pulling	49
			Bilateral Pushing	50
14	(BS14RE) 70FX01; 70FX02; 80FX01; 80FX02 Rear End Complete	23	Bilateral below waist lift	51
			Unilateral Pulling	52
		24	Bilateral below waist lift	53
			Unilateral Pulling	54
15	(BS10RE) 10FX01; 20FX01; 20FX02; 15FX01; 40FX01; 40FX02 Rear End Complete	25	Bilateral above waist lift	55
			Unilateral Pulling	56
		26	Bilateral above waist lift	57
			Unilateral Pulling	58
16	(BS20FE) ST10; ST20; ST25: ST30 Front End Complete Firewall	27	Unilateral Pulling	59
		28	Unilateral Pulling	60
17	(BS64RE) 45FX01; 55FX01; 55FX02; 55FX03; 80FX01; 80FX02 Rear End Carrier	29	Bilateral above waist lift	61
		30	Bilateral above waist lift	62
18	(BS63RE) 50FX01 CO2 (Welding) Rear End Complete	31	Unilateral Pushing	63
			Unilateral Pulling	64
		32	Unilateral Pushing	65
			Unilateral Pulling	66
19	BS21 - Defo element bracket attachment	33	Unilateral below waist lift	67
			Bilateral Pushing	68
		34	Unilateral below waist lift	69
			Bilateral Pushing	70
No. of jobs	Name of Job	Research Identity of	Endurance Test Type	No. of Test

		Worker.		
20	BS22 - Cleaning & Grinding Booth	35	Unilateral below waist lift	71
		36	Unilateral below waist lift	72
21	BS27 - Fender Fitment	37	Bilateral below waist lift	73
			Bilateral Pushing	74
			Bilateral Pulling	75
			Unilateral Pulling	76
		38	Bilateral below waist lift	77
			Bilateral Pushing	78
			Bilateral Pulling	79
			Unilateral Pulling	80
22	BS23 - Rear Door Fitment	39	Bilateral below waist lift	81
			Bilateral Pushing	82
			Bilateral Pulling	83
		40	Bilateral below waist lift	84
			Bilateral Pushing	85
			Bilateral Pulling	86
23	BS29 & 30 - Bonnet fitment, manipulation & alignment	41	Bilateral above waist lift	87
			Bilateral Pushing	88
			Bilateral Pulling	89
		42	Bilateral above waist lift	90
			Bilateral Pushing	91
			Bilateral Pulling	92
24	BS31 - Bonnet stay fitment	43	Bilateral Pushing	93
		44	Bilateral Pushing	94
25	BS24 - Front Door Fitment	45	Bilateral below waist lift	95
			Bilateral Pushing	96
			Bilateral Pulling	97
			Unilateral Pulling	98
		46	Bilateral below waist lift	99
			Bilateral Pushing	100
			Bilateral Pulling	101
			Unilateral Pulling	102
26	BS28 - Bonnet Hinge Fitment	47	Unilateral below waist lift	103
			Bilateral Pulling	104
27	BS26 - Bootlid Fitment	48	Bilateral above waist lift	105
		49	Bilateral above waist lift	106
28	BS25 - Boot Hinge Fitment	50	Unilateral below waist lift	107

			Bilateral Pushing	108
			Bilateral Pulling	109
		51	Unilateral below waist lift	110
			Bilateral Pushing	111
			Bilateral Pulling	112
29	BS13 Bonnet Alignment	52	Bilateral Pulling/Pushing	113
30	(PS27-29) Topcoat Flatting Horizontal	53	Bilateral Pulling/Pushing	114
			Unilateral Pulling/Pushing	115
		54	Bilateral Pulling/Pushing	116
			Unilateral Pulling/Pushing	117
		55	Bilateral Pulling/Pushing	118
			Unilateral Pulling/Pushing	119
		56	Bilateral Pulling/Pushing	120
			Unilateral Pulling/Pushing	121
31	(PS27-29) Topcoat Flatting Vertical	57	Unilateral Pushing	122
			Unilateral Pulling	123
		58	Unilateral Pushing	124
			Unilateral Pulling	125
		59	Unilateral Pushing	126
			Unilateral Pulling	127
		60	Unilateral Pushing	128
			Unilateral Pulling	129
		61	Unilateral Pushing	130
			Unilateral Pulling	131
32	PS25 - Spray Booth - Clearcoat Manual	62	Unilateral Pulling/Pushing	132
		63	Unilateral Pulling/Pushing	133
		64	Unilateral Pulling/Pushing	134
33	PS18 - Primer Finish Horizontals	65	Bilateral Below waist lift	135
		66	Bilateral Below waist lift	136
34	PS17 - Primer Finish Vertical / Doors	67	Unilateral Pushing	137
			Unilateral Pulling	138
		68	Unilateral Pushing	139
			Unilateral Pulling	140
		69	Unilateral Pushing	141
			Unilateral Pulling	142

