THE EFFECTS OF INTERMITTENT TASK PARAMETERS ON MUSCLE FATIGUE DEVELOPMENT DURING SUBMAXIMAL DYNAMIC EXERTIONS

BY

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ABSTRACT

The negative effects of localised muscle fatigue on accidents, injuries and poor work performance are well known, as is the realisation that modifying task characteristics can minimise fatigue development. A large amount of literature has investigated the effects of task-dependent factors on localised muscle fatigue, most studies have focussed on prolonged or intermittent static (isometric) exertions. Few studies have investigated muscle fatigue development during more complex tasks, namely those which resemble common work activities and which tend to be intermittent and dynamic in nature. More specifically, the interactions between the main intermittent parameters - duty cycle, force level, and cycle time - during dynamic exertions are poorly understood. The purpose of this study was to investigate the effects of cycle time and combinations of duty cycles and force levels on the development of muscle fatigue during submaximal dynamic exertions while the overall mean muscle load was kept constant.

A two-factorial repeated-measures experiment was developed for this study. Nine experimental conditions, each lasting 16 minutes, aimed at inducing muscle fatigue in the middle deltoid muscle via intermittent dynamic shoulder abduction and adduction motions at three cycle times (30, 60, and 120 seconds) and three combinations of duty cycles and force levels. The percentage of muscle activation during one cycle (i.e. the duty cycle) varied depending on the exertion intensity (force level) so that the overall mean muscle load remained consistent throughout all experimental conditions, namely at 20% of maximum force exertion. As a result, the three duty cycle/force level combinations were: 0.8/25% of maximum voluntary force (MVF), 0.5/40%MVF, and 0.4/50%MVF. Muscle fatigue development was inferred by changes in peak torque, total work, average power, local Ratings of Perceived Exertion (RPE), and surface electromyographical (EMG) activity (time domain and frequency domain). Two-factorial analyses of variance with Tukey post-hoc tests were used to identify significant condition effects at $p<0.05$.

All dependent measures showed that muscle fatigue was induced by the 16-minute fatigue protocol. Peak torque, total work, average power, and EMG percentage of maximum showed that cycle time and the duty cycle/force level combination had no effect on the development of muscle fatigue, whereas the measures evaluated during the 16-minute fatigue protocol did. The cycle time of 120 seconds induced the greatest change in six of the eight variables, while the duty cycle/force level combination (0.8/25%) also resulted in the greatest effect in six of the measures. Fatigue was also found to be dependent on the interaction of cycle time and duty cycle/force level combination. The conclusion draws from this study is that shorter cycles and activities with short activation periods, and proportionally longer rest breaks result in the lowest fatigue developments.

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CHAPTER I - INTRODUCTION

1.1. Background to the Study

Fatigue is a broad term describing a complex and multi-factorial phenomenon (Rashedi & Nussbaum, 2015), thus making it difficult to define and measure (Chalder, Berelowitz, Pawlikowska, Watts, Wessely, Wright, & Wallace, 1993). Fatigue indicators range from subjective feelings such as tiredness, exhaustion or an increased effort to sustain an activity (Enoka & Duchateau, 2008). As well as objective measures such as the inability to sustain power, a gradual decrease in force capacity and an endpoint of a sustained activity. This is due to physiological changes in electromyography or exhaustion of the contractile function (Sherman, 2003; Enoka & Duchateau, 2008). Localised muscle fatigue has been described by Bigland-Ritchie and Woods (1984) as "any exercise-induced reduction in the ability of a muscle to generate force or power, regardless of the ability to sustain the task" (p. 691). The effects of localised muscle fatigue have been implicated to play a significant role in discomfort, accidents and injuries, and poor work performance (Kumar, 2001; Gorelick, Brown, & Groeller, 2002; Rashedi & Nussbaum, 2015). Localised muscle fatigue has also been hypothesised to be associated with work-related musculoskeletal disorders (WMSD) (Sahlin, Tonkonogi, & Söderlund, 1998; Seghers & Spaepen, 2004; Rashedi & Nussbaum, 2015). However, the exact role of localised muscle fatigue on the development of WMSDs is not clear yet (Frazer, Norman, Wells, & Neumann, 2003; Punnett & Wegman, 2004; Seghers & Spaepen, 2004; Rashedi & Nussbaum, 2016b). Nevertheless, it is important to investigate and understand localised muscle fatigue in order to develop interventions that can help improve the level of human performance, health and well-being (Sahlin *et al.,* 1998; Enoka & Duchateau, 2008).

Localised muscle fatigue has been studied in prolonged static exertions (e.g. Rohmert, 1960; Gamet & Maton, 1989; Hunter & Enoka, 2003) and there is a well-known relationship between the endurance time and level of effort that the muscle produces (Rohmert, 1960; Masuda, Masuda, Sadoyama, Mitsuharu, & Katsuta, 1999; Iridiastadi &

Nussbaum, 2006). A major factor that contributes to localised muscle fatigue under these prolonged static exertions is the increase in intramuscular pressure which reduces the blood flow to the working muscle (Tortora & Derrickson, 2009), which in turn decreases the oxygen and substrate supply to the muscle, while preventing metabolite removal (Sahlin *et al.,* 1998). With an increased understanding of localised muscle fatigue under prolonged static exertions, the attention has shifted to include exertions that are dynamic and intermittent in nature (Nussbaum, 2001; Frey-Law, Looft, & Heitsman, 2012; Ma, Chablat, Bennis, & Ma, 2012; Rashedi & Nussbaum, 2015). Prolonged static exertions have a large literature base and have been investigated extensively, therefore recommendations based on responses of static exertions have limited applicability. Understanding fatigue development during more complex manual work scenarios entailing intermittent and dynamic exertions can help with the design of less fatiguing occupational activities.

Intermittent tasks can be explained as variations in muscle activation levels, which include stopping and starting at regular or irregular intervals (Iridiastadi & Nussbaum, 2006). Cycle time, duty cycle, and force level are known as the primary task characteristics which, when used together in a task, characterise intermittent work (Potvin, 2012). The force levels allow for variations of muscle exertions, while duty cycle is the proportion of time an individual is engaged in the frequency of the task (Potvin, 2012). Cycle time is the total time from the beginning to the end of one process (Seghers & Spaepen, 2004), thus allowing a single cycle of activation and rest phase to be completed. Understanding the effects of the different task dependents (cycle time, duty cycle, and force levels) can provide an indication on how these tasks effect the development of muscle fatigue (Enoka & Stuart, 1992). As it is important to understand the effects and interactions of these intermittent elements because muscle fatigue is task dependent, meaning fatigue is heavily influenced by the variations of activation and rest phases and the way the task is structured (Enoka & Stuart, 1992; Potvin, 2012; Enoka & Duchateau, 2016).

Cycle time, duty cycle, and force levels have different effects on the development of muscle fatigue (Björkstén & Jonsson, 1977; Hermans & Spaepen, 1997; Hunter & Enoka, 2003; Seghers & Spaepen, 2004; Iridiastadi & Nussbaum, 2006). Moore (2000) pointed out that short cycle times can lead to the muscle not being able to relax completely which can affect the outcome of muscle fatigue development, conversely Iridiastadi & Nussbaum (2006), Yassierli & Nussbaum (2007), and Dickerson, Meszaros, Cudlip, Chopp-Hurley, & Langenderfer (2015) stated that even though fatigue development did not differ significantly between cycle times they did link shorter cycle times with a slower development of muscle fatigue. Therefore, the effects of cycle time on muscle fatigue development remain uncertain and this could be due to other task-related variables such as the variations of cycle time, variation in duty cycle or the amount of force that the task needs to be produced (Mathiassen, 1993; Seghers & Spaepen, 2004; Rashedi & Nussbaum, 2016b). Research findings on the effects of duty cycle and variation in force levels also tend to be inconsistent (Finneran & O'Sullivan, 2010b; Potvin, 2012) but the more common understanding is that a high level of force with a long duty cycle tend to increase the development of muscle fatigue compared to an exertion that has a low force level with a short duty cycle (Björkstén & Jonsson, 1977; Iridiastadi & Nussbaum, 2006).

Most studies in this area of research have kept at least one of these three task parameters constant and varied the other two which resulted in different overall workloads among conditions (Iridiastadi & Nussbaum, 2006). Therefore, differences found in localised muscle fatigue development could have been the result of the level of effort and not the effect of the individual task characteristics (Yassierli & Nussbaum, 2007). Dickerson *et al.* (2015) suggested that the overall workload (expressed as the "overall mean muscle load") needs to remain consistent. In other words, since the overall mean muscle load is the product of duty cycle and force level, an exertion with a high force level requires a short duty cycle, while a low force exertion level needs a greater duty cycle to achieve the same overall mean muscle load. By not having the same overall mean muscle load the fatigue responses could be influenced by the difference in the overall workload and not the intermittent characteristics (Yassierli & Nussbaum, 2007; Dickerson *et al.,* 2015). In theory, it is suggested that if each condition has the same overall mean muscle load the development of muscle fatigue should be the same, but Seghers and Spaepen (2004) state that it is still unclear whether different muscle-loading patterns with the same overall mean muscle load will have the same effect on the development of muscle fatigue.

Investigating intermittent isometric tasks is considered more relevant to the development of guidelines for occupational activities than prolonged static exertions (Rashedi & Nussbaum, 2015). However, intermittent tasks under isometric conditions account for neither important task-related biomechanical factors such as joint angle/muscle length and velocity, nor physiological aspects such as length-tension and velocity-tension relationships (Rashedi & Nussbaum, 2015). Yassierli & Nussbaum (2007) highlighted that, "while a number of studies have characterised muscle fatigue during purely isometric exertions, few have assessed fatigue associated with dynamic contractions" (p.1120). The reason why dynamic exertions are limited in research is because they are complex since the biomechanical and physiological aspects associated with the movement have to be taken into account (Farina, 2006). Research into the complexities of muscle fatigue development has been conducted on different and varying movement patterns as well as task characteristics (Nussbaum, 2001; Farina, 2006; Yassierli & Nussbaum, 2007; Yassierli & Nussbaum, 2009). Therefore, further investigation of intermittent dynamic exertions will elucidate how muscle fatigue development occurs under strenuous conditions, which can lead to decreased discomfort, accidents and injuries, and poor work performance (Iridiastadi & Nussbaum, 2006; Finneran & O'Sullivan, 2010a)

1.2. Statement of the Problem

Despite the extensive body of literature on localised muscle fatigue development during prolonged static muscle efforts, as well as intermittent isometric exertions, relatively few studies have investigated muscle fatigue development during more complex tasks such as dynamic intermittent exertions. Studies of localised muscle fatigue development need to include tasks that resemble common real life work activities and thus need to incorporate dynamic movements with intermittent task parameters, these being cycle time and the combinations of duty cycles and variations of force levels, as muscle fatigue is specific to the task being performed. This can provide a better understanding of the muscular reactions to relatively complex loading, which in the longer term could be used for more effective evaluation and design of work activities, which in turn could contribute towards reducing the accumulation of muscle fatigue and the problems related to it.

1.2.1. Aims of the Study

The objective of this study was to investigate the effects that cycle time and combinations of duty cycle and force level have on the development of muscle fatigue during dynamic exertions. Another objective was to determine whether these two factors, namely cycle time and the duty cycle/force level, would interact in ways that would results in different fatigue outcomes.

CHAPTER II - REVIEW OF RELATED LITERATURE

This review of literature has a three-fold focus, namely muscle exertions, muscle fatigue and the variations of task-related factors that lead to localised muscle fatigue. The section on muscle exertion will explain how a muscle exertion works, the factors that comprise of a muscle exertion, and the different types of muscle exertions. The section on muscle fatigue explains how muscle fatigue occurs and the consequences that are faced with muscle fatigue. The final section will explain the influences of different task characteristics and how they affect localised muscle fatigue.

2.1. Muscle Exertions

In 1954, Huxley & Niedergerke, and Huxley & Hanson published two papers that observed the changes in the sarcomeres and the position of the myosin and actin filaments at various stages of a muscle exertion. From these studies they concluded the theory of the sliding filament model which states that a muscle exertion occurs as a result of the myosin heads attaching to and moving along the thin actin filaments at both ends of a sarcomere.

In the skeletal muscle fibre, a contraction or relaxation starts at the neuromuscular junction. Neural impulses originate in the central nervous system and are propagated by the somatic motor neurons to the neuromuscular junction, (Farina, Negro, Muceli, & Enoka, 2016). For every somatic motor neuron there is an axon that extends from the brain or spinal cord to a group of skeletal muscle fibres. At the neuromuscular junction the nerve impulse triggers the release of acetylcholine (ACh) from the somatic motor neuron (McArdle, Katch, & Katch, 2010) into the synaptic cleft (the space between the neuron and target cell) at the synapses (the interface between the somatic motor neuron and muscle fibre). This release of the neurotransmitter allows chemical communication between the motor neuron and muscle fibre (Krans, 2010). The ACh binds to its receptors in the motor endplate, a region of the sarcolemma, opening an ion channel, and allowing Sodium (Na^+) to flow across the membrane. The inflow of Na^+ results in the muscle being more positively charged, and this charge triggers the next muscle action potential. This action potential runs along the sarcolemma and into the transverse tubule (T-tubule), which in turn causes the sarcoplasmic reticulum to release calcium ions (Ca^{2+}) (Disselhorst-Klug, Schmitz-Rode, & Rau, 2009; Enoka, 1995).

The release of Ca^{2+} into the sarcoplasmic reticulum initiates a complex cellular reaction with adenosine triphosphate (ATP). During this process the myosin filament of a myofibril attaches its head to the myosin binding site of the actin filament (crossbridge formation), and pulls on the actin filament during what is known as the power stroke. This results in the filaments sliding past one another and thus generating force (Sahlin *et al.,* 1998). At the onset of a contraction, and as long as Ca^{2+} and ATP are available, the actin and myosin filaments will continue pulling on each other and the twitching of the muscle will continue (Sahlin *et al*., 1998).Electromyography can be used to observe the number of motor units and the frequencies of the electrophysiological discharges, indicating the rate of muscle activity (Disselhorst-Klug *et al.,* 2009). Motor neurons are the major efferent neurons that supply muscle fibres with control commands from the central nervous system (Lui, Brown, & Yue, 2002; Dimitrova & Dimitrov, 2003). Motor units, contract simultaneously, resulting in motor unit action potentials. This leads to an increase in the firing rate and the number of active motor units will lead to an increase in the muscle tension and thus the force produced. Relaxation occurs when the stimulation of the muscle fibres via the motor neurons stops. When this occurs, the Ca^{2+} is pumped back into the sarcoplasmic reticulum, away from the actin and myosin, thus breaking the link between both of them. When Ca^{2+} is removed, the actin and myosin cannot interact and they return to their natural state, which is ultimately a relaxed muscle (Tortora & Derrickson, 2009).

2.1.1. Types of Muscle Exertions

A muscle's force-generating capacity depends on the number of crossbridges in each sarcomere and the geometrical arrangements of the sarcomeres (Bigland-Ritchie & Woods, 1984; Krans, 2010). A muscle exertion is described by two factors, namely muscle length and muscle force (Tortora & Derrickson, 2009). Muscle length are defined by exertions known either as concentric or eccentric exertions (Padulo, Laffaye, Chamari,

& Concu, 2013). These exertions depend on whether the distance between a muscle's origin and its insertion decreases or increases respectively (Tortora & Derrickson, 2009). When a muscle shortens the thin filaments pull towards the M-line, meaning that the filaments meet at the centre of the sarcomere (Huxley & Niedergerke, 1954; Huxley & Hanson, 1954). Tortora and Derrickson (2009) explain that when a muscle tissue is stimulated by an action potential the muscle will contract and generate tension, which allows a pulling force to be exerted on its attachment points. If the tension produced is greater than the resistance of the object, the muscle will shorten and movement will occur. This is known as a concentric exertion, while during an eccentric action, the length of the muscle increases. During this exertion, the tension that is formed by the myosin crossbridges resists movement of a load that is produced on the muscle and thus slowing the lengthening process. This leads to a drop in force capacity of the muscle fibres, leading to less motor unit activity (Duchateau & Enoka, 2016).

Muscle force can be defined as the active force generated by a muscle exertion in response to resisting the external forces (Tortora & Derrickson, 2009). This means that the amount of muscle force that can be produced is dependent on the level of tension created within the muscle (Liu *et al*., 2002) during the power stroke. It is the pulling of the actin filaments by myosin heads towards each other that exerts this tension (Rassier, MacIntosh, & Herzog, 1999).The magnitude of the force created depends on the number of motor units that are recruited and the rate at which they discharge action potentials (Duchateau & Enoka, 2016).

There is a general consensus in the literature that the two broad terms to explain movements are "static" and "dynamic" (Klavora, 2007; Ma *et al.,* 2012; Luger, Bosch, Hoozemans, Veeger, & de Looze, 2016). A static, also known as an "isometric" exertion (Tortora & Derrickson, 2009) is a muscle action where there is no visible change in the muscle length, the fibre length, or sarcomere length, even though the muscle produces a force (Rassier *et al.,* 1999). Dynamic exertions, on the other hand, involve movement and therefore changes in the muscle length. These exertions are more complex due to inherently larger variations in motor unit recruitment and blood flow and changes in the muscle fibre recruitment strategies (Rashedi & Nussbaum, 2015). When performing a dynamic exertion, there is a continuous change in joint angle and movement speed which results in either an increase or decrease in tension (Klavora, 2007). It is for these reasons that dynamic movements are complicated to measure since these factors influence the way that muscle fibres are recruited (Farina, 2006).

2.2. Muscle Fatigue

Fatigue has been described as the body's natural protection against serious damage due to physical overexertion (Sherman, 2003; Chaffin, 2009). Awareness of fatigue in the body is an important part of the feedback loop needed to provide information about individual threshold limits (Sherman, 2003; Chaffin, 2009). The sources of fatigue development can occur anywhere along the neuromuscular pathways. Central fatigue occurs at the level of the central nervous system which consists of the brain and the spinal cord where the impulses that stimulate muscles originate (Davis, 1995; Tortora & Derrickson, 2009). Central fatigue can be expressed as the failure, voluntary or involuntary, of the neural drive, resulting in a decrease in the number of stimulated motor units or the decrease in motor unit firing frequency (Edwards, 1981).

Peripheral fatigue is known as the failure of the force generation capacity of the muscle itself. This occurs at the level of the peripheral nervous system and the contractile mechanisms within the muscle, thus encompassing all the nervous tissues that are not comprised in the central nervous system, namely the spinal nerves and their branches, sensory receptors, cranial nerves, and the ganglia (Tortora & Derrickson, 2009). When the muscle is fatigued at a peripheral level there may be fault in the transmission mechanism that can be caused by the depletion of substances or even the accumulation of catabolites or other by-products that have been discharged by the muscle activity (Asmussen, 1979). This happens because during exertions, muscles recruit ATP from creatine phosphate by anaerobic cellular respiration and by aerobic cellular respiration. Both pathways generate metabolites and waste products, which accumulate and significantly decrease the pH inside the muscle cell (Rozand, Cattagni, Theurel, Martin, & Lepers, 2014). This build-up of metabolites and waste products interferes with the many biochemical reactions that are necessary for the actin and myosin to produce enough force to create a muscle exertion (Sahlin *et al*., 1998). Even though central fatigue is considered a causal factor of muscle fatigue, peripheral fatigue is noted as being a more substantial contributor to localised muscle fatigue development (Rashedi & Nussbaum, 2015), which is why localised muscle fatigue has received large amounts of attention as a research variable, particularly during sub-maximal exertions in occupational settings.