35	PS13 - Primer Tac Rag	70	Bilateral Pulling/Pushing	143
		71	Bilateral Pulling/Pushing	144
36	PS32a & 32b Waxing Preparation	72	Bilateral Pushing	145
		73	Bilateral Pushing	146
37	PS22 Basecoat Manual Bonnet & Boot Lid	74	Bilateral below waist lift	147
		75	Bilateral below waist lift	148
38	PS23 Basecoat Manual Doors	76	Unilateral Pushing	149
			Unilateral Pulling	150
		77	Unilateral Pushing	151
			Unilateral Pulling	152
39	PS21 Basecoat Tac rag	78	Bilateral Pulling/Pushing	153
			Unilateral Pulling/Pushing	154
		79	Bilateral Pulling/Pushing	155
			Unilateral Pulling/Pushing	156
40	PS44- Offline- polish line-outer surface (station 1 & 2)	80	Bilateral pulling/pushing	157
			Bilateral Pulling/Pushing	158
		81	Bilateral pulling/pushing	159
			Bilateral Pulling/Pushing	160
41	Dispatch - Cushman Driver (CKD)	82	Bilateral below waist lift	161
			Steering wheel	162
			Ankle Plantar flexion	163
		83	Bilateral below waist lift	164
			Steering wheel	165
			Ankle Plantar flexion	166
		84	Bilateral below waist lift	167
			Steering wheel	168
			Ankle Plantar flexion	169
		85	Bilateral below waist lift	170
			Steering wheel	171
			Ankle Plantar flexion	172
		86	Bilateral below waist lift	173
			Steering wheel	174
			Ankle Plantar flexion	175
		87	Bilateral below waist lift	176
			Steering wheel	177
			Ankle Plantar flexion	178
		88	Bilateral below waist lift	179
			Steering wheel	180
			Ankle Plantar flexion	181
		89	Bilateral below waist lift	182
			Steering wheel	183

			Ankle Plantar flexion	184
		90	Bilateral below waist lift	185
			Steering wheel	186
			Ankle Plantar flexion	187
42	Dispatch Cushman Driver (Engine)	91	Bilateral below waist lift	188
			Steering wheel	189
			Ankle Plantar flexion	190
		92	Bilateral below waist lift	191
			Steering wheel	192
			Ankle Plantar flexion	193
		93	Bilateral below waist lift	194
			Steering wheel	195
			Ankle Plantar flexion	196
43	CKD Plant 6 Receiving Unboxing	94	Bilateral below waist lift	197
			Bilateral above waist lift	198
			Bilateral Pushing	199
		95	Bilateral below waist lift	200
			Bilateral above waist lift	201
			Bilateral Pushing	202
		96	Bilateral below waist lift	203
			Bilateral above waist lift	204
			Bilateral Pushing	205
		97	Bilateral below waist lift	206
			Bilateral above waist lift	207
			Bilateral Pushing	208
		98	Bilateral below waist lift	209
			Bilateral above waist lift	210
			Bilateral Pushing	211
44	Engine Warehouse Receiving Unboxing	99	Bilateral below waist lift	212
			Bilateral above waist lift	213
			Bilateral Pushing	214
		100	Bilateral below waist lift	215
			Bilateral above waist lift	216
			Bilateral Pushing	217
		101	Bilateral below waist lift	218
			Bilateral above waist lift	219
			Bilateral Pushing	220

Appendix E – Ethics Approval (University)

R14/49 «Tit init name»

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M170417

NAME: **(Principal Investigator)**	Thulani Khumalo
DEPARTMENT:	Centre for Exercise Science and Sports Medicine BMW Plant in Rosslyn, Pretoria - Health Management Department
PROJECT TITLE:	Determining the Normative Endurance Index for Automotive Workers. A Retrospective Study.
DATE CONSIDERED:	05/05/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Estelle Watson
APPROVED BY:	Professor P. Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	31/05/2017

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 3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the conditions under which I am/we are authorised 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 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 review in April and will therefore be due in the month of April 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 F – Ethics Approval (Automotive Company)

BMW GROUP
South Africa

Human Research Ethics Commitee.
University of the Witwatersrand.
Phillip Tobias Building,
Cnr York Road and Princess of Wales Terrace,
Parktown,
Johannesburg,
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2193

Your reference 0609713F
Our reference Thulani Khumalo (584308)
Department/From ZA-P
Telephone +27-12-522-2109
Fax +27-86-674-6302
e-mail Charissa.hector@bmw.co.za
Date 13 March 2017
Subject **Letter of Permission**

To Whom It May Concern,

This Letter serves as a declaration of my approval for Mr. Thulani Khumalo to use BMW employee data for his Masters research entitled:

"Determining the normative endurance index for automotive workers. A retrospective study."

Yours faithfully
BMW (South Africa) (Pty) Ltd.