2.2.1. Indicators of Localised Muscle Fatigue

Localised muscle fatigue can be characterised by feelings of discomfort, pain or other changes that individuals tend to notice occurring within the body before objective changes occur (Hunter & Enoka, 2003). Borg (1982) pointed out that subjective ratings may be more important that objective ones, since the observations of discomfort may result in changes in performance regardless of whether, or not, the discomfort has exhibited physiological changes within the body. The ratings of perceived exertions (RPE) scale has been used as the set standard for most studies that measured subjective fatigue resulting from a given task (Hermans & Spaepen, 1997; Hunter & Enoka, 2003; Iridiastadi & Nussbaum, 2006; Finneran & O'Sullivan, 2010a; 2010b).

Localised muscle fatigue can also be identified by a decline in work output (Sherman, 2003) which can have a large impact on the level of task performance. As a muscle fatigues work output could be diminish due to the decline in force or power (Vøllestad, 1997), since the force producing mechanisms in the muscle are inhibited (Chaffin, 1973).

The effect of muscle fatigue on the motor units can be observed from surface electromyography (EMG) signals. To sustain a particular force a motor unit needs to be repeatedly activated (Clancy, Bouchard, & Rancourt, 2001). The overall magnitude of the motor units excitation level can provide insight into muscle effort (Clancy *et al.,* 2001), because the magnitude of a muscle activation depends on the number of motor units that are recruited and the rate at which they discharge action potentials (Duchateau & Enoka, 2016). The debate on whether EMG can be measured when doing dynamic movements is because when doing a dynamic movement there is change in the joint angle as the muscle moves through a ROM (Farina, 2006). To address this problem Halaki and Ginn (2012) recommended that "maximum dynamic (usually isokinetic) contraction be used to obtain reference EMG levels in order to normalise EMG data obtained during movement"

(p. 184). Their method proposes that a participant needs to perform a maximum isokinetic contraction at a speed that is similar to the dynamic task that is being measured.

The measurement from EMG can show that a muscle is fatiguing in a number of ways. The first being, increases in EMG signal amplitude during submaximal exertions by means of root mean square (RMS) (Balasubramanian, Adalarasu, & Regulapati, 2008; Bosch, Mathiassen, Hallman, de Looze, Lyskov, Visser, & Van Dieën, 2012). This amplitude is used to quantify the electric signal recorded by EMG as it reflects the physiological activity from the motor units (Fukuda, Echeimberg, Pompeu, Lucareli, Garbelotti, Gimenes, & Apolinário, 2010) and therefore there should be an increase in amplitude when the muscle fatigues. Secondly, a decrease in the EMG amplitude produced during maximum voluntary exertions (MVE), as a decrease in maximal EMG amplitude expresses that the muscle is fatigued (Christensen, Søgaard, Jensen, Finsen, & Sjøgaard, 1995; Potvin & Bent, 1997; Nussbaum, 2001; Yassierli & Nussbaum, 2007; de Looze, Bosch, & Van Dieën, 2009). Thirdly, a shift in the frequency spectrum to lower frequencies (Bosch *et al*., 2012; González-Izal, Malanda, Gorostiaga, & Izquierdo, 2012). During a task there will be changes in the shape of the EMG frequency spectrum, and when a muscle fatigues there is usually a spectral shift to the left as lower frequencies are maintained when a muscle is fatigued (Halaki & Ginn, 2012). This means that, as a muscle fatigues, there is a shift to the lower frequencies as fast twitch motor units drop out first, these are the higher frequencies and slow twitch motor units are obtained, these being the lower frequencies (Dimitrova & Dimitrov, 2003). Other evidence indicates that changes in EMG due to fatigue can also be explained by the effects of fatigue on motor unit action potential conduction velocity. Conduction velocity is the speed with which motor units are recruited when performing an exertion (Farina, 2006). When the muscle fatigues there is a utilization of ATP, which generates metabolites and waste products, which in turn leads to a decrease in the pH inside the muscle cell (Rozand *et al*., 2014). This decrease in the pH causes a decrease in the conduction velocity, which shows on EMG data as a decrease in the spectral frequencies (Farina, 2006; González-Izal *et al*., 2010). Due to that normalisation of the EMG power frequency is not needed as the important part when looking for fatigue is the shape of the power spectrum and not the amplitude of the EMG signal (Halaki & Ginn, 2012, González-Izal *et al.,* 2012). Both median power frequency (MdPF) and mean power frequency (MnPF) are resultant from the spectral analysis. Therefore, if there is a decrease in the MdPF and the MnPF it can be concluded that fatigue has occurred (De Luca, 1993; Soderberg & Knutson, 2000; Phinyomark, Thongpanja, Hu, Phukpattaranont, & Limsakul, 2012).Usually, it is the combination of these factors (RMS, EMG(%MVE), MnPF, and MdPF) that indicates the development of muscle fatigue (Halaki & Ginn, 2012).

2.3. Task Factors

Muscle fatigue is task dependent, meaning that the development of muscle fatigue is influenced by the specific task demands that the muscle needs to execute (Enoka & Stuart, 1992). Tasks can vary in their exertion times, durations, frequencies, load magnitudes, on-off ratios, and recovery times (Rashedi & Nussbaum, 2015). These task characteristics can be investigated during maximal and submaximal exertions, static or dynamic muscle actions, as well as prolonged or intermittent exertions, thus creating a complex picture of the many task-dependent variables that contribute to fatigue development.

Determining whether a muscle exertion is producing a maximal or submaximal force depends on the magnitude of a muscle activation (Duchateau & Enoka, 2016). A maximal muscle exertion has been studied under two conditions: one being an involuntary maximal exertion, and the other being a voluntary maximal exertion. Involuntary maximal exertions have limited applicability, since they rarely occur in real life tasks. Electrical stimulation is used to recruit all motor units, therefore achieving the maximum contractile force of that muscle (Vøllestad, 1997). This produces higher values compared to a maximal voluntary exertion (MVE), which is defined as the greatest muscular force generated with feedback and encouragement, and when participants believe that they have exerted their maximal force (Vøllestad, 1997). When a participant produces a MVE most of the motor units are activated in a muscle, but there will always be some inactive motor units. Since most of the motor units are used, a maximal exertion cannot be held for a long period of time (Maton, 1981).

In contrast to maximum exertions, a submaximal exertion refers to a percentage of the maximal exertion that can be produced, and the resultant force is generated by a certain number of motor units. Fewer motor units recruited during a submaximal exertion means that a lower tension is produced by the muscle, which in turn allows for the force duration to last longer since there are more inactivate motor units that can be recruited, or rotated (Klavora, 2007). Moritani, Stegeman, & Merletti (2004) express that motor unit recruitment and firing frequency depend primarily on the level of force and the velocity of the condition. Therefore, both MU recruitment and firing rates cannot be used individually for expressing the increase in EMG activity. Changes in EMG activity can be affected by MU recruitment, firing rates, individual muscle fibre potential, degree of MU discharge synchronisation, and fatigue (Moritani, Stegeman, & Merletti, 2004). Since submaximal exertions are performed in real life situations and occupational factors, investigating the effects of task parameters on localised muscle fatigue needs to be done during a submaximal state.

2.3.1. Submaximal Prolonged Static Exertions

Prolonged work is expressed as a muscle exertion that is performed continuously, without work-rest intervals (Rohmert. 1960; Maton & Gamet, 1989; Hunter & Enoka, 2003). These types of tasks lead the muscle to fatigue quickly, as they do not allow the muscle to recover. This results in insufficient blood flow to muscles caused by an increase in intramuscular pressure, which in turn decreases the supply of energy (oxygen) and leads to an accumulation of metabolites (Bigland-Ritchie & Woods, 1984). When oxygen is present in a muscle the oxidative phosphorylation pathway can produce ATP at very fast rates (Tortora, & Derrickson, 2009). However, when the demand for oxygen is greater than the supply, the muscle starts to fatigue due to an inadequate oxygen supply, since the Krebs cycle and electron transport chain cannot function without it, hence hindering the excitation-contraction coupling process (Bigland-Ritchie & Woods, 1984; Tortora & Derrickson, 2009). The resultant accumulation of by-products and lack of oxygen to the muscle would interfere with the force production.

Rohmert (1960) stated that a prolonged static exertion of up to 15% MVE could be maintained indefinitely. However, Sjøgaard, Kiens, Jorgensen, and Saltin (1986) and Enoka (1995) contested this, stating that not even an activation of 5% MVE could be maintained indefinitely. This could be because, as the muscle performs a submaximal exertion, mainly type I muscle fibres are recruited first and, as the exercise fatigues the muscle, an increasing amount of type II muscle fibres are recruited (Srinivasan, Lungren, Langenderfer, & Hughes, 2007; Reese & Bandy, 2013). In addition, the motor unit action potential (MUAP) firing rate is increased (Maton, 1981). Non-active motor units that are in reserve are due to the ability to recruit higher thresholds and the potential increase in the firing rates (Merletti & Parker, 2004). Only once all the motor units have been recruited, and the MUAP firing rate has increased to its maximum, is the muscle said to be exhausted (Bigland-Ritchie, Furbush, & Woods, 1986). Performance can also be maintained during submaximal exertions due to motor unit rotation. This theory states that motor units that are fatigued are replaced by other previously non-active motor units (Maton, 1981), thereby maintaining the muscles' force output.

Recovery, or the total amount of rest time available in a task, is important in ensuring adequate rest for active fibres as this allows restoration of blood flow. Blood flow brings oxygen to the muscles and removes waste produces that may interfere with the contractile mechanisms (Rozand *et al.,* 2014). The pattern of these work-rest phases are also important (Moore, 2000). Workers who produce great levels of muscle load/force need to have sufficient amount of recovery or rest breaks so that their motor units do not get overloaded (Mathiassen, 2006). Prolonged exertions, even under such low MVEs result in a faster development of fatigue because the muscle does not get a moment to rest (Klavora, 2007).

If a task is using a low to moderate force level and the task is constant over time; muscle fatigue will develop and lead to a failure point. This failure point is well defined for prolonged static muscle loads. However, substantially less is known about the development of muscle fatigue during low exertion intermittent and dynamic tasks (Sherman, 2003; Iridiastadi & Nussbaum, 2006). Understanding muscle fatigue development under intermittent and dynamic tasks moves the attention to more realistic exertions, as prolonged static exertions are not nearly as prevalent as intermittent or dynamic exertions for real life situations and occupational factors, therefore having limited applicability (Rashedi & Nussbaum, 2015).

To prevent the development of localised muscle fatigue and problems associated with it, investigations should focus on understanding the fatigue mechanisms of all exertions, including those than are more complex in nature, such as intermittent and dynamic tasks.

2.3.2. Submaximal Intermittent Isometric Exertions

Intermittent isometric tasks are more relevant to occupational activities than single, prolonged static exertions (Rashedi & Nussbaum, 2015). They also have a positive effect on the delay of muscle fatigue compared to prolonged static exertions, because the development of muscle fatigue likely depends on the task as well as the amount of recovery time that is between each exertion (Sherman, 2003). For this reason authors such as Veiersted, Westgaard, & Anderson (1990), Mathiassen (1993), and Lui *et al.* (2002) propose that an increased variation in a task may lead to less muscle fatigue compared to merely decreasing the load in a task. Even if a load is reduced, if there is no time for the muscle to completely rest, the muscle will fatigue over time, which is why a prolonged static exertion will always reach a failure point (Sherman, 2003) regardless of the level of force generated.

Muscle fatigue will affect the level of force production (Lui *et al.,* 2002; Enoka & Duchateau, 2008), but if the muscle is allowed to rest, the time in the absence of force production is used to restore the fatigued muscle state due to the restoration of blood flow (Rashedi & Nussbaum, 2016a). There are however numerous other factors that allow for recovery in the absence of force production; for example, central factors such as the body's ability to recognise serious damage due to physical overexertion determine threshold limits and thus determine recovery rates (Sherman, 2003). It is important to acknowledge that central factors underlying fatigue and recovery are broad and that this investigation on localised muscle fatigue is limited to the peripheral level. While the total amount of rest time available in a task is important in ensuring adequate rest for active fibres, Moore (2000) pointed out that a work-rest schedule is also important. Workers who perform hard labour produce high muscle loads and therefore need to have the right amount of recovery or rest breaks to prevent overloading their motor units (Mathiassen, 2006). Understanding the influence of cycle time, duty cycle and force variation (intermittent loads) in muscle recovery is needed to conclude the suitable loading pattern for the muscle to prevent the development of muscle fatigue.

Research studies on intermittent work have used a wide spectrum of cycle times, ranging from 10 to 166 seconds (Mathiassen, 1993; Hermans, & Spaepen, 1997; Seghers & Spaepen, 2004; Iridiastadi & Nussbaum, 2006; Yassierli & Nussbaum, 2009; Dickerson *et al*., 2015), thus complicating comparisons between studies. This shows that the effect of cycle time on muscle fatigue development are currently contradictory. Researchers such as Mathiassen (1993), Iridiastadi & Nussbaum (2006), Dickerson *et al.* (2015), and Rashedi & Nussbaum (2016b) state that shorter cycle times could be linked to a slower development of muscle fatigue; however, the differences in responses were not sufficient to state that cycle time duration is a main dependent factor linked to the development of muscle fatigue and Iridiastadi & Nussbaum (2006) express that there is no consensus on the physiological benefits of shorter cycle times. Studies by Mathiassen (1993), Iridiastadi & Nussbaum (2006), Dickerson *et al*. (2015), and Rashedi & Nussbaum (2016b) all express that cycle time may have played a factor in the development of muscle fatigue but it cannot be considered in isolation as the contraction levels and duty cycle may have influenced the level of muscle fatigue. Byström, Mathiassen, & Fransson-Hall (1991) and Finneran & O'Sullivan (2010a), on the other hand, believe that longer cycle times which include varieties of subtasks (force variations and duty cycles) may be more beneficial than short cycle times that are highly repetitive. Rashedi & Nussbaum (2016b) agree that very short cycle times are not beneficial to preventing the development of muscle fatigue either. However, Rashedi & Nussbaum (2016b) believe that very long cycle times can have the same effect. Yassierli & Nussbaum (2007) and Rashedi & Nussbaum (2015) also express that cycle time may impact the development of localised muscle fatigue, but with less significant effects compared to the force level that is produced on a muscle.

Studies such as Mathiassen (1993), Iridiastadi & Nussbaum (2006), and Dickerson *et al*. (2015) have investigated cycle time involving biomechanically complex systems such as the shoulder joint. Conversely, a study conducted by Rashedi & Nussbaum (2016b) investigated the effects of cycle time on the development of muscle fatigue using a simple biomechanical system, the index finger. Rashedi & Nussbaum (2016b) stated that using complex systems may make it more difficult to identify the effects of cycle time on localised muscle fatigue development, as changes in load sharing between multiple muscles or within muscles, i.e. changes in agonistic and antagonistic recruitment or changes in recruitment of the muscle, could be the reason why cycle time has displayed inconsistent results across various measures (Rashedi & Nussbaum, 2016b). These authors' study concluded that when using simple biomechanical systems, there was a beneficial effect from a shorter cycle time. However, Rashedi & Nussbaum (2016b) did point out that their study was not beneficial for industrial or other tasks. Nevertheless, focusing at the simple systems rather than at a complex systems helps to address the mixed outcomes from previous research, such as the effects of cycle time.

Studies that have investigated the interactions between cycle time, duty cycle and variation in force levels on the development of localised muscle fatigue under isometric conditions in biomechanically complex systems showed that muscle fatigue is sensitive to the intermittent elements, but the specific effects from cycle time still remain uncertain (Hermans & Spaepen, 1997; Seghers & Spaepen, 2004; Iridiastadi & Nussbaum, 2006; Rashedi & Nussbaum, 2015). The fact that the effects of cycle time on muscle fatigue development is unclear could be due to other task-related variables, such as the variations of cycle time throughout studies, the amount of force that needs to be produced, or the variation in duty cycle (Björkstén & Jonsson, 1977; Mathiassen, 1993; Hermans & Spaepen, 1997; Engström, Hanse, & Kadefors, 1999; Seghers & Spaepen, 2004; Moore & Wells, 2005; Rashedi & Nussbaum, 2016b).

Armstrong, Buckle, Fine, Hagberg, Jonsson, Kilbom, Kuorinka, Silverstein, Sjogaard, & Viikari-Juntura (1993) explain that a muscle is able to recover from fatigue if the muscle is given sufficient rest. However, the amount of rest that is needed depends on the amount of fatigue that has accumulated, the intermittent task demands, and individual factors such as motivation (Armstrong *et al.,* 1993). Christain, Bishop, Billaut, & Girard (2014) also express that the effects on the muscle from a submaximal exercise is influenced by a conscious pacing strategy. This strategy is determined by the experience of the task, motivation, and knowledge of the task duration. The effects of fatigue can also be noted in studies such as those by Björkstén & Jonsson (1977) and Moore & Wells (2005) who concluded that high exertion levels and high duty cycles caused higher rates of localised muscle fatigue development since there was an increase in the total effort generated over the given time period. This is in line with the study by Finneran & O'Sullivan (2010b) that investigated the effects of force and exertion duration on duty cycle time. They found that a task with a high level of force resulted in a higher level of discomfort and a decrease in the self-paced duty cycle duration, meaning that when participants performed a task requiring a high force production, they needed a longer recovery time. It can thus be suggested that to prevent a muscle from fatiguing, the maximum amount of rest is dependent on the task duty cycle (% of total working time) (Moore, 2000). This was also suggested in the Horton, Nussbaum, & Agnew (2012) study which investigated the difference between rotating between a high and low force (15% and 30% MVE) during a static intermittent shoulder exertion protocol (cycle time: 30 seconds; duty cycle: 0.33). The condition that had a 30% MVE and did not alternate between force levels resulted in the greatest fatigue effect, while the condition that required an exertion level to stay the same for the whole task was more fatiguing than a condition that changed exertion levels through the protocol. Rotating between force levels in a task can hence be considered to be more effective for the prevention of muscular fatigue than only performing a task at a consistently high force level (Horton *et al*., 2012). However, the task that did not alternate force levels and had the lowest exertion level (15%MVE) was found to be the least fatiguing condition. This indicates that conditions that have a higher overall mean muscle load will produce a higher fatigue rate over conditions that have a lower mean muscle load. The same outcome was seen by Iridiastadi & Nussbaum (2006) who also found that low duty cycles and low exertion levels were less fatiguing compared to all the other conditions that had either a higher duty cycle or a higher exertion level. This strengthens the argument that when the workload is higher the muscle will fatigue more. This should be the case as a condition that has a low duty cycle and a low exertion level would have the lowest overall mean muscle load and this condition would therefore be the least fatiguing compared to conditions with either a higher duty cycle, or exertion level, or both. Therefore, the effects on the muscles are highly dependent on the interaction between the duty cycle and force levels (Iridiastadi & Nussbaum, 2006). Yung, Mathiassen, & Wells (2012) also investigated the effects of intermittent work designs during isometric exertions. The purpose was to examine the effects of sustained exertions compared to intermittent exertions on muscular fatigue. In addition, the study also investigated whether intermittent workloads of 0%MVE rest between exertions was different to force variations that would have the same overall mean muscle load. King and Mattison (2017) investigated the same aspect and noted that conditions, that had the same overall mean muscle load, but had an intermittent ratio of 0%MVE fatigued less compared to other conditions which had a low exertion levels. Yung *et al* (2012) concluded that fatigue rates would be less when a condition has an intermittent aspect compared to a condition that is prolonged static. Conditions that were intermittent also vary in fatigue levels, showing that a condition with a 0%MVE may be the less fatiguing. However, Yung *et al* (2012) did express that there needs to be more attention on the effects of "time-varying forces" meaning looking at conditions that have an underlying low exertion load (without complete muscle rest). To investigate which condition would lead to less muscular fatigue, conditions would need to have the same overall mean muscle load so that the resultant muscle fatigue can be attributed to the intermittent characteristics, rather than the effect of the workload placed on the working muscles. Therefore, what needs to be investigated is the interactive effect between cycle time, variations in duty cycle and force levels when the overall mean muscle load is the same in order to determine how fatigue development is influenced by each task variable (Dickerson *et al*., 2015). In theory, it is suggested that if each condition has the same overall mean muscle load (which is calculated as the product of the force produced and the duration of this exertion (or lack thereof)) the development of muscle fatigue should be the same; however it is still unclear if that is the case (Seghers & Spaepen, 2004) Therefore, during an intermittent protocol the cycle time, duty cycle and force level must be changed in a systematic manner as the variation in the muscle load may help prevent the development of muscle fatigue, rather than just the decrease in the amount of load.

Even though the studies cited above have explored many questions to understand muscle fatigue development under different task conditions, they have only investigated intermittent work with isometric exertions. This is because isometric muscle exertions are easier to test and can be performed with simpler equipment and with fewer factors needing to be controlled, such as the range of motion, the shortening and lengthening of the muscle, and the velocity of the movement (Rashedi & Nussbaum, 2015). Tasks that are closer to real life workplaces need to incorporate dynamic movements with intermittent task parameters. However, the evaluation and understanding of dynamic exertions is complicated, which is why limited amounts of studies that have investigated these exertions exist.

2.3.3. Submaximal Intermittent Dynamic Exertions

Masuda *et al*. (1999) investigated muscle fatigue development by comparing the fatigue responses of a prolonged static exertion with those of a prolonged dynamic exertion. They concluded that the static prolonged exertion resulted in significantly greater muscular fatigue than the dynamic exertion. Masuda *et al.* (1999) and Kay, St. Clair Gibson, Mitchell, Lambert, & Noakes (2000) argued that this was due to differences in blood flow, which was maintained during the dynamic exertion, but occluded during the static exertion. When producing a dynamic exertion the muscle lengthens and shortens which enhances the blood flow through improved venous return from the contracting muscle. This increase in blood flow removes metabolic by-products and thus slows down the decrease in the intracellular pH (Masuda *et al*., 1999). The reason for this is that dynamic exertions involve movement, and these changes in the muscle length make the exertions less fatiguing due to inherently larger variations in blood flow. This is because when performing a dynamic exertion the muscle contracts and relaxes, thus acting like a pump for the flow of the blood in the blood vessels, which in turn allows the body to supply oxygen to the muscles (Rashedi & Nussbaum, 2015). Concentric and eccentric exertions were also found to produce less fatigue compared to isometric exertions by Kay et al. (2000) study as well. It was even noted that participants were able to maintain an eccentric submaximal exertion longer than a concentric or isometric exertion. Kay et al. (2000) express that the reason for this may be because during an eccentric exertion the incomplete use of the motor units could allow for the backup of fresh motor units during this activity, which allows the muscle to maintain its capacity without the need to amend the firing frequency. This means that exertions that are dynamic in nature would be better for the prevention of muscular fatigue compared to prolonged static exertions. However, studies such as these are limited due to the complex nature of a dynamic movement (Rashedi & Nussbaum, 2015).

Studies that have investigated the effects of dynamic actions on fatigue tend to only consider the movement when doing a maximal exertion rather than during a submaximal exertion. To eliminate the problems faced with dynamic actions such as ROM, velocity and force, these studies test dynamic actions with the use of isokinetic movements (Gerdle, Elert, & Henriksson-Larsén, 1989; Kellis, 1999; Larsson, Månsson, Karlberg, Syvertsson, Elert, & Gerdle, 1999). The isokinetic dynamometer measures force production at a constant movement velocity by accommodating the resistance throughout a joint's range of motion (Drouin, Valovich-mcLeod, Shultz, Gansneder, Perrin, 2004). When performing maximal dynamic isokinetic exertions the above studies noted that as a muscle fatigues there is a decrease in maximal force, a shift in the spectral frequency, and an increase in EMG (RMS) amplitude. However, dynamic actions do not always have to only be done through the use of an isokinetic movement as González-Izal, Malanda, Navarro-Amézqueta, Gorostiaga, Mallor, Ibańez, & Izquierdo (2010) and Rogers & MacIsaac (2013) also identified the same effect from EMG when performing a maximal dynamic exertions.

Studies by Kossev & Christova (1998), Kellis (1999), Linnamo, Bottas, & Komi (2000), and Pincivero, Gandhi, Timmons, & Coelho (2006) investigated the effects of motor unit activity during concentric and eccentric movements and noted that motor unit activity differs when a muscle is lengthening or shortening due to the length-tension, and force-velocity relationships. The length-tension relationship refers to the relationship between the length of a muscle fibre and the force that it can produce by the muscle's active components at that length (Abbott & Wilkie, 1953; Hill, 1953). It indicates how the forcefulness of a muscle exertion depends on the length of the sarcomeres (or the overlap of actin and myosin) within a muscle before an exertion begins (Tortora & Derrickson, 2009). An inverted-U depicts the relationship between muscle length and force producing capability, with the greatest tension generally created mid-way through the range of motion. The force–velocity relationship refers to the phenomenon that a muscle's force and the velocity of the exertion are related. For a concentric action the relationship is inversely related, meaning that when an exertion velocity is high, the maximum muscle force that can be produced is low, and when the exertion velocity is low the muscle force produced will be high (Bobbert, 2012). However, for an eccentric action the force-velocity relationship is the other way around, namely when contraction velocity is low, the force producing capacity is also low, while a high velocity allows the muscle to produce a high force (Abbott & Wilkie, 1953). Due to these factors, the EMG activity will differ between static and dynamic exertions, which complicates the quantification of the internal effort or workload. The practical application of using internal load as a measure of internal workload is therefore not viable when dealing with workplace scenarios.

The outcome of the above discussion is thus a shift towards using external load, which refers to the forces that are executed on the body (Karwowski & Marras, 2003), as a more convenient, accessible, and practical method to control the amount of external resistance the muscle encounters throughout the task (Costa, Herda, Herda, & Cramer, 2016). A weight, or external load, placed onto a moving extremity will have the same resistance throughout the range of motion, meaning that there is the same inertia in both the concentric and eccentric phases of the movement (Klavora, 2007). The range of motion affects the movement of the muscle, due to the length-tension theory, which in turn affects the magnitude of a muscle exertion, even though the external load applied to the extremity does not change (Tsianos & Loeb, 2013).

A study by Sundberg & Bundle (2015) investigated the effects of a short and long duty cycle (0.3 and 0.6) with the same force and dynamic leg movement and found that the condition that had the longer rest (i.e. the 0.3 duty cycle) led to less fatigue and better force production. This was seen through the shift of the power spectrum to the lower frequencies and the increase in RMS amplitude. The authors argued that this could have been because the longer rest phases may have provided a greater opportunity for blood flow and oxygen delivery. Yassierli & Nussbaum (2007) conducted a study on the fatigue effects of the shoulder joint in 2007, and of the torso in 2009 during intermittent isokinetic exertions. Both studies found that manipulating cycle time, duty cycle or force levels, exertions with a higher workload (overall mean muscle load) resulted in higher levels of muscular fatigue, as evidenced by shorter endurance times and a larger changes in the fatigue measures such as maximal force and changes in EMG measures (both time and frequency domain). These outcomes concur with findings from intermittent isometric exertions that greater workloads result in increased fatigue responses. It is for these reasons that investigations into fatigue development during more realistic scenarios need to not only acknowledge the dynamic and intermittent nature of these tasks, but also keep the over overall mean muscle load constant.

CHAPTER III: METHODS

3.1. Hypotheses and Experimental Design

The purpose of the current study was to investigate the influence of selected task characteristics on muscle fatigue development during intermittent dynamic exertions. This was guided by the following questions:

1. Whether changes in cycle time during intermittent dynamic exertions would lead to different levels of muscle fatigue
2. How do various combinations of duty cycle and force levels (with the same overall mean muscle load) influence muscle fatigue development
3. Whether muscle fatigue is affected by an interaction between cycle time and the duty cycle/force level combinations.

A repeated measures 3x3 factorial study was developed, with participants performing nine different fatigue protocols involving dynamic intermittent exertions, with cycle time as one factor and combinations of duty cycle and force levels as the second factor. Each factor had three levels, hence resulting in nine experimental conditions (Table i).

Table i: Experimental Design Matrix

		Duty Cycle / Force Level (%max force) combination		
		0.8/25%	**0.5/40%**	**0.4/50%**
Cycle Time (sec)	**30**	30(0.8/25%)	30(0.5/40%)	30(0.4/50%)
	60	60(0.8/25%)	60(0.5/40%)	60(0.4/50%)
	120	120(0.8/25%)	120(0.5/40%)	120(0.4/50%)

Since the purpose of this study was to compare localised fatigue development between the different conditions, peak torque, total work, average power, EMG(%MVE) were measured prior to and after the fatigue protocol and ratings of perceived exertion (RPE) and EMG activity were recorded at set intervals and continuously throughout the duration of the protocol respectively. Reasons for the selection of the independent and dependent variables can be found under the relevant headings below.

3.1.1. Statistical Hypotheses

Hypothesis 1: Effect of Cycle Time on Fatigue Responses

The null hypothesis (H_O) states that localised muscle fatigue responses are not dependent on cycle time, while the alternative hypothesis (H_A) does infer different fatigue responses due to differences in cycle time.

H_O: µCT30s = µCT60s = µCT120s

H_A: µCT30s ≠ µCT60s ≠ µCT120s

Where: CT30s refers to a cycle time of 30 seconds.

CT60s refers to a cycle time of 60 seconds.

CT120s refers to a cycle time of 120 seconds.

Hypothesis 2: Effect of Combinations of Duty Cycle/Force Level on Fatigue

The second null hypothesis states that localised muscle fatigue responses are not dependent on the duty cycle and force level variations, while the alternative hypothesis states that the fatigue response are dependent on these task characteristics, despite the having the same overall mean muscle load.

H_O: µ(0.8/25%) = µ(0.5/40%) = µ(0.4/50%)

H_A: µ(0.8/25%) ≠ µ(0.5/40%) ≠ µ(0.4/50%)

Where: (0.8/25%) refers to the conditions that have a duty cycle of 0.8 and reach a maximum force level of 25% of maximum voluntary force.

(0.5/40%) refers to conditions that have a duty cycle of 0.5 (i.e. equal periods of activation and rest), and reach a maximum force level of 45% of maximum voluntary force.

(0.4/50%) refers to conditions that have a duty cycle of 0.4 and reach a maximum force level of 50% of maximum voluntary force.

Hypothesis 3: Interaction Effect of Cycle Time and Duty Cycle/Force Level combinations

The final null hypothesis states that localised muscle fatigue responses are not dependent on the interaction of the independent measures. The alternative hypothesis therefore states that the fatigue response are dependent on such an interaction.

H_O: μ30s(0.8/25%) = μ30s(0.5/40%) = μ30s(0.4/50%) = μ60s(0.8/25%) = μ60s(0.5/40%)
= μ60s(0.4/50%) = μ120s(0.8/25%) = μ120s(0.5/40%) = μ120s(0.4/50%)
H_A: μ30s(0.8/25%) ≠ μ30s(0.5/40%) ≠ μ30s(0.4/50%) ≠ μ60s(0.8/25%) ≠ μ60s(0.5/40%)
≠ μ60s(0.5/40%) ≠ μ120s(0.8/25%) ≠ μ120s(0.5/40%) ≠ μ120s(0.4/50%)

All experimental conditions had the same overall workload (mean muscle load) so that the responses could be compared to one another. The mean force produced averaged 20% of maximum voluntary force across all conditions.

3.2. Selection of the Independent Variables

3.2.1. Cycle Time

Cycle time refers to the time taken for a protocol or task to repeat itself, which means the cycle time includes both the exertion period and the rest time (Finneran & O'Sullivan, 2010b). To determine the effect of cycle time on fatigue development, cycle times of 30 seconds, 60 seconds and 120 seconds were selected, as they were multiples of each other and fall into in the wide spectrum of cycle times that have been studied, which ranges from 10 seconds to 166 seconds (Mathiassen, 1993; Hermans, & Spaepen, 1997;

Seghers & Spaepen, 2004; Iridiastadi & Nussbaum, 2006; Yassierli & Nussbaum, 2009; Dickerson *et al*., 2015).

3.2.2. Combination of Duty Cycle and Force Level Variations

Force levels varied between a minimum of 0% of maximum voluntary force (i.e. relaxed/no force exertion) and a maximum force level of 25%, 40% and 50% of the maximal voluntary force (%MVF) produced prior to the fatiguing protocol and measured using an isokinetic dynamometer. Sjøgaard *et al*. (1986) pointed out that during a prolonged static exertion, force levels as low as 10-15% MVF may affect the blood supply due to the increasing intramuscular pressure, leading to muscle fatigue. However, when performing an intermittent dynamic protocol, the rest period between exertions allows for an increase of blood flow to supply the muscle with oxygen, which in turn can slow down the development of muscle fatigue (Vøllestad, 1997; Sahlin *et al.,* 1998). It is for this reason that the condition with the lowest force level was set at 25% MVF. The condition with the highest force level of 50% MVF was selected since only one study was found that had used a 50% MVF level (Seghers & Spaepen, 2004). The third force level (40% MVF) was one that allowed for equal proportions of work and rest, in other words, a duty cycle of 0.5. This can be explained as follows:

Since the maximum force levels exerted during the fatigue protocol varied between conditions, duty cycle also had to be manipulated in order to achieve the same overall workload across all experimental conditions. To avoid varying workloads from influencing fatigue responses this meant that as the duty cycle increased (i.e. the proportion of time an exertion is activated in a cycle became greater), magnitude of the force exertion had to decrease, and vice versa. To illustrate this, the following formula by Björkstén & Jonsson (1977) was used, followed by two examples:

Overall mean muscle load (%MVF) = Force Level (%MVF) x Duty Cycle

(where MVF = maximum voluntary force)

Example:

Condition 30s(0.8/25%): *25%MVF (force level) x 0.8 (duty cycle) = 20%MVF (mean muscle load)*

Condition 30s(0.4/50%): *50%MVF (force level) x 0.4 (duty cycle) = 20%MVF (mean muscle load)*

Figure 1 was adapted from Yassierli & Nussbaum (2007, p.1114) to illustrate this relationship between duty cycle and force level. It depicts the number of muscle exertions as well as the duration of the rest periods within a 30 second cycle, with a duty cycles of 0.8 (blue line) and 0.4 (orange line).

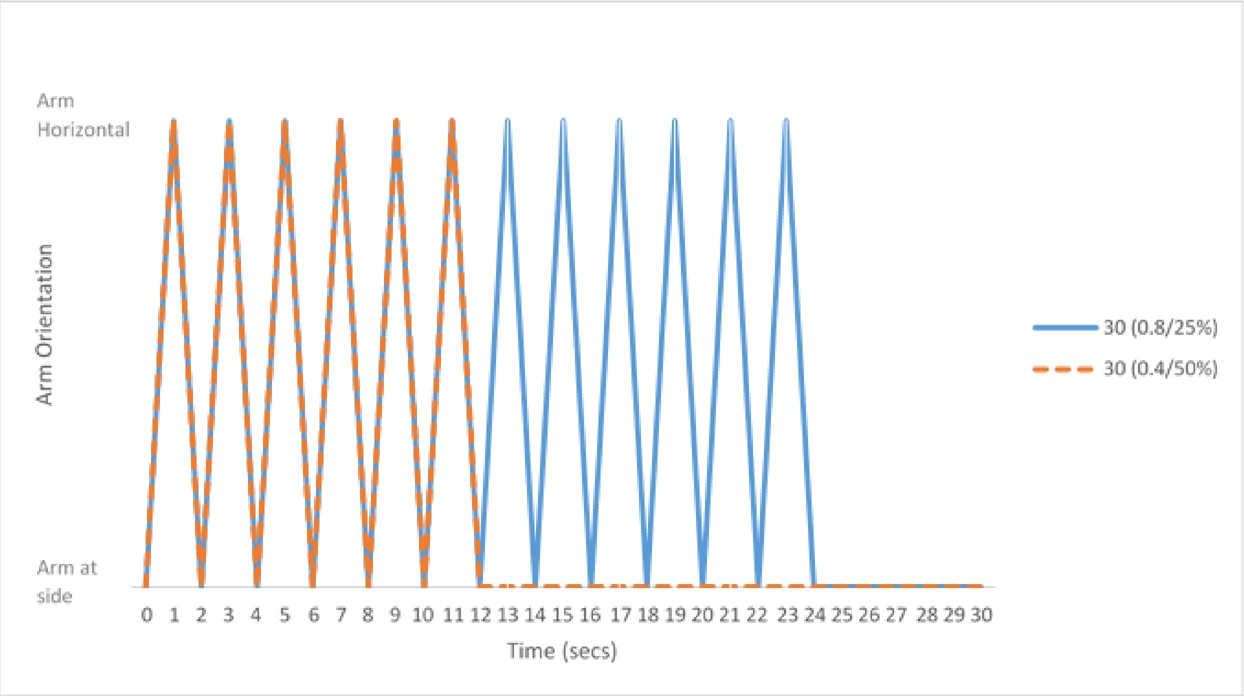

Figure 1: Graphical presentation of range of motion of the arm for two of the experimental conditions (**"Arm at Side": 0º when resting. "Arm Horizontal": 90º*)

Condition 30s(0.8/25%), depicted in blue, shows repeated sets of dynamic exertions consisting of 12 motions abduction-adduction movements (during a 24 second activation phase) and a 6 second rest period, hence resulting in a duty cycle of 0.8. At this duty cycle a maximum force exertion would be set at 25%MVF to result in a mean muscle load of 20%MVF. However, condition 30s(0.4/50%), shown in orange, depicts 6 repetitions of dynamic exertions at a peak force level of 50%MVF for a 12 second activation phase, and with an 18 second rest period per cycle. This maximum force level, together with the duty cycle of 0.4, would also result in the mean muscle load of 20%MVF (reasons for this specific mean muscle load are provided under “Variables of no interest”).

Table ii: A visual presentation of the frequencies for each condition

Conditions	Cycle Time (sec)	Activation (sec)	Rest (sec)
30(0.8/25%)	30	24	6
30(0.5/40%)	30	15	15
30(0.4/50%)	30	12	18
60(0.8/25%)	60	48	12
60(0.5/40%)	60	30	30
60(0.4/50%)	60	24	36
120(0.8/25%)	120	96	24
120(0.5/40%)	120	60	60
120(0.4/50%)	120	48	72

3.3. Variables of No Interest

3.3.1. Overall Mean Muscle Load

The overall mean muscle load can be expressed as the average muscle force performed over a period of time, as the force levels vary between zero and other force levels (% of MVF) (Seghers & Spaepen, 2004). Low force levels of around 12-28% MVF are seen in many occupational jobs (Iridiastadi & Nussbaum, 2006), hence an overall mean muscle load of 20%MVF was selected for the current study since it falls halfway in this range.

3.3.2. Protocol Duration

Many investigations on intermittent work reported on in the literature want to mimic working tasks, and have thus selected long protocol durations, with many continuing until task failure or exhaustion (Yassierli & Nussbaum, 2009; Dickerson *et al*., 2015). Others have limited their investigation to around 20, 30 or 60 minutes (Hermans & Spaepen, 1997; Seghers & Spaepen, 2004; Iridiastadi & Nussbaum, 2006) and obtained significant findings. Results by Maton (1981) showed that as soon as a given level of force was maintained, muscular activity began to change, implying that the process of muscle fatigue can be well established early in the protocol from changes in EMG signals, maximal force, and RPE. Rather than using time to task failure or exhaustion as a measurement variable, the conditions in this current study were limited to a duration of 16 minutes, which was considered sufficiently long to induce fatigue from previous explorations in this area.

3.3.3. Muscle

A large body of literature relates muscle fatigue development of the upper extremities to injury in the workplace (Hermans & Spaepen, 1997; Nussbaum, 2001; Seghers & Spaepen, 2004; Iridiastadi & Nussbaum, 2006). It has been suggested that the neck and shoulder muscles are the most strained during occupational tasks (Hermans & Spaepen, 1997) as many occupational activities are executed above shoulder height. The deltoid muscle is the muscle that forms the rounded shape of the shoulder and it is made of three distinct strands – the anterior, middle and posterior strand. Each of these originates from a different point and moves the shoulder joint differently (Rispoli, Athwal, Sperling, & Cofield, 2009). Even though all three parts are used for movement around the shoulder joint and in turn will influence the resilience to fatigue, the present study's scope is limited to one compartment, namely the middle deltoid, as abduction of the shoulder is relevant to overhead work (Tortora & Derrickson, 2009).

3.3.4. Range of Motion

The shoulder is a complex joint, and when it moves through a range of motion it will be affected by movements from other joints, ligaments and muscles as each movement is interlinked (Whitney, 2015). In the present study, one repetition (i.e. cycle) of the required force exertion entailed the shoulder joint completing an abduction–adduction movement along the scapular plane. To explain this in more detail, as the shoulder performs an abduction movement the middle deltoid muscle concentrically contracts thus instigating movement against gravity. During shoulder adduction, the middle deltoid needs to eccentrically exert a force to control the movement of lowering the arm back to the side of the body. These exertions were repeated continuously, depending on the duty cycle of each specific condition. During the rest time of the cycle the shoulder did not move and the muscle therefore did not contract. The range of motion for abduction-adduction of the shoulder is generally large, ranging from 0º to 160º (Wimpenny, 2016). However, to isolate the middle deltoid muscle and to make the motion most comfortable for the participants, the movement was limited to between 0º (arm hanging against the trunk) to 90º (perpendicular to the ground).

3.3.5. Movement Velocity

An angular velocity of 90º per second was selected for the maximal voluntary isokinetic exertions that were conducted pre and post fatigue protocol on an isokinetic dynamometer. This angular speed was selected as the exertion went through a 90º movement in one second so that the speed for the maximal exertions and the fatiguing exertions were the same as is described below.

For the fatiguing protocol participants performed one abduction-adduction cycle of the shoulder in two seconds (1 second for abduction and 1 second for adduction), thus mimicking the 90º per second speed of the maximal isokinetic exertions. Depending on the duty cycle and the cycle time, the number of repetitions varied while the speed of the movement was kept constant.

3.4. Dependent Variables

3.4.1. Demographic Data

Age, sex, stature and body mass were measured and recorded during the introduction/habituation session. Age and sex were obtained verbally, while stature was measured using a stadiometer *(Veeder-Root. Elizabethtown, U.S.A.),* and body mass was measured with a scale *(Model: Toledo Scale corp. type no. 8142)*.

3.4.2. Peak Torque

Peak torque is the highest muscular force output at any moment during a repetition and is a good indication of a muscle’s maximum strength capability (Wilkie, 1950). An indication of muscle fatigue would be the decrease in peak torque from the pre- to post-protocol maximal test (Wilkie, 1950).

3.4.3. Total Work

Total work is used to measure the total amount of force produced throughout the ROM, meaning total work is measured by multiplying force with movement distance for every repetition (Dvir & Keating, 2001). Under non-fatigued conditions, the middle deltoid shoulder muscle should maintain a relatively constant torque throughout the protocol (Wimpenny, 2016). However, if the protocol induces fatigue, the amount of work should decrease over time (Dvir & Keating, 2001), since the torque the muscle is able to produce decreases.

3.4.4. Average Power

Average power provides a true measure of work rate intensity and is defined as total work divided by time (Kovaleski, Heltman, Scaffidi, & Fondren, 1992). Power represents the amount of work that can be done over a given time period, with work, in turn being dependent on the amount of force produced. When a muscle is fatigued, the force cannot be produced as quickly, hence decreasing average power output (Kovaleski *et al.,* 1992).

3.4.5. Electromyographical (EMG) activity

EMG based measures are commonly used for the identification of muscular fatigue, as muscle activity can be evaluated through the signal of EMG (Nussbaum, 2001; Thongpanja, Phinyomark, Hu, Limsakul, & Phukpattaranont, 2015). Although there has been debate about the validity and reliability of using EMG data during dynamic exertions to determine muscle fatigue, researchers such as Christensen *et al.* (1995), Nussbaum (2001), and Yassierli & Nussbaum (2007) state that surface EMG can be used for dynamic protocols, provided the maximal reference EMG measurement used for normalisation is obtained during movement at a speed similar to the task that is being measured. Muscle fatigue can be detected using EMG by determining changes over time, either by using the time domain (e.g. normalising EMG to its maximum, or considering the root mean square (RMS)), or by analysing the frequency domain (e.g. median power frequency or mean power frequency) (Iridiastadi & Nussbaum, 2006; Bosch *et al.,* 2012; Yung *et al.,* 2012).

3.4.6. Ratings of Perceived Exertion (RPE)

RPE is an indicator of fatigue as individuals subjectively tend to notice changes that are occurring to their own body before objective changes occur (Hunter & Enoka, 2003). It is therefore important to understand the subjective symptoms and how they relate to objective findings (Borg, 1982). Garg, Hegmann and Kapellusch (2006) stated that an exertion of the shoulder girdle with an RPE rating of higher than 3.5 is an indication of high stress and thus fatigue inducing.

3.5. Equipment

3.5.1. Isokinetic Dynamometer

An isokinetic dynamometer was used to measure peak torque, total work, and average power during maximal exertions prior to and after the submaximal fatigue protocol. The Biodex4 *(Model: Biodex System 4 Pro. Biodex Medical systems, Inc. New York; 11967-4704)* is an isolated joint isokinetic system, meaning it measures the amount of force produced at different velocities and through a range of motion (Drouin *et al.,* 2004). Isokinetic muscle loading allows a fixed speed of movement while measuring the force produced, since the system can vary the resistance. The isokinetic dynamometer was set with the chair at a 75º angle, and the dynamometer at the correct side of the chair, depending on participant's dominant arm. As per manufacturer's instructions, the dynamometer orientation was set at an angle of 0º, with a tilt of 10º, and with the adduction and abduction shoulder attachment in place, as depicted in Figure 2a. Finer adjustments to the chair set-up were performed once the participant was seated and securely strapped into the Biodex.

3.5.2. Ratings of Perceived Exertion (RPE)

Local perceived exertion of the middle deltoid muscle was recorded by using the Borg 10-point scale (CR-10) (Borg, 1982) (Appendix B.1.). Participants were instructed to focus on the feelings of effort of the dominant middle deltoid muscle while performing the experimental task. The CR-10 scale starts at 0, representing the resting state (no effort), and ends with 10; this being the maximal effort that a muscle can produce.

3.5.3. Surface Electromyography (EMG)

The EMG component of the Biometrics data logger system (*Model: Biometrics Ltd. Type no. SX230)* was used to record muscle activity for the full duration of the experimental protocol. The signals were analogue processed with an amplifier (CMRR 96dB -110dB at 60Hz; input impedance >10,000,000 M Ohms; signal-to-noise ratio (SNR) <5µV; and gain range of 1000). Preparation of the skin lying over the deltoid muscle entailed shaving the area of excess hair and cleaning it with alcohol to improve the electrode-skin contact, and then swabbed the area once more to get rid of the alcohol residue. To record the muscle activity two Kendall™ 200 foam silver-silver bipolar surface electrodes (*Medtronic, Canada*) with built-in amplifiers, (*Model: Meditrace* ^{TM} *Ground electrode strips, Type no. SX230FW)* were placed, according to the manufacturer's specifications, over the belly of the middle deltoid muscle along the direction of the muscle fibres. The location for the middle deltoid was standardised by determining the midpoint between the acromion process of the scapula and the insertion point on the deltoid tuberosity of the humerus (Tortora & Derrickson, 2009). The reference electrode (*Model: Killstat ® high quality grounding product. Type no. CA4AADB)* was placed on an uninvolved muscle, namely the brachoradialis. EMG signals were recorded continuously throughout the fatiguing protocol as well as during the pre and post maximal tests, using the EMG amplitude system *(Model: Biometrics Ltd. Type no. SX230).* Raw EMG data had a sampling frequency at 1000Hz and bandpass filtered (10–500 Hz).

(a) (b)

Figure 2: Set up of the isokinetic dynamometer for (a) abduction-adduction shoulder exertions during the maximal pre- and post-test exertions, and (b) with the wrist weight for the submaximal fatigue protocol.

3.5.4. Wrist Weights

The submaximal external load required for the fatiguing protocols (i.e. 25%, 40% of 50%MVF) was applied in the form of a standard weight training wrist weight (*Make: Body Sculpture*) that could be attached to the participants' dominant wrist (Figure 2b). The mass of this wrist weight was adjusted by adding or removing lead weights and the final mass was confirmed using a *Prochef*^{TM} electronic kitchen scale.

3.5.5. Monitor for Instructions

Instructions to guide the participants' movement velocity and work/rest ratios were displayed on a computer screen with the use of a Microsoft PowerPoint *(Model: Microsoft Office. Type no. 2013)* slideshow.

3.6. Participants

Thirty participants were recruited for this study - 12 males and 18 females. The age range for all participants was set for 18-25 years. Individuals past the age of 25 years may be subject to reduced muscle function since motor unit remodelling gradually deteriorates with age, which leads to denervation muscle atrophy (irreversible degeneration of muscle fibres) This in turn leads to the decrement in strength, which could increase the risk of injury (Kwan, 2012) and act as a confounding variable. Younger adults are also normally the 'fittest' and healthiest population group and thus the risk of any adverse effects happening is the lowest of all populations groups (McArdle *et al.*, 2010).

Other characteristics of the participants included having to engage in regular physical activity to reduce the risk of injury and to ensure that they were able to complete the fatigue protocol. Individuals recruited participated in moderate weight training of 2-4 times a week as suggested by Hongu, Wells, Gallaway, & Bilgic (2015).

Since the equipment was designed to isolate and fatigue the middle deltoid shoulder muscle, completely sedentary individuals may have been at an increased risk of getting injured. However, since the maximum force exertions (which were considered the riskiest aspect of the protocol) were voluntary in nature, the risk of muscle strains was considered to be minimal. This is because a voluntary exertion is limited to as much force/effort a person feels he/she can produce, therefore not exerting the body to anything further that he/she may believe is harmful (Potvin, 2012).

All participants needed to be healthy at the time of testing, with no recent history (i.e. within the past 6 months) of acute injuries, or any history of musculoskeletal disorders of the upper extremities, especially the shoulder area which may have affected the strength and endurance of the muscle (Tortora & Derrickson, 2009). It is for these reasons that participants were drawn mainly from the Rhodes University student population, since it constituted a sample of convenience that possessed the required participant characteristics. Differences between sexes was of no interest and inter-individual differences were accounted for by normalising results.

These requirements were presented to potential participants together with a letter of information and instructions they should adhere to before testing, which included avoiding heavy exercise at least 48 hours before the testing sessions due to the possible effects of delayed onset soreness (DOMS) or residual muscle fatigue, which in turn could affect muscle recruitment and fatigue responses during the experimentation (McArdle *et al.,* 2010).

Participants were also instructed to not consume alcohol less than 24 hours before the testing as the use of alcohol has been directly linked to the rate of injury in sports events, as well as having detrimental effects on exercise performance (O'Brien & Lyons, 2000, El-Sayed, Ali, & El-Sayed, 2005). Participants should also not have consumed caffeine or tobacco less than three hours prior to testing (Graham, 2001). Caffeine acts directly on the muscles, enhancing exercise capacity, as it was noted in a study by Graham (2001) that during sub-maximal efforts caffeine increases the force output for a low-frequency electrical stimulation before and after muscle fatigue. It has also been stated by Conway & Cronan (1992) that smoking has an effect on physical fitness even after controlling for the effects of exercise activity, which in turn could influence the results of the fatigue protocol. The effects of nicotine on strength expression and muscle fatigue are still inconclusive, but Wüst, Morse, De Haan, Rittweger, Jones, & Degens (2008) did hypothesise that fatigue resistance and the reduction in skeletal muscle function could be correlated to the cumulative dose of smoking.

It can only be emphasised that it was expected that participants were truthful when asked about their level of health, physical activity and certain demographic information.

3.7. The Protocol

3.7.1. Ethical considerations and Recruitment

Prior to experimentation, approval for conducting this research was obtained from the Human Kinetics and Ergonomics Ethics Committee (Appendix C.1.), as well as from the University Registrar (Appendix C.2). 30 participants were recruited, via social media and personal advertising (Appendix A.3.) and interested individuals were sent an email with the letter of information (Appendix A.1.). Willing participants were requested to attend five sessions at the Department of Human Kinetics and Ergonomics: the first two sessions were dedicated to familiarising/habituating participants with the task requirements, with the first session also including an information session about the experimentation. The last three sessions were the testing sessions, each of which entailed testing three experimental conditions.

3.7.2. The Introductory and Habituation Sessions

During the first session, which lasted approximately 40 minutes, participants were first informed about the study, what was expected of them, as well as the risks and benefits of the study. Ethical considerations such as their right to anonymity and confidentiality, and the option to withdrawal voluntarily were also referred to. Once they had been presented with the opportunity to ask questions and they had consented verbally, they were asked to sign the informed consent form (Appendix A.2.). Basic demographic data namely age, sex, stature, mass, as well as isokinetic dynamometer positions were recorded, followed by an opportunity to practice the different experimental conditions. Since the isokinetic dynamometer is unfamiliar to most participants, participants were requested to attend a second habituation session so they could feel comfortable with the Biodex system and understand the task requirements of the protocol. A particular focus of the habituation was achieving the correct timing of the concentric and eccentric exertions of the motions. If the participant did not feel comfortable with the dynamometer system and the task requirements after the two sessions, they were asked to attend more habituation sessions before they started the experimental sessions, until such a time that they felt comfortable with the equipment and task requirements.

3.7.3. Experimental Sessions

After the habituation sessions, each participant participated in three experimental sessions of about 3 ½ hours each (Figure 3). Participants were asked to pair up with another participant during the session, so that while one participant was resting (outside of the testing room), the other participant would perform a testing condition. Each participant needed to rest for 30 minutes between conditions. During each experimental session, three of the nine experimental conditions were tested. Conditions were permutated to minimise the learning effect and cumulative fatigue from influencing the results. Randomisation was done individually for the variables, namely the force levels/duty cycles and cycle times (Appendix B.2. – Tables 2 and 3) and then these combinations were permutated (Appendix B.2. - Table 4). There needed to be at least a three-day break between the three experimental sessions as the participant may have experienced DOMS. Given that all participants were moderately trained, and had been habituated to the task, it was expected that the DOMS would be minimal. However, it still needs to be considered as it could alter the participants' responses to the study's protocol. If the following testing was scheduled for three days after and participants still where experiencing DOMS the session would be rescheduled until the participant had recovered.

One day of experimental sessions

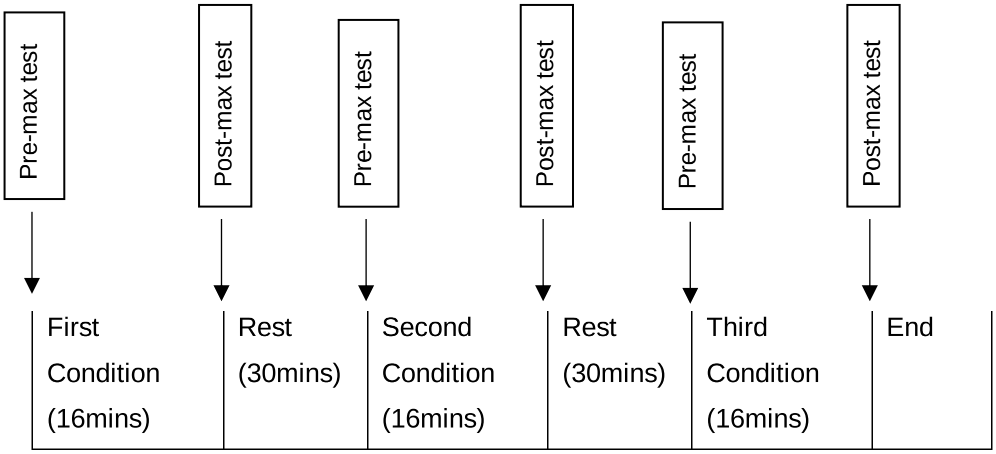

Figure 3: Graphical representation of one day of experimentations during which three of nine experimental conditions were performed.

At the start of each testing session the participants were informed which experimental conditions would be performed that day. Upon arrival the isokinetic dynamometer would already have been set up. Participants were then secured in a seated position using straps at the shoulder and waist. The skin over the shoulder was prepared and two EMG bipolar electrodes placed over the belly of the middle deltoid shoulder muscle of the dominant arm. The reference electrode was placed on an uninvolved muscle, namely the non-dominant forearm. The dynamometer's centre of rotation was aligned with the centre of the participant's glenohumeral joint, just below the acromion process (Nussbaum &

Zhang, 2000). Each participant then performed a brief warm-up of 10 self-paced movements though a ROM with no resistance as suggested by Yassierli & Nussbaum (2007).

3.7.3.1. Pre-fatigue Maximal Exertions

Participants first generated four maximal abduction-adduction efforts in the scapular plane against the isokinetic dynamometer attachment, during which peak torque, total work, average power, and EMG signal were recorded. Abduction demanded a concentric effort by the deltoid muscle, while adduction involved an eccentric exertion, hence the middle deltoid was always activated during the movement periods. The largest peak torque was used to calculate the submaximal forces needed for the fatigue protocol, while the mean of the highest 3-second EMG activity during these maximum voluntary exertions (MVE) was used for calibration proposes.

3.7.3.2. Fatiguing Protocol

Once the maximal test has been completed, participants let go of the abduction-adduction shoulder attachment and were told to rest for ten minutes, after which they performed the submaximal intermittent dynamic fatigue protocol of the first condition. A wrist weight was adjusted to correspond to the submaximal force needed for the upcoming experimental condition (i.e. either 25%, 40% or 50% of MVF) and was then strapped onto the participants' wrist once the rest duration was complete. The fatigue protocol required repetitive abduction and adduction movements of the shoulder, without the use of the isokinetic dynamometer. To control for the range of motion, 'stoppers' had been placed at the end of the abduction range of motion. Instructions to guide participants with the movement velocity and the work/rest ratios (as dictated by the duty cycle and cycle time) were displayed via a Powerpoint presentation on a monitor. At four-minute intervals participants were also asked to provide a perceptual feedback on their perceived exertion of the working shoulder, using the RPE 10-Borg scale (Borg, 1982). EMG signal was recorded throughout this protocol.

3.7.3.3. Post- Maximal Exertion

After the fatiguing protocol was completed, the weight was immediately removed from the participants' wrist and they generated another four maximal efforts against the isokinetic dynamometer attachment. The attachment was still attached to the dynamometer, meaning the participant just had to grasp it and perform the maximal exertions. The participant was then afforded a 30-minute rest break, after which the same procedures were repeated for the second and the third experimental conditions assigned for that day. The second and third testing sessions occurred in the same manner as described above. Figure 4 provides a graphical overview of one experimental protocol.

The "Pre" Maximal Voluntary Isokinetic Exertion

4 maximal efforts through the scapular plane (±5 minutes) using an isokinetic dynamometer and surface electromyography system

Measures

1. Peak Torque (Nm)
    - Calculation of submaximal forces
2. Total Work (J)
3. Average Power (Watts)
4. EMG – Maximal Voluntary Exertion (MVE)
    - for calibration of EMG signal as %MVE

REST (10 minutes)

Experimental Protocol

Repetitive movement of shoulder abduction-adduction (duration: 16 minutes) with weights set at a load stipulated by experimental condition.

Measures

1. EMG signal recorded throughout for the purpose of analysing
    - Median Power Frequency (MdPF)
    - Mean Power Frequency (MnPF)
    - Root Mean Square (RMS)
2. RPE (every 4 minutes)

The "Post" Maximal Voluntary Isokinetic Exertion

4 maximal efforts through the scapular plane (±5 minutes) using an isokinetic dynamometer and surface electromyography system.

Measures

1. Peak Torque (Nm)
2. Total Work (J)
3. Average Power (Watts)
4. EMG – Maximal Voluntary Exertion (MVE)

Figure 4: Graphical representation of the timeline of one experimental protocol

3.8. Data Analysis

All data collected were analysed using the Statistica Software, *Model: Statistica 12*$^{©}$ *StatSoft Inc. Type no. 74104. USA (1984-2014).*

3.8.1. Data Reduction and Processing

Reduction and processing of data involved normalising the post-fatigue protocol biomechanical variables to their pre-fatigue maximum. EMG data obtained during the post-fatigue maximum exertions were full wave rectified and smoothed, before being normalised to the highest 3-second period extracted from the maximum pre-fatigue exertions. EMG results obtained during the maximal exertions are thus presented as a percentage of maximum voluntary exertion (%MVE). Inspection of the EMG data however revealed an outliner. One participant's data seemed aberrant as normalised EMG data were 200%MVE or higher. It was thus decided to exclude all EMG data for this participant only.

The raw EMG data recorded during the submaximal fatigue protocol were also normalized to the highest 3-second maximum activation period and then divided into three intervals, namely the first 12 seconds, the middle 12 seconds, and the final 12 seconds. The MdPF, MnPF, and RMS(normalised) were extracted after which the data where rectified and smoothed.

3.8.2. Basic Descriptive Statistics

All demographic, anthropometric, biomechanical, physiological and perceptual responses were summarised using the mean, standard deviation, and coefficient of variances.

3.8.3. Inferential Statistics

3.8.3.1 Determination of Fatigue

Fatigue was determined by analysing the effects of time on all dependent variables. Repeated measures T-tests, using the General Linear Models option in Statistica, were used to determine changes over time for the pre-post measures (peak torque, total work, average power and EMG(%MVE)). EMG(RMS), MdPF, MnPF underwent a one-factorial repeated measures ANOVA, also using the General Linear Models using the three 12-

second intervals extracted during the reduction process. The same analysis method was applied to the four measurements obtained for RPE over the duration of a fatigue protocol. The confidence level was set at 95%, meaning significant differences were identified as at a p-value of less than 0.05. Any significant differences identified underwent the Tukey post-hoc test to determine where the differences lay. Sex was used as a covariate to determine whether sex could be a source of variance.

3.8.3.2 Determination of Condition Effects

A two-factorial repeated measures analysis of variance, using General Linear Models, was used to identify the individual condition effects, as well as any interaction effects of the last measurement interval obtained for each variable, as it was assumed that at participants would be most fatigued at the end of each protocol. The p-value was again set at 0.05. Any significant differences identified underwent Tukey post-hoc analyses to determine where the differences lay.

CHAPTER IV – RESULTS

This chapter displays and compares the biomechanical, physiological, and perceptual responses measured during each maximal exertion and fatiguing task. This chapter analyses each variable in terms of: (1) the effect of time, to determine whether the protocol did indeed induce fatigue, and (2) the effects of the two factors under investigation to identify how each of these task characteristics influence fatigue development. All statistical tables for this section can be found in Appendix D.

4.1. Basic Anthropometric and Demographic Data

30 young and healthy students (12 males, 18 females) gave their written informed consent to participant in this study. Table ii provides an overview of the basic anthropometric and demographic data collected.

Table iii: The means, standard deviations (SD), and coefficients of variation (CV) of the participants' basic anthropometric and demographic data.

	All (n=30)	Female (n=18)	Male (n=12)	p-value
Age	21.43 ±2.14 (10%)	20.5 ±1.69 (8.24%)	22.83 ±2.04 (8.92%)	p=0.00197 *
Stature (m)	1.68 ±0.11 (6.91%)	1.61 ±0.06 (3.78%)	1.8 ±0.07 (3.88%)	p=0.0000 *
Weight (kg)	69.23 ±19.2 (27.74%)	58.06 ±12.52 (21.57%)	85.99 ±14.8 (17.21%)	p=0.00001 *

* indicates significant difference ($p<0.05$) between male and female participants.

4.2. Overview of all Results

For the purpose of these analyses, the maximum post-protocol exertions of peak torque, total work, average power, and EMG(%MVE) were normalised to the maximum pre-protocol values as there was no systemic fatigue effects. EMG(RMS), median power frequency (MdPF), mean power frequency (MnPF) and RPE values used the final 12-second measurement interval obtained from the sub-maximal fatigue protocol.

Table iv: P-values for the individual condition effects (cycle time, duty cycle/force level), as well as the interaction of cycle time and duty cycle / force level.

	Cycle Time	Duty Cycle/ Force Level	Interaction Effect
Peak Torque (Nm)	p=0.194	p=0.233	p=0.535
Total Work (J)	p=0.199	p=0.088	p=0.849
Average Power (Watts)	p=0.358	p=0.127	p=0.621
EMG (%MVE)	p=0.316	p=0.233	p=0.653
EMG (RMS) (mV)	p=0.0004*	p=0.005*	p=0.005*
MdPF – Hz	p<0.0001*	p=0.003*	p=0.026*
MnPF – Hz	p<0.0001*	p<0.0001*	p=0.0004*
RPE	p<0.0001*	p<0.0001*	p=0.034*

* indicates significant difference (p<0.05).

Table iii indicates that all biomechanical variables and as well as EMG(%MVE) showed no significant effects for cycle time and duty cycle/force level as well as the interaction of these factors. However, all other measures, namely EMG(RMS), MdPF, MnPF and RPE showed significant condition and interaction effects. Details of the individual variables are displayed in the following sections.

4.3. Biomechanical Measures

4.3.1. Effect of Time

Significant differences were found between the pre and post measures for all three measures obtained from the isokinetic dynamometer, with post values all being significantly lower than the pre protocol values, implying that fatigue occurred. Due to the high variance in responses, sex was used as a co-variate to determine whether this was a reason for the high variance. A significant difference was found between males and females for peak torque (p<0.0001), total work (p<0.0001), average power (p<0.0001), hence the results obtained during and after the fatigue protocol were normalised to each individual's maximum values to reduce the influence of inter-individual variability.

Table v: Time effects of peak torque, total work and average power.

	Pre	Post	p-value
Peak Torque (Nm)	52.33 ±20.17 (38.54%)	47.66 ±18.96 (39.77%)	p< 0.0001 *
Total Work (J)	139.46 ±69.98 (50.18%)	130.40 ±63.82 (48.94%)	p=0.0009 *
Average Power (Watts)	43.68 ±23.38 (53.52%)	40.92 ±21.34 (52.14%)	p=0.0034 *

* indicates significant difference (p<0.05) between pre and post fatigue protocol.

4.3.2. Condition Effect

4.3.2.1. Peak Torque

Table vi: The normalised values (mean ± SD (CV)) (post-fatigue protocol values presented as a percentage of pre-fatigue values) for peak torque of each condition.

		Duty Cycle / Force Level		
		0.8/25%	0.5/40%	0.4/50%
Cycle Time	30s	87.00 ±19.31 (22.19%)	90.61 ±13.61 (15.02%)	92.38 ±11.16 (12.08%)
	60s	88.21 ±15.98 (18.12%)	95.77 ±16.62 (17.35%)	96.12 ±11.86 (12.34%)
	120s	89.95 ±21.11 (23.47%)	93.78 ±17.7 (18.88%)	92.13 ±9.03 (9.8%)

Neither cycle time, nor duty cycle/force levels had a significant effect on the development of muscle fatigue (p=0.194 and p=0.233 respectively). There was also no interaction effect between cycle time and duty cycle/force levels (p=0.535). Peak torque decreased between 3.88% and 13%, while variance ranged between 9.8% and 23.5%. It was however noted that the conditions with a duty cycle/force level (0.8/25%) showed a trend towards being the lowest peak torque.

4.3.2.2. *Total Work*

Table vii: Summary data (mean ± SD (CV)) for total for each experimental condition work (normalized to pre-fatigue values).

		Duty Cycle / Force Level		
		0.8/25%	0.5/40%	0.4/50%
Cycle Time	30s	92.77 ±14.51 (15.65%)	95.37 ±10.50 (11.01%)	97.70 ±10.31 (10.55%)
	60s	91.91 ±13.80 (15.02%)	95.79 ±11.05 (11.54%)	98.37 ±11.76 (11.95%)
	120s	90.38 ±15.24 (16.86%)	94.29 ±9.97 (10.57%)	94.93 ±11.79 (12.42%)

Similar to peak torque, neither cycle time, nor duty cycle/force levels had a significant effect on total work (p=0.199 and p=0.088 respectively). No interaction effect was found either (p=0.850). Total work decreased between 1.63% and 9.62%, while variance ranged between 10.55% and 16.86%. Although not significant, conditions with a duty cycle/force level of (0.4/50%) indicated a trend of the highest work output, thus suggesting to be the least fatiguing, while the duty cycle/force level conditions of (0.8/25%) showed a trend for the greatest fatigue development. Similarly, the 120 second cycle time conditions consistently resulted in lower total work outputs compared to the other two cycle times (30 and 60 seconds).

4.3.2.3. *Average Power*

Average power results also indicate that cycle time and duty cycle/force level did not play a factor in the development of muscle fatigue, as there were no significant differences for cycle time (p=0.358), duty cycle / force level (p=0.127) or the interaction of the two (p=0.621). The decrease in average power was no less than 8.2%, while variance ranged between 9.42% and 17.93%. Average power also had a trend that all conditions with a duty cycle/force level of (0.8/25%) had the lowest average power values, indicating that these conditions may have been the most fatiguing, although this findings was not statistically significant. In general, the 120s cycle time conditions also showed the greatest power decrement.

Table viii: Summary data (mean ± SD (CV)) for average power (% pre-fatigue)of each condition.

		Duty Cycle / Force Level		
		0.8/25%	0.5/40%	0.4/50%
Cycle Time	30s	92.60 ±14.83 (16.02%)	96.35 ±10.17 (10.56%)	98.26 ±9.25 (9.42%)
	60s	92.10 ±14.96 (16.25%)	95.77 ±12.08 (12.62%)	98.54 ±11.56 (11.73%)
	120s	91.80 ±16.46 (17.93%)	95.22 ±11.62 (12.20%)	94.95 ±10.91 (11.49%)

4.4. Physiological Measures

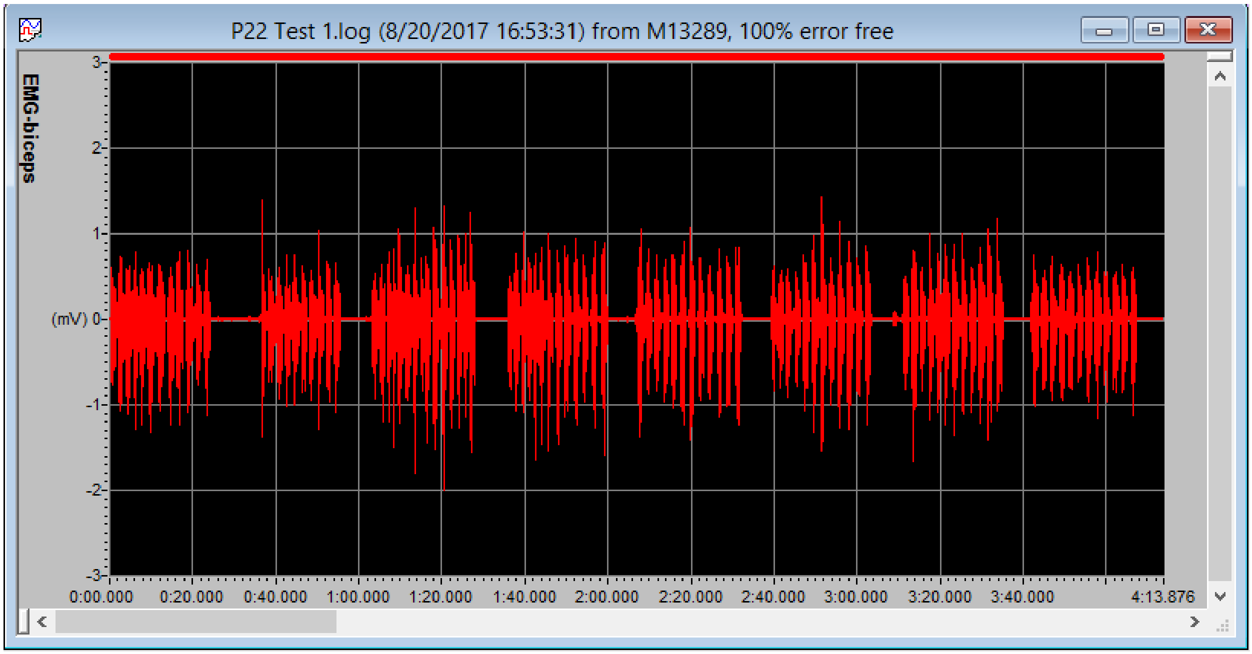

Figure 5: Figure of data EMG data from a participant during condition 1 (30s(0.8/25%)) for the first 4 minutes of the submaximal fatigue protocol

4.4.1. EMG - Percentage of Maximum Voluntary Exertion (%MVE)

Table ix: EMG results, presented as a percentage of maximum voluntary exertion (%MVE), for all experimental conditions.

		Duty Cycle / Force Level		
		0.8/25%	0.5/40%	0.4/50%
Cycle Time	30s	80.21 ±16.02 (19.97%)	79.38 ±13.76 (17.34%)	75.41 ±12.59 (16.70%)
	60s	80.44 ±11.37 (14.13%)	75.46 ±12.69 (16.82%)	76.12 ±14.67 (19.27%)
	120s	81.16 ±10.36 (12.76%)	79.74 ±14.25 (17.87%)	78.59 ±15.21 (19.35%)

EMG activity decreased for all conditions on average by 21.50%MVE, indicating that the muscle could not produce the same level of effort as prior to the protocol. Variances ranged between 12.76% and 19.97%. No significant effects were found for cycle time (p=0.316), duty cycle/force level (p=0.223), or the interaction between these two factors (p=0.653).

4.4.2. EMG - Root Mean Square (RMS)

4.4.2.1. Effect of Time

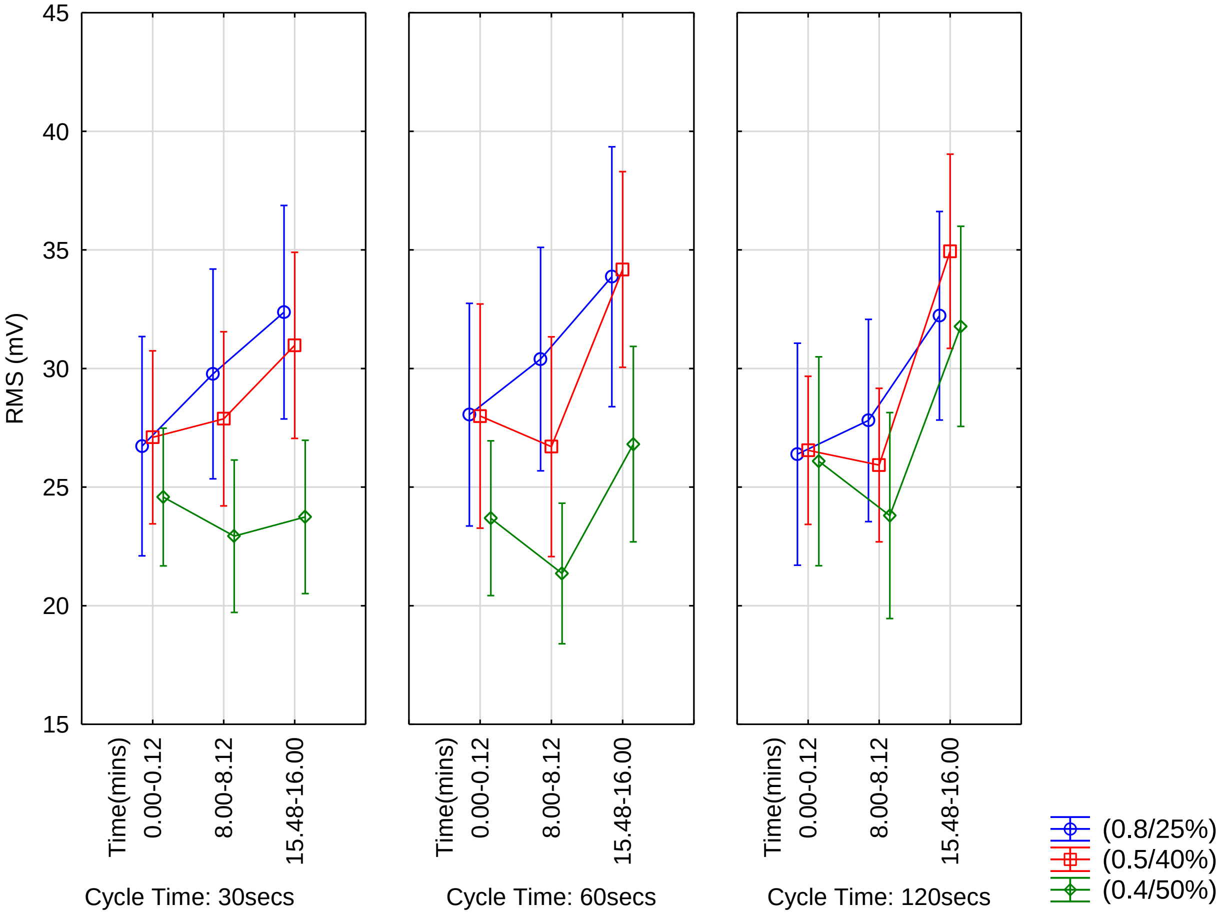

Figure 6: The RMS of all conditions throughout time

A significant time effect was found ($p<0.001$), with EMG(RMS) increasing significantly from the first to the last 12-second interval, except for condition 30s(0.4/50%) which was not significant overtime. The conditions with the duty cycle/force level of (0.4/50%) consistently showed the lowest motor unit activation over time.

4.4.2.2. Condition Effect

Table x: The RMS (mV) responses during the final 12 seconds of the fatigue protocol.

		Duty Cycle / Force Level		
		0.8/25%	0.5/40%	0.4/50%
Cycle Time	30s	32.38 ±11.83 (36.54%)	30.98 ±10.32 (33.31%)	23.74 ±8.50 (35.81%)
	60s	33.87 ±14.40 (42.52%)	34.18 ±10.85 (31.74%)	26.81 ±10.84 (40.41%)
	120s	32.23 ±11.56 (35.86%)	34.95 ±10.77 (30.81%)	31.78 ±11.09 (34.92%)

Comparisons of the activation levels during the final 12 seconds indicated that cycle time and duty cycle/force level had a significant effect on EMG(RMS) (p=0.0004 & p=0.005, respectively) and there was an interaction effect between these factors (p=0.005). The post-hoc analysis showed that at the end of the fatigue protocol the EMG(RMS) values for condition 30s(0.4.50%) were significantly lower compared to condition 30s(0.8/25%) and 30s(0.5/40%) (p<0.001 for both). This same condition (30s(0.4/50%)) was also significantly lower compared to 120s(0.4/50%) (p<0.001). Conditions with duty cycle/force levels of (0.5/40%) were significantly greater for the 60s cycle time compared to the 120s cycle times (p=0.003). It was also determined that during last 12 seconds both the 60s(0.8/25%) and 60s(0.5/40%) conditions were significantly lower than the 60s(0.4/50%) condition.

4.4.3. EMG - Median Power Frequency (MdPF)

4.4.3.1. Effect of Time

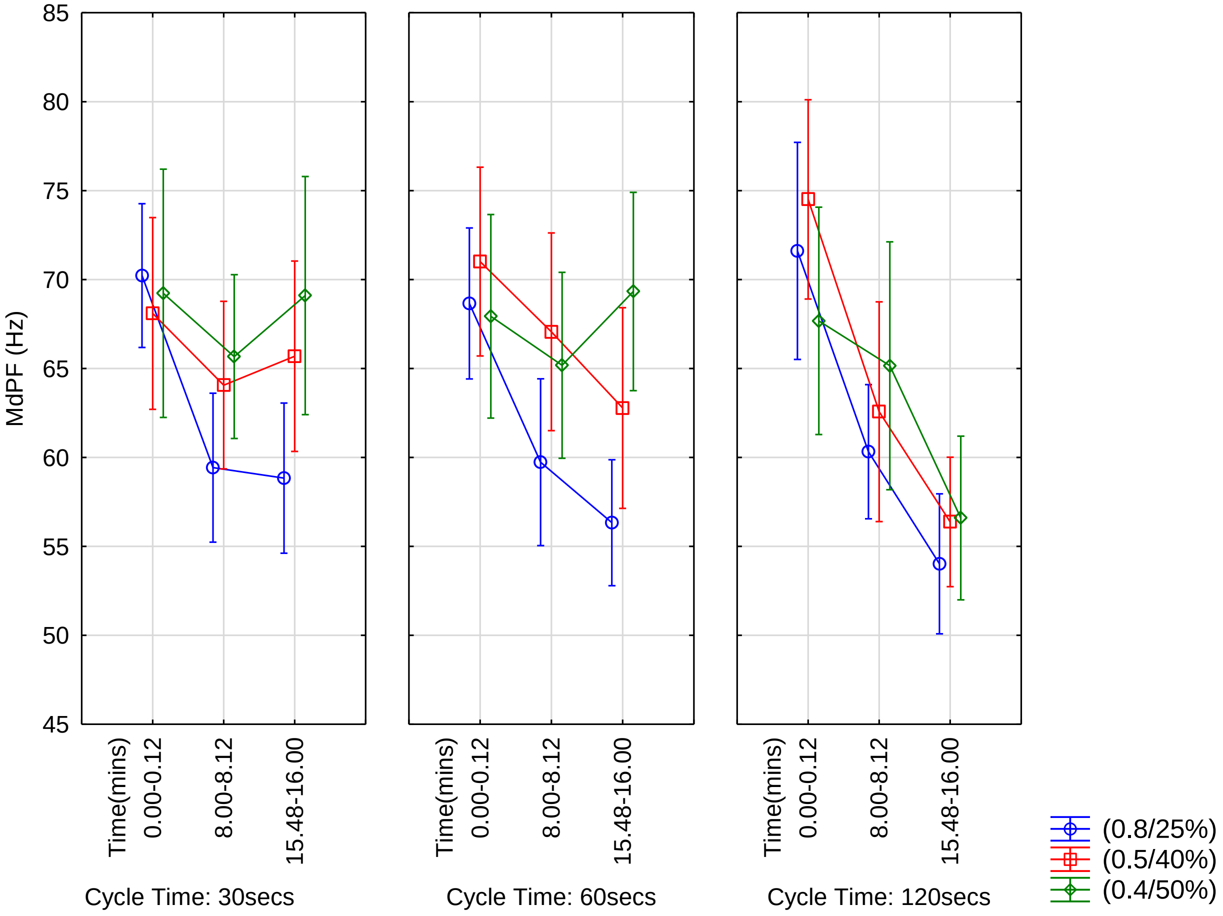

Figure 7: The MdPF of all the conditions throughout time

MdPF showed a significant time effect ($p<0.001$), with a significant decrease in MdPF fatigue occurring in all conditions, except for conditions 30s(0.5/40%) and 60s(0.5/40%); and 30s(0.4/50%) and 60s(0.4/50%). .

4.4.3.2. *Condition Effect*

Table xi: The median power frequency responses (Hz) during the final 12 seconds of the sub-maximal fatigue protocol.

		Duty Cycle / Force Level		
		0.8/25%	0.5/40%	0.4/50%
Cycle Time	30s	58.84 ±11.10 (18.87%)	65.69 ±14.07 (21.42%)	69.10 ±17.60 (25.47%)
	60s	56.33 ±9.31 (16.53%)	62.78 ±14.83 (23.62%)	69.33 ±14.65 (21.13%)
	120s	54.02 ±10.34 (19.14%)	56.38 ±9.56 (16.96%)	56.60 ±12.09 (21.37%)

During the final 12 seconds of the protocol both cycle time and duty cycle/force level had a significant effect ($p<0.001$ and $p=0.003$ respectively) on MdPF. There was also a significant interaction effect ($p=0.026$). Post-hoc analyses showed that conditions 30s(0.8/25%) and 30s(0.4/50%) had significantly different MdPF values ($p=0.004$). The same duty cycle/force level conditions were also found to be significantly different under the 60 second cycle time ($p<0.001$). For the duty cycle/force level of (0.5/40%) a significant difference was found between the 30 second and 120 second cycle ($p=0.02$). The MdPF of the 120s(0.4/50%) condition during the last 12 seconds was significantly lower compared to both the 30s(0.4/50%) and 60s(0.4/50%) conditions ($p<0.0001$ and $p<0.0001$ respectively).

4.4.4. EMG - Mean Power Frequency (MnPF)

4.4.4.1. Effect of Time

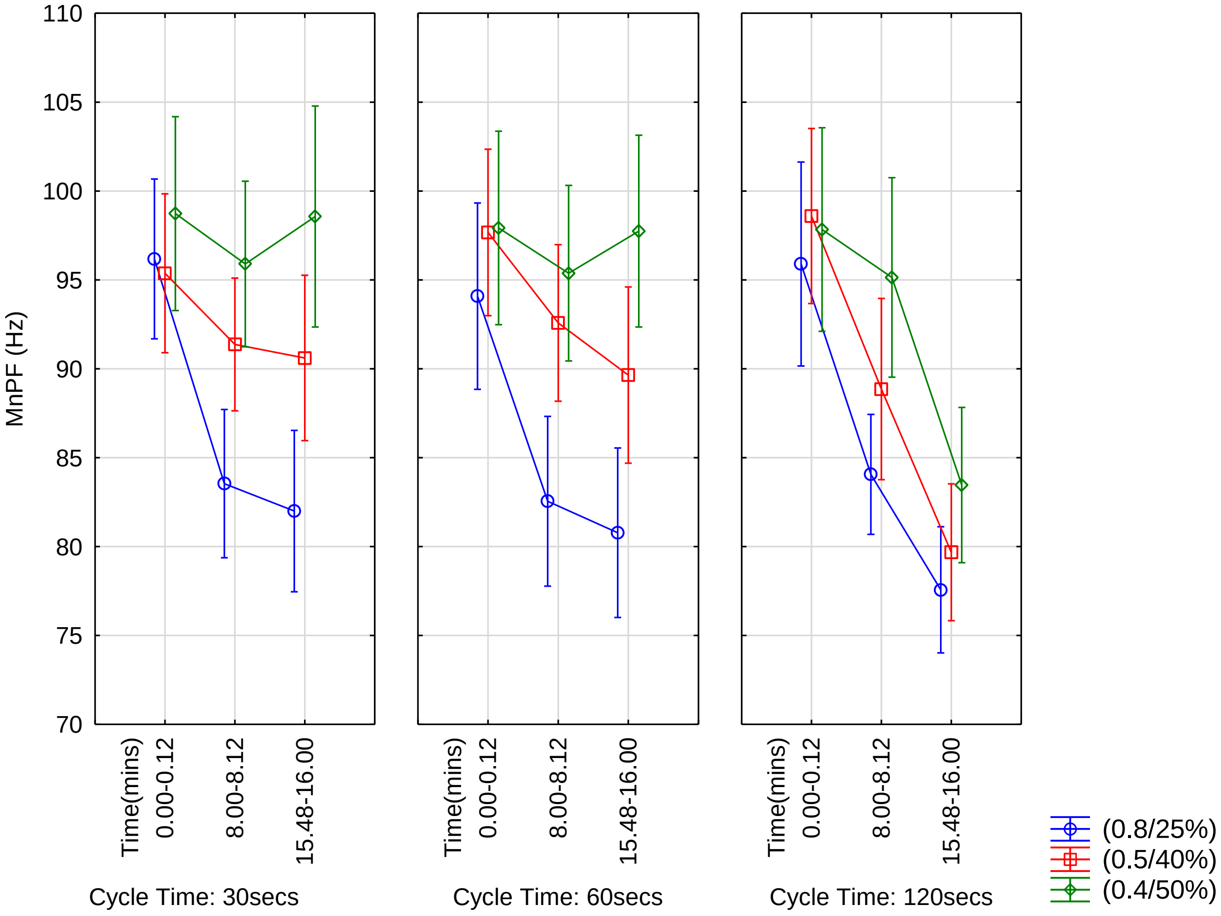

Figure 8: The mean power frequency responses of all the conditions over time.

A significant time effect was found (p<0.001) for mean power frequency. The post-hoc analysis revealed that all conditions showed a significant decrease over time, with exception of conditions 30s(0.5/40%); 30s(0.4/50%); and 60s(0.4/50%).

4.4.4.2. Condition Effect

Table xii: The MnPF responses (Hz) obtained during the final 12 seconds of the submaximal fatigue protocol.

		Duty Cycle / Force Level		
		0.8/25%	0.5/40%	0.4/50%
Cycle Time	30s	82.00 ±11.93 (14.55%)	90.61 ±12.22 (13.49%)	98.56 ±16.33 (16.57%)
	60s	80.78 ±12.54 (15.52%)	89.65 ±13.02 (14.53%)	97.74 ±14.18 (14.51%)
	120s	77.57 ±9.33 (12.03%)	79.68 ±10.12 (12.70%)	83.46 ±11.47 (13.75%)

During the final 12 seconds of the fatigue protocol cycle times of 30 and 60 seconds resulted in significantly lower mean power frequencies for the duty cycle/force level (0.8/25%) compared to (0.5/40%) and (0.4/50%) ($p<0.001$ for all differences), as well as between duty cycle/force levels of (0.5/40%) and (0.4/50%) ($p=0.003$ and $p=0.002$ respectively). The cycle time of 120 seconds only yielded a significant difference between the duty cycle/force levels of (0.8/25%) and (0.4/50%) ($p<0.001$). It was also noted that condition 120s(0.4/50%) was significantly different to condition 60(0.4/50%) ($p<0.0001$) and 30s(0.4/50%) ($p<0.0001$). The same effect was seen for condition 120(0.5/40%), being significant to the 30 second ($p<0.0001$) and 60 second ($p<0.0001$) cycle time.

4.5. Perceptual Measures

4.5.1 Ratings of Perceived Exertions

4.5.1.1 Effect of Time

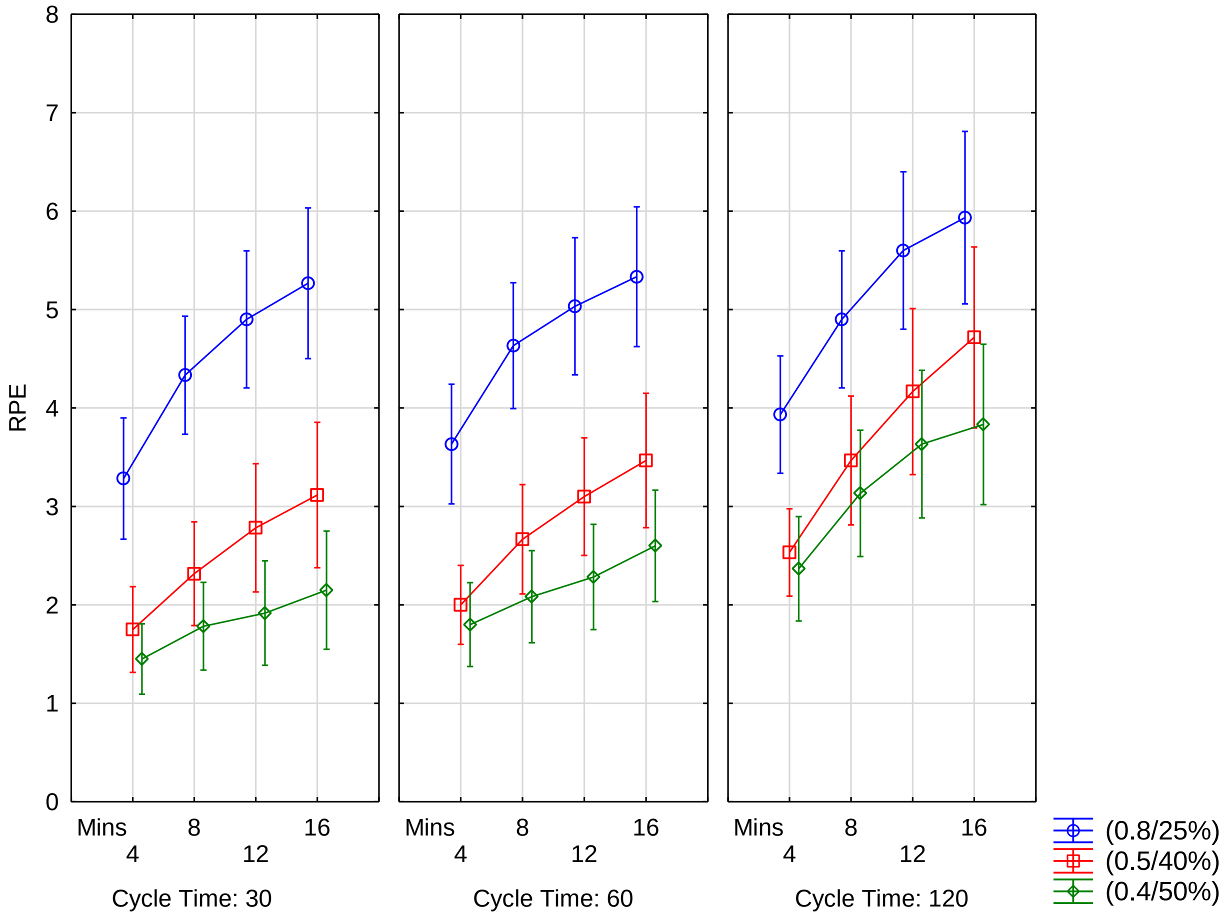

Figure 9: The RPE response over time for all experimental conditions.

There was a significant effect of time (p<0.001) for RPE, implying that perceptually, participants fatigued in all conditions, since RPE increased almost linearly from minute 4 to minute 16. All participants started each experimental condition fully rested, in other words with an RPE of 0. By minute 16 all conditions had increased to a minimum rating of 2 ("fairly light") for the least fatiguing conditions and a rating of 6 ("hard-very hard") for the most fatiguing condition. A post hoc analysis shows that all conditions had a significant difference between the 4th minute and the 16th minute (p<0.0001).

4.5.1.2. Condition Effect

Table xiii: The RPE responses for the final minute of the fatigue protocol.

		Duty Cycle / Force Level		
		0.8/25%	0.5/40%	0.4/50%
Cycle Time	30s	5.27 ±2.05 (38.92%)	3.12 ±1.98 (63.43%)	2.15 ±1.61 (74.84%)
	60s	5.33 ±1.9 (35.62%)	3.47 ±1.83 (52.75%)	2.6 ±1.52 (58.33%)
	120s	5.93 ±2.35 (39.57%)	4.72 ±2.46 (52.21%)	3.83 ±2.18 (56.94%)

Cycle time and duty cycle/force level both had an effect on the final ratings of perceived exertion ($p<0.001$ for both) and an interaction effect was also found ($p=0.036$). For all three cycle times conditions with a duty cycle/force (0.8/25%) showed significantly greater RPE responses at minute 16. The 120-second cycle time yielded significantly greater ratings of perceived exertions for all duty cycle/force levels compared to the 30-second cycle time and the 60 second cycle time. All conditions had very high variances, the lowest variances being 35.62%. Conditions with a duty cycle/force level of (0.8/25%) was significant different to both (0.5/40%) and (0.4/50%) duty cycle/force level at all three cycle times ($p<0.0001$ for all).

4.6. The Interaction Effect of Cycle Time and Duty Cycle/Force Level on Muscle Fatigue

Table xiv: The effects of the submaximal measures on the level of muscle fatigue

		Duty Cycle / Force		
		0.8/25%	0.5/40%	0.4/50%
Cycle Time	30s	**RMS – 5** **MdPF- 5** **MnPF - 6** **RPE - 7** **Ø - 5.75**	**RMS - 4** **MdPF- 3** **MnPF - 3** **RPE - 3** **Ø - 3.25**	**RMS - 1** **MdPF- 2** **MnPF - 1** **RPE - 1** **Ø - 1.25**
	60s	**RMS – 7** **MdPF- 8** **MnPF - 7** **RPE - 8** **Ø - 7.5**	**RMS - 9** **MdPF- 4** **MnPF - 4** **RPE - 4** **Ø - 5.25**	**RMS - 2** **MdPF- 1** **MnPF - 2** **RPE - 2** **Ø - 1.75**
	120s	**RMS – 6** **MdPF- 9** **MnPF - 9** **RPE - 9** **Ø - 8.25**	**RMS - 8** **MdPF- 7** **MnPF - 8** **RPE - 6** **Ø - 7.25**	**RMS - 3** **MdPF- 6** **MnPF - 5** **RPE - 5** **Ø - 4.75**

Red indicates the most fatigued conditions; green indicates the least fatiguing conditions; orange indicates the moderately fatiguing conditions. Numbers from each submaximal independent measure show the ranking order.

Table xiii shows each variable's ranking for each of the experimental conditions. The mean rank for each condition is also depicted for each condition. It indicates that certain conditions affect the development of muscle fatigue more than others do, and that this depends on the interaction between the cycle time and duty cycle/force level. Conditions with the lowest cycle time (30s), as well as the lowest duty cycle/highest cycle time

(0.4/50%) resulted in the lowest fatigue development, while the highest cycle time (120s) and highest duty cycle (0.8) resulted in the greatest fatigue development.

CHAPTER V- DISCUSSION

5.1. The Effect of Time on Localised Muscle Fatigue

Localised muscle fatigue occurred in all experimental conditions due to significant changes over time in all variables. Peak torque values decreased between pre and post protocol recordings, thus indicating fatigue development, as Wilkie (1995), Drouin *et al.* (2004) and Enoka & Duchateau (2008) all express that a decrease in the muscle's maximum strength producing capability infers fatigue. Iridiastadi & Nussbaum (2006) pointed out that under unfatigued conditions strength measures can vary by as much as 10%. Similarly, a significant decrease in total work produced over time is also said to indicate fatigue (Dvir & Keating, 2001; Wimpenny, 2016), as does the decrease in average power relative to the pre-protocol baseline measure. Kovaleski *et al.* (1992) explain that average power is defined as the force a muscle can produce force during a given timeframe, and when this force decreases, fatigue is said to have occurred. EMG amplitude during the maximal exertions decreased on average by 21.5%MVE. A significant drop in EMG amplitude from the baseline maximum confirms that fatigue occurred (Christensen *et al.,* 1995; Potvin & Bent, 1997; Nussbaum, 2001; Yassierli & Nussbaum, 2007). During a maximal exertion motor neurons are activated to produce the highest voluntary force (Vøllestad, 1997). A muscle in a fatigued state is not able to recruit as many motor units, while the discharge rate also decreases, thus resulting in a decrease in the EMG(%MVE) (Edwards, 1981). González-Izal *et al*. (2012) express that this is due to the central component, which reduces the neural drive that activates the muscle, which in turn decreases the work/force output of the muscle.

EMG data collected during the 16-minute protocol fatigue indicated a shift of the power spectrum to the left, as seen by a decrease in MdPF and MnPF (González-Izal *et al.,* 2012; Halaki & Ginn, 2012). While not all experimental conditions resulted in significant changes, the overall time effect on MnPF and MdPF showed a steadily decrease and is attributed to the different muscle compositions, namely type I muscle fibres and type II muscle fibres (Tortora & Derrickson, 2009). A fatigued muscle demonstrates a shift to the lower frequencies, meaning the fast twitch motor units (the higher frequency units) drop out first, while slow twitch motor (lower frequency units) units are maintained, as they are the more fatigue resistant muscle fibre type (Srinivasan *et al.,* 2007; Reese & Bandy, 2013). Also indicating fatigue was the EMG(RMS), which generally increased over time. The magnitude of the muscle activation depends on the number of motor units that are recruited and the rate at which they discharge action potentials (Duchateau & Enoka, 2016). During sub-maximal exertions, increases in RMS amplitude indicate the additional recruitment of motor units and the changes in the motor unit firing rates, (Iridiastadi & Nussbaum, 2006). As fatigue increases, more motor units need to be recruited to maintain the required task requirements, hence resulting in higher amplitudes (Disselhorst-Klug *et al.,* 2009). Herman & Spaepen (1997), Hunter & Enoka (2003), Balasubramanian *et al.* (2008), and Fukuda *et al.* (2010) all point out that the increase in RMS can be used as an indicator of muscle fatigue.

Localised muscle fatigue was confirmed by the subjective measures, as perceptual effort steadily increased throughout the protocol for all conditions, and showed the highest significant differences compared to the objective measures. This could be due to the fact that a participant's judgement is based on the effort that is needed to produce a force, instead of the required absolute magnitude of the force (Enoka & Stuart, 1992). Borg (1998), Hunter & Enoka (2003), Iridiastadi & Nussbaum (2006), and Enoka & Duchateau (2008) all expressed that an increase in RPE response indicates a fatigue effect. Acknowledging subjective feelings during a fatiguing protocol is important, as individuals tend to notice changes that are occurring to their own body before objective changes occur (Hunter & Enoka, 2003).

5.2. The Effect of Cycle Time on Muscle Fatigue

All dependent variables measured during the maximal isokinetic exertions (biomechanical recordings, and EMG(%MVE)) showed that cycle time did not have an effect on the development of muscle fatigue. The isokinetic dynamometer records force production at a constant movement velocity by accommodating the resistance throughout a joint's range of motion (Drouin *et al.,* 2004). Although this approach allows for more control over the movement velocity and range of motion, relatively few studies have used measures from the isokinetic dynamometer. However, two studies by Yassierli & Nussbaum in 2007 and 2009 did investigate the effects of dynamic intermittent movements with an isokinetic dynamometer, using changes in maximum torque during isokinetic exertions to infer fatigue of the shoulder and the torso. In neither study was fatigue significantly influenced by cycle time, which concurs with the outcomes of the current study. Vøllestad (1997) stated that the decrease in maximal voluntary force (as seen by a decrease in peak torque) is the 'gold standard' used to identify whether fatigue occurred. However, force produced during maximum voluntary exertions can be affected by psychological factors such as motivation, which is why measuring EMG may be a better indicator for fatigue. The effects of the maximal exertions on EMG(%MVE) however also concluded that cycle time had no effect on the development of muscle fatigue. This, too, concurred with studies by Iridiastadi and Nussbaum (2006) and Dickerson *et al*. (2015), who also failed to detect significant differences in the EMG(%MVE) between cycle times. One reason for this may be that performing a dynamic abduction-adduction movement involves other synergistic muscles when one is fatigued. This means that, over time, the middle deltoid may have fatigued, but when asked to produce the final maximal exertion on the isokinetic dynamometer, the force may have been produced by other synergistic muscles of the shoulder girdle. Subtle changes in the participants' postures may have led the shoulder girdle to recruit other muscles such as the supraspinatus, anterior or posterior deltoid muscles. EMG would not have been able to measure this, as the electrodes only measured the middle deltoid's activity, and which may thus explain the conflicting results. Dickerson *et al*. (2015) study also did not measure EMG for all shoulder muscles, and it was assumed that this could have interfered with the identification of which intermittent task parameter may have had the greatest effect on the development of fatigue.

While none of the variables recorded during the pre- and post-protocol maximal exertions revealed any effects of cycle time, the recordings of both MdPF and MnPF obtained during the final 12 second interval of the submaximal exertions showed that cycle time did have a significant effect on muscle fatigue. For both variables the 120-second cycle time yielded the greatest shift of the power spectrum to the left, irrespective of the duty cycle/force level. Similarly, the results for EMG(RMS) also showed that the 120s cycle time had an effect during the final 12 seconds of the fatiguing protocol, as it yielded the highest amplitude (Halaki & Ginn, 2012). The perceived effort ratings also indicated significant effects of cycle time on fatigue; already at minute 4, the longest cycle time (120 seconds) was perceived as the requiring highest effort to meet the task demands, and this continued throughout the protocol to the final minute. Differences between the 30-second and 60-second cycle time were however less pronounced, although it did generally appear than the 30-second cycle time resulted in the lowest fatigue development.

The literature is inconclusive about the effects of cycle time on muscle fatigue under both isometric and dynamic movements, since there are many variables influencing it, including the force level, the exertion period, the ROM and the velocity (Mathiassen, 1993; Iridiastadi & Nussbaum, 2006; Yassierli & Nussbaum, 2007; Yassierli & Nussbaum, 2009; Dickerson *et al.,* 2015; Sundberg, & Bundle, 2015; Rashedi & Nussbaum, 2016b). The measurements that were recorded throughout the fatiguing protocol showed that a cycle time of 120 seconds was statistically the most fatiguing compared to the shorter cycle times. Konz (1998a) stated that more frequent breaks should be used to prevent the accumulation of muscle fatigue, rather than less frequent but longer rest breaks. Konz (1998b) explained this by stating, “three breaks of 5min have more benefit than one break of 15 min” (p. 76). Fatigue accumulates over time, and with an increase in fatigue there needs to be enough rest to allow the muscle to recover before it produces another exertion. The following figure was taken from Helbig and Rohmert (1998) and can be used to explain how fatigue and recovery work together overtime.

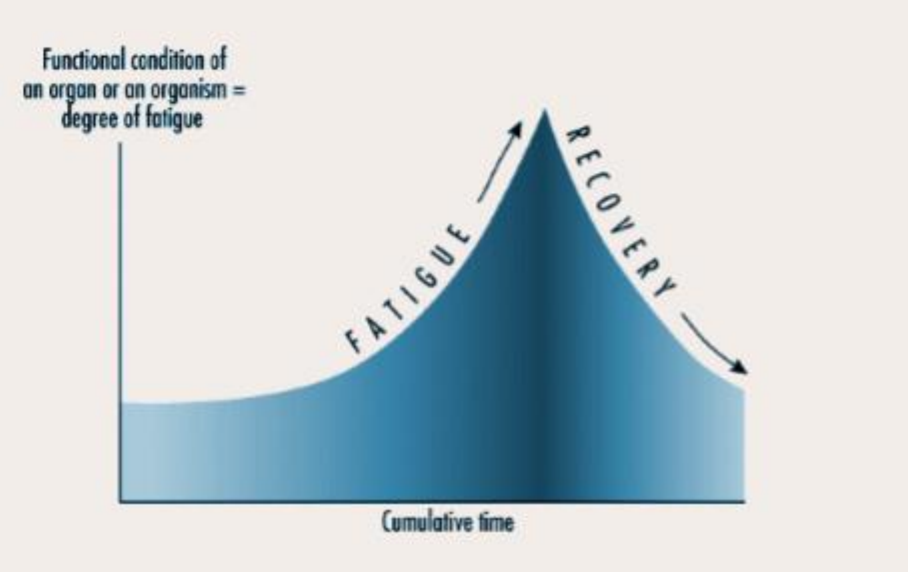

Figure 10: Principal trend of fatigue and recovery (Helbig & Rohmert, 1998).

A condition that has a shorter cycle time will lead to less fatigue accumulation during the activation state, which can be recovered quickly during frequent and short rest breaks, since recovery during the initial moments of a break are highest, before decreasing exponentially. Long cycle times lead to exponential fatigue accumulation, which would need a much longer recovery period. This could be explained by either the effect of blood flow or the neural drive mechanism. During a long cycle time, long activation times can lead to impairment of the blood flow, which prevents sufficient oxygen from reaching the working muscles and also impedes metabolic by-product removal, thus increasing the intracellular pH, which in turn interferes with the contraction mechanism (Masuda *et al*., 1999).

However, when there is a long cycle time the activation is long but so is the rest period, which is why the neural drive mechanism could be more influential to the effects of cycle time. The influence of the neural drive is noticed when there is a decrease in the number of stimulated motor units or a decrease in the motor unit firing frequency (Edwards, 1981). This is seen in the current study since a long cycle time leads to the highest decrease in EMG activity irrespective of the duty cycle/force level combinations. Similarly, Dickerson *et al*. (2015) and Rashedi & Nussbaum (2016) noted that shorter cycle times led to longer endurance times and a slower increase in RMS values. Lui *et al*. (2002) explained that recovery is an important consideration in preventing motor neurons from fatiguing.

Björkstén & Jonsson (1977), Mathiassen (1993), Hermans & Spaepen (1997), Engström *et al.* (1999), Seghers & Spaepen (2004), Moore & Wells (2005), Iridiastadi & Nussbaum (2006), Dickerson *et al*. (2015), and Rashedi & Nussbaum (2016b) all express that, while cycle time may affect the development of muscle fatigue, this factor cannot be looked at in isolation, as fatigue may also be affected by other task-related variables, such as the variations in force levels and duty cycle.

5.3. The Effect of Duty Cycle/Force Level on Muscle Fatigue

Similar to cycle time, the results of this study show that all biomechanical measures, as well as the EMG recordings obtained during the maximal exertions, responded similarly for all three duty cycle/force level combinations. The reason for this could be due to the equal workloads across all conditions, as Dickerson *et al.* (2015) stated that similar workloads would not vary the development of muscular fatigue. However, as a general trend, conditions with a duty cycle/force level of (0.8/25%) consistently indicated slightly greater fatigue levels compared to the other two duty cycle/force level conditions, irrespective of the cycle time.

During the last 12 seconds of the protocol, when fatigue should have been at its greatest, both measures obtained from the frequency domain analysis (MdPF and MnPF), as well as EMG(RMS) showed that duty cycle/force level significantly influenced the development of muscle fatigue. However, while the frequency domain analyses noted that the duty cycle/force level (0.8/25%) was the most fatiguing, RMS indicated that the duty cycle/force level (0.5/40%) was the most fatiguing. All three measures showed that the duty cycle/force level (0.4/50%) was the least fatiguing. From minute 4 onwards, the RPE recorded for the duty cycle/force level (0.8/25%) resulted in a significantly greater perceived effort, compared to the other two duty cycle/force conditions.

Unlike Dickerson *et al.* (2015) who argued that similar workloads could result in similar responses, Mathiassen (1993) explained that the development of muscle fatigue is sensitive to the variations of the task, even if the overall load is kept constant. Similarly, Armstrong *et al.* (1993) proposed that muscle fatigue may not be affected by the magnitude of the load, but rather by the duration of the exertion or movement. This was confirmed by the Sundberg & Bundle (2015) study, which noted that longer exertion periods, relative to the rest periods, lead to a quicker development of muscle fatigue. This could be due to the fact that, when a muscle is fatiguing it is normally able to recover if given enough rest (Armstrong *et al*., 1993; Moore, 2000; Finneran & O'Sullivan, 2010b). However, since fatigue accumulation and recovery are exponential, it follows that longer activation periods results in greater fatigue accumulation, which cannot be reversed by the proportionally shorter rest periods (Konz, 1998b).

Yassierli & Nussbaum (2009) pointed out that a decrease in the effort level helped with the prevention of fatigue. However, they did not take into account the interaction of force with duty cycle. Björkstén and Jonssen (1977) found that high duty cycles and high force levels caused higher rates of muscle fatigue development, compared to low duty cycles in combination with the low force level. Similarly outcomes were found by Iridiastadi & Nussbaum (2006) who investigated fatigue development during eight conditions that combined two force levels (28% and 12%MVE), two duty cycles (0.75 & 0.25), and two cycle times (166s & 34s). The fact that low duty cycles and low forces were the least fatiguing, while the high duty cycle and high force level resulted in the greatest fatigue development can be explained by the differences in workload. The current study found the low duty cycle/high force level combination to be the least fatiguing. This correlates with Punnett and Wegman (2004) who pointed out that even though a low level exertion would seem to be safer than a high level exertion, a low exertion sustained for a long period of time could be more strenuous to the muscle than a high exertion with a short activation duration.

5.4. The Interaction Effect of Cycle Time and Duty Cycle/Force Level on Muscle Fatigue

The interaction between cycle time and duty cycle/force level deserves special consideration, because it has been noted from the results of the current study, as well as those by Björkstén & Jonsson (1977), Mathiassen (1993), Hermans & Spaepen (1997), Engström *et al.* (1999), Seghers & Spaepen (2004), Moore & Wells (2005), Iridiastadi &

Nussbaum (2006), Dickerson *et al*. (2015), and Rashedi & Nussbaum (2016b), that the intermittent task factors are not independent of each other.

The interaction effect indicates that the most fatiguing cycle time (120s), together with the most fatiguing duty cycle / force level combination (0.8/25%) had the greatest summative effect on fatigue, whereas the opposite is true for the 30s(0.4/50%) condition. Fatigue will increase to a greater extent if there is a long activation time, which is why the cycle time of 120 seconds was seen as the most fatiguing. However, the combination of cycle time 120 seconds and the duty cycle/force level (0.8/25%) had the highest fatigue development because the exertion period is long which increases the fatigue and the rest phase is short so there is not enough time for the muscle to recover completely. This leads to residual fatigue and fatigue build up which is still there when the next exertion needs to be started. This can also explain that condition 120(0.4/50%) was less fatiguing than the other conditions with a 120s cycle time because the duty cycle allowed for enough rest. Conditions that were the least fatigue where conditions that had more frequent activation and rest phases and had enough rest. Therefore, conditions that have a long activation phase and a short rest should only be paired with short cycle times and the longer the cycle time get the shorter the activation phase to prevent the development of muscle fatigue. Changes in either the cycle time, or the duty cycle/force level combination seem to have similar effects on fatigue, as is indicated by conditions 60s(0.8/25%) and 120s(0.5/40%), for example.

5.5. The Effect of Maximal and Submaximal Exertions on the outcomes of the Study

The results of this study have been characterised by a distinct split in the condition effects between the biomechanical variables and EMG(%MVE), and the remaining the EMG variables (RMS, MnPF, MdPF) and RPE, where the former variables were not affected by either factor, while the latter variables were significantly influenced by cycle time, duty cycle/force level combination, as well as the interaction of the two. Peak torque, total work, average power, EMG(% MVE) were all recorded during the maximum voluntary exertions prior to and at the end of the fatigue protocol, while RMS, MnPF, MdPF and

RPE were recorded during the fatigue protocol which entailed the execution of submaximal exertions.

The differences between the results from the maximal measures to the submaximal measures could be because of different motor unit recruitment strategies (Tortora & Derrickson, 2009). Recruitment is influenced by the demands of the task, hence the recruitment and firing rate of motor units depend greatly on the type of contraction and the amount of force produced by the muscle (Maton, 1981). When performing a submaximal exertion slow twitch muscle fibres are normally used, since these fatigue-resistant muscle fibres can be used for prolonged activities under submaximal conditions (Klavora, 2007). Producing maximal exertions, however, tend to use type II muscle fibres, which result in a decrease in the number of stimulated motor units or the decrease in motor unit firing frequency (Edwards, 1981). Muscles of the upper extremities tend to have a mix of muscle fibre types, but the shoulder muscle group displays a tendency to a higher proportion of type I muscle fibres (Srinivasan *et al.,* 2007). This could be due to the fact that many occupational activities that require task execution above shoulder height with low loads, slower speeds, and higher number of repetitions for a full working day, thus requiring a more fatigue resistant muscle fibre type (Srinivasan *et al.,* 2007; Reese & Bandy, 2013).

CHAPTER VI – CONCLUSIONS & RECOMMENDATIONS

6.1. Purpose of the Study

Localised muscle fatigue has an extensive body of literature for prolonged static exertions, and more investigations emerging with intermittent isometric exertions. However, relatively few studies have investigated muscle fatigue development during more complex task such as dynamic intermittent exertions. Studies on localised muscle fatigue therefore need to incorporate dynamic movements with intermittent task parameters, these being cycle time and the combinations of duty cycles and variations of force levels. The aim of this study was to investigate the development of muscle fatigue during intermittent dynamic exertions by investigating the effects of cycle time and combinations of duty cycles and force levels with the same overall mean muscle load.

6.2. Summary of Procedures

Nine experimental conditions were tested, consisting of three cycle times (30, 60, 120 seconds) and three combinations of duty cycles and submaximal force levels (0.8/25%, 0.5/40%, 0.4/50%). 30 participants underwent a 16-minute fatigue protocol during which they were required to perform repetitive shoulder abduction-adduction motions using the middle deltoid muscle. At the start of each experimental testing session all participants had to produce four maximum voluntary isokinetic exertions on the isokinetic dynamometer during which peak torque, total work and average power were recorded. EMG was also recorded and the maximum torque values used to calculate the submaximal force levels for the individual conditions of the fatigue protocol. Once the fatigue protocol had been completed, another four maximal exertions were performed. During the submaximal protocol, time domain (RMS) and frequency domain (MnPF and MdPF) EMG activity were measured, and RPE recorded at four-minute intervals.

6.3. Summary of Results

Significant changes occurred over time for all variables recorded during the maximal and submaximal exertions, indicating that the muscle did indeed fatigue. Neither cycle time, nor duty cycle/force level had an effect on the variables collected during the maximal exertions (i.e. peak torque, average power, total work and EMG(%MVE)). However, the measurements obtained during the 16-minute protocol showed that both cycle time and duty cycle/force level did have a significant effect on muscle fatigue, and that there were significant interactions. Conditions with a low cycle time of 30 seconds and a low duty cycle but high force level combination of (0.4/50%) were found to be the least fatiguing. Conversely, the longest cycle time of 120 seconds and the duty cycle / force level combination of (0.8/25%) showed the greatest fatigue development. It was also determined that these conditions effect on fatigue could only be determined using data obtained during the submaximal exertions, suggesting that motor neuron recruitment differs between maximal and submaximal force exertions.

6.4. Response to Hypotheses

Hypothesis 1: The null hypothesis stated that cycle time during intermittent exertions would not have an effect on muscle fatigue. This hypothesis was rejected for the peak torque, average power, total work and EMG(%MVE) measures, but accepted for EMG(RMS), MnPF, MdPF and RPE responses.

Hypothesis 2: This null hypothesis, which stated that the duty cycle / force levels variation would not affect muscle fatigue development, was accepted for the biomechanical and EMG(%MVE) measures, but rejected for the physiological and subjective response measures.

Hypothesis 3: The third null hypothesis stated that muscle fatigue is influenced by an interaction between cycle time and the duty cycle / force level combinations. The null hypothesis was rejected for the biomechanical and EMG(%MVE) measures, but accepted for the physiological and subjective response measures.

6.5. Limitations and Recommendations

Factors affecting the results of this study include the effect of the dynamic movement and not investigating the surrounding muscles, as they may have had an effect on the maximal exertions, understanding what is happening around the muscle that is meant to be doing the movement (in this case the middle deltoid for adduction- abduction) can give insight to compensatory effects.

Repeating the experiment with more levels of each of the independent variables could strengthen the outcomes of this study as interpretations of the duty cycle/ force level as well as the cycle time may have been effected from the conditions not being evenly spaced out. In other words, even though the cycle times of 30 seconds, 60 seconds, and 120 seconds were multiples of 30, the difference between the 60 and 120 second cycles times was twice the difference between the 30s and 60s cycle times. Similarly, duty cycles of 0.4 and 0.5 were more similar compared to the 0.8 cycle time. Investigating the protocol until exhaustion could have given more insight as to what condition would be better for an 8-hour working day. It would have also informed how the muscle fatigues and recovers over extended durations.

It is acknowledged that the fatigue protocol did not adjust the wrist weight to account for the weight of the arm, whereas the Biodex provided maximum torque responses using gravity correction, in other words, excluding the weight of the arm. This would have resulted in slight variations of the participants' percentage of maximum weight moved. However, this weight remained constant for each individuals across all conditions.

The weights were calculated by converting 20% of the peak torque values to kilograms and adjusting the wrist weights to this. The Biodex system accounted for the weight of the arm during the maximal exertions. However, it could not be accounted for during the fatigue protocol with the sub-maximal exertions. This was acknowledged as a limitation to the study Similarly, the maximum exertions necessitated the participant to exert a force to the handle of the Biodex, while during the fatigue protocol the weight was attached to the wrist and therefore closer to the fulcrum, i.e. the elbow. While this is a limitation of the study, the manner in which the fatigue was induced was standardized for each individual across all experimental conditions, and pre and post measurements were recorded and compared using the same set-up and procedures. .

Even though there was a 30 minute break between conditions and there was no significant difference between the participants' maximum force recordings prior to the start of each fatigue protocol, cumulative fatigue still could affected fatigue development that may have skewed the data.

The task was very monotonous and this could have affected the participant's perceived perception of the task, as well as the effort invested into the maximal exertions at the end of the protocol.

Future recommendations would to be to look at the effects of age, work experience, gender, and manual workers.

Shoulder movements are not just limited to adduction-abduction, thus the rigidity of the task was limiting. Investigating tasks that consider shoulder movements along other planes, such as flexion can give insight to the effects of shoulder activities on muscle fatigue development. Additional areas of interest in developing occupational guidelines would include muscles of the forearm and hand, as well as the trunk.

Further considerations should be given to the validity of the methods for fatigue determination. The current study's results suggest that motor unit recruitment differs between maximal and submaximal exertions, which means that the task-specific fatigue effects from a fatiguing submaximal protocol could be missed, if fatigue is only assessed via changes in maximal exertions.

6.6. Significance of Findings

The findings from this study suggest that development of muscle fatigue is greatest for conditions with a cycle time of 120 seconds and a duty cycle/force level of (0.8/25%). The interaction of factors resulted in the 120s(0.8/25%) developing the highest levels of muscle fatigue. Theoretically, conditions that had shorter but more frequent activation periods resulted in lower fatigue development, as did conditions with a high force level but a long rest period. Therefore, to prevent the onset of muscle fatigue in the working environment tasks that are dynamic in nature should allow for more frequent rest breaks, tasks that are repetitive and do not allow recovery can lead to employees being fatigued and injured. This can negatively affect the productivity of the workplace. Despite the same overall workload, it is more beneficial for activities to produce a greater force, e.g. lifting heavier weights with equal activation and rest phases, or with a rest break that is longer than the activation time.

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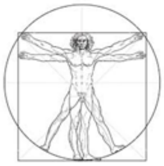
APPENDIX A

A.1. INFORMATION TO PARTICIPANT



LETTER TO PARTICIPANTS

RHODES UNIVERSITY

DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

Phone: 083 611 3716 • E-mail: josie.king1992@gmail.com

Dear (Mr/Mrs/Ms) ………………………………………………………………………………

Thank you for showing an interest towards the research project titled:

“THE EFFECTS OF DIFFERENT INTERMITTENT TASK PARAMETERS DURING SUB-MAXIMAL DYNAMIC EXERTIONS ON MUSCLE FATIGUE DEVELOPMENT”.

This study will take place at Rhodes University’s Department of Human Kinetics and Ergonomics (HKE) and will be conducted by the principal researcher who is a Master’s student of the Department.

Since there is limited literature on muscle fatigue development during intermittent submaximal dynamic exertions, this research is aimed at identifying: (i) the effects of cycle time and (ii) the effects of a higher exertion period with a longer rest or a lower exertion period with a shorter rest, on muscle fatigue development. The outcomes of this study will assist in contributing to understanding fatigue development and making recommendations pertaining to suitable work design.

Protocol

In addition to two familiarization sessions, you will be required to attend three experimental sessions during which you will perform nine conditions, which will be separated by at least three days and should take approximately 2 hours each. Each condition will require you to execute shoulder abduction and adduction movements, using your middle deltoid muscle, at a given submaximal intensity, number of repetitions and cycle time for a duration of 20 minutes. The cycle times (the time of one repetition of a muscle contraction and relaxation) will be set either at 30, 60 or 120 seconds. The ratio of muscle contraction to muscle relaxation (called the duty cycle) will vary depending on the intensity/ force of the muscle contraction and has been calculated so that the average muscle load remains the same, namely at 20% of your maximum voluntary force (MVF) for all experimental conditions. This is detailed in Table I.

Table I: Graphical presentation of all conditions.

Conditions cycle time (duty cycle / force as a % of maximum)	Cycle Time (sec)	Maximum Voluntary force (%)	Activation (sec)	Rest (sec)
30(0.8/25%)	30	25	24	6
30(0.5/40%)	30	40	15	15
30(0.4/50%)	30	50	12	18
60(0.8/25%)	60	25	48	12
60(0.5/40%)	60	40	30	30
60(0.4/50%)	60	50	24	36
120(0.8/25%)	120	25	96	24
120(0.5/40%)	120	40	60	60
120(0.4/50%)	120	50	48	72

Study Project Procedures

You will be required to visit the HKE Department 5 times, and each time you will be required to wear a sleeveless shirt so that your dominant arm’s deltoid (shoulder) muscle can easily be accessed. The first two visits will make up the information and habituation sessions during which everything outlined in this letter will be explained to you verbally. You will also be practicing the required tasks so you can become familiar with the equipment and the procedures. You will then be asked to sign an informed consent form. Basic demographic information (age, sex, height, weight) and isokinetic dynamometer positions will also be recorded.

Three to four days after your last habituation session you will be required to visit the HKE department for the first testing session. During this session you will perform three of the nine conditions. For logistical reasons you will be paired up with another participant during the session, so that when you are resting between conditions the other participant will be performing a condition. If you do not feel comfortable to do the testing with another participant, please inform me and we can arrange for an individual testing session.

Every time you arrive for a testing session you will be fitted with the EMG system (which measures muscle activity). EMG electrodes, which pick up the muscle’s electrical signal, will be stuck over the belly of the middle deltoid muscle, and a reference electrode will be placed on an uninvolved muscle. You will then be asked to perform three maximal efforts against the isokinetic dynamometer attachment of a machine called the Biodex, a machine which measures the force produced while performing a movement. The greatest force that is measured will be taken as your maximum force and this will be used as a reference to determine the target force for the fatigue protocol, which will follow after a ten minute rest break. For the fatigue protocol, a weight corresponding to the required submaximal force will be strapped to your wrist. Instructions pertaining to the speed of movement and the contraction and rest intervals will be provided on a computer screen. During the protocol you will also be asked to provide, at five minute intervals, a perceptual feedback on the effort it takes to perform the movement. At the end of the fatiguing protocol the weight will be removed and you will be asked to generate another three maximal efforts on the Biodex. Upon completion of all the conditions in the session, the equipment will be removed and an appointment will be scheduled for the next session, if required.

Potential Risks

Since this experiment includes a fatigue protocol, it is possible that you may feel discomfort associated with muscle fatigue during testing, and you may also feel delayed onset muscle soreness (DOMS) after the testing. However, DOMS is typically a temporary discomfort which passes within 24 to 72 hours. Given that you will have 3-4 rest days between sessions, it is expected that you will have enough time to recover.

There is also a slight risk of muscle strain during the maximum exertions; however, this is highly unlikely since the force produced is a voluntary force, meaning you determine how much force to create. Voluntary contractions are below the threshold level of injury.

Potential Personal Benefits

You will have the opportunity to learn about muscle-related fatigue, and how fatigue impacts task performance over time. You will also have the opportunity to learn about ergonomic research methods, research equipment, and the potential impact of ergonomic research at a university level.

Archived Information, Anonymity, and Feedback

All the data from the study will be stored until the study has been completed and the student researcher has received positive feedback from the examiners, signifying the completion of the degree. Thereafter, the data may be used for publication purposes, so it will generally be stored for a period of 5 to 10 years. Any personal information that may have been collected from you will be stored and accessed by only the main researcher or her supervisor, while the data collected from you will be stored using a code ensuring anonymity. Any resultant publications will only show the group’s summary data.

Requirements

Before and during the habituation and testing sessions please:

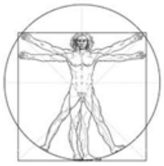
- Refrain from consuming the following items 3 hours before testing: caffeine and tobacco, and a whole day for alcohol.
- Do not participate in heavy exercise on the day as well as 48 hours before your habituation and testing sessions to prevent any DOMS or residual muscle fatigue.
- Wear unrestrictive clothing for both your habituation and testing sessions
- Report any changes in your health status and medication intake.
- Immediately report any signs of pain, dizziness, nausea or other feelings of not feeling well to the researcher and / or her research assistant.

Thank you for wanting to take part in my thesis – I appreciate your willingness to dedicate some of your time towards this research. While your participation is voluntary and you are entitled to discontinue your participation at any time without negative repercussions, I would appreciate full commitment from you.

If you have any further questions, concerns or complaints, please contact me, my supervisor, or the HKE Department.

Josephine King	0836113716	josie.king@gmail.com
Supervisor: Miriam Mattison	0823194626	m.mattison@ru.ac.za
HKE Department: Miriam Mattison	046-603 8468	
HKE Department:	046-603 8471	

A.2. CONSENT ISSUES



CONSENT FORM

RHODES UNIVERSITY

DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

Phone: 083 611 3716 • E-mail: josie.king1992@gmail.com

I, ______________________, hereby consent to participate in the following research study: **“THE EFFECTS OF DIFFERENT INTERMITTENT TASK PARAMETERS DURING SUB-MAXIMAL DYNAMIC EXERTIONS ON MUSCLE FATIGUE DEVELOPMENT”.** I have been informed about the study’s purpose, expectations of me, as well as the possible risks involved and potential benefits. These have been explained to me by the primary researcher both verbally and in writing. I am aware of all procedures that I am expected to comply with and am still willing to participate in the above-mentioned study.

By agreeing to partake in this study, I accept joint responsibility with the Department of Human Kinetics and Ergonomics in that should any injury occur due to the experimental protocol, the department will cover medical fees incurred and take steps to rehabilitate the injury. I do however waive any legal recourse against the researcher, or against Rhodes University, and will take full responsibility in the event that the injury is shown to be self-inflicted and/or due to non-compliance with the researcher's instructions. I will inform the researcher and/or assistant immediately should I feel any discomfort, pain or other feelings of ill-health during familiarization or testing. I am aware that at any point I may withdraw my consent and participation in the study without any negative consequences.

I understand that my privacy will be protected and that confidentiality during the research period will be prioritised. I am aware of the experimental conditions that will be performed and measures that will be recorded during the testing period by the principal researcher, and understand that the information collected will be used for scientific purposes. I am aware that should photographs be taken during the testing phase, my approval must first be obtained for this. In such cases I understand that recognizable features will be obscured in the images and that these will only be used for illustrative purposes.

I have read and understood the information above as well as the additional information about the study provided. Any queries concerning this study have been answered to my satisfaction.

<u>Please tick the appropriate box</u>

I agree to have my photo taken ☐

I do not agree to have my photo taken ☐

Signed at Rhodes University

PARTICIPANT

____________________	____________________	____________________
(Print name)	(Signed)	(Date)

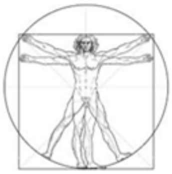
RESEARCHER

____________________	____________________	____________________
(Print name)	(Signed)	(Date)

WITNESS

____________________	____________________	____________________
(Print name)	(Signed)	(Date)

A.3. SOCIAL MEDIA POSTER



HUMAN KINETICS AND ERONOMICS DEPARTMENT,
RHODES UNIVERSITY
Masters Project
Participant Recruitment

“THE EFFECTS OF DIFFERENT INTERMITTENT TASK PARAMETERS DURING SUB-MAXIMAL DYNAMIC EXERTIONS ON MUSCLE FATIGUE DEVELOPMENT”

There has been an increased attention on muscle fatigue and the role it plays in workplace discomfort, accidents, injuries and performance. Therefore; research and interventions on muscle fatigue is needed.

Participants will be required to attend:

- 2 habituation sessions (no longer than 45 minutes): study will be further outlined in depth for you, you will also have a chance to become familiar with the equipment and the procedures
- 3 experimental sessions that will last about 2 ½ hours. Each session will require you to perform 3 different dynamic sub-maximal conditions.
- All sessions can be completed with a colleague or friend.

Participants must be:

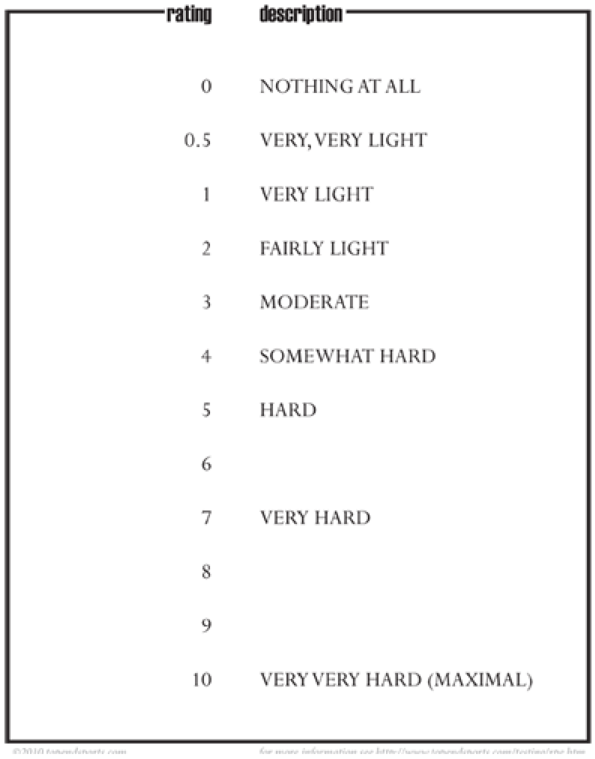
- Male or Female
- Age: 18-25
- Should engage in moderate weight training (2-4 times a week)
- No recent history (within the past 6 months) of acute injuries, or