Mrs. Charissa Hector
Director: Human Resources

Company
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Appendix G – Turn it in report

a0032182:Literature_Review_TK_12022018v2_(2).docx

ORIGINALITY REPORT

10%	5%	6%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	"Biochemical Adaptations to Endurance Exercise in Muscle", Annual Review of Physiology, 03/1976 Publication	1%
2	jap.physiology.org Internet Source	1%
3	www.sajcn.co.za Internet Source	1%
4	Holloszy, J.O.. "Adaptations of muscular tissue to training", Progress in Cardiovascular Diseases, 197605/06 Publication	1%
5	www.thefreelibrary.com Internet Source	1%
6	Cardiac Adaptations, 2013. Publication	1%
7	Submitted to Florida International University Student Paper	<1%
	Erin N. Branton. "A Short-Form Functional	

Appendix H – How data was collected from previous study

Measuring Tools for HR:

The Firstbeat Sports team premium pack from Firstbeat technologies (Yliopistonkatu) was used to collect HR data and it comprises of the following:

- Firstbeat Sports software license,
- Firstbeat heart rate belt monitors and
- Firstbeat team receiver with antenna, cable and tripod.

Measuring Tools for Work:

- Primus RS from BTE Technologies Inc. (Baltimore, MD).

Measurement Procedure:

This measurement procedure was done prior to this study and is not part of this research. It is included to give the reader an insight to how the data was collected prior to this current study.

The workers were invited to participate testing and this was during the period of 2014 – 2015, and would then sign an informed consent that their results could be used for research purposes but anonymity would be ensured On arrival the worker would be asked to sit down while a heart rate belt is being put on the chest. A physical readiness questionnaire would then be asked to risk stratify the worker. Resting blood pressure measurements (using Welch Allyn – Flexiport Reusable BP cuff: Adult 11) would then be taken after 5min of quiet sitting on the left arm. Height and weight measurements (using the Adam MDW-250L model scale) would follow and then the Appley's test would be performed to check for any upper limb ROM limitations and a squat test to check for lower body ROM limitations. When all of these were completed the participant would then be tested for dynamic endurance on the Primus BTE Machine based on the job that they do. The set force, height and attachment tool of the dynamic endurance test was specific to the uniqueness of each job. Heart rate responses at any instant were recorded by the Firstbeat devices. The endurance tests are a set of repetitive movements and the test dimensions based on force, height and attachment used were based on the specificity of the job. The endurance test would be done until one or some of the following criteria were met: 1. HR reached 85% of predicted HRmax, 2. Biomechanical signs of fatigue such as using substitutional muscles, 3. Drop in power output below the 75th percentile as shown in the Primus RS machine, 4. Doing the movement for 5 minutes as steady state will already be reached as explained in a book by Plowman and Smith (32), (see figure 1) and 5. Worker requests to stop due to fatigue.

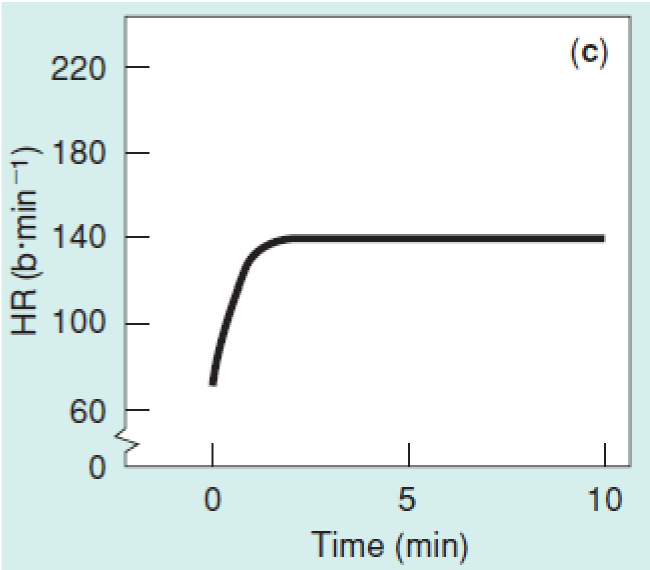

Figure 1. Steady state of HR

Physical demands/Endurance

The FCE which was performed on a worker is dependent on where the individual works. Dynamic endurance (at a set resistance based on the job requirements) which involves activities such as lifting (below/above waist), pushing (unilateral/bilateral), pulling (unilateral/bilateral) was tested. These dynamic tests were validated by Lechner and colleagues. They found that the interrater values (k coeffient) for below waist lifting was 0.78, 0.77 for above waist lift, 0.62 for pushing and 0.68 for pulling. The overall reliability was reported to be 0.74. The Dynamic endurance was tested on the BTE Primus RS machine which allows for functional dynamic testing and simulates real world dynamics as it has both concentric and eccentric components unlike

Isokinetic machines which test joints with accommodating resistance and at a constant speed. The BTE Primus machine is a machine which replicates functional activity that an individual performs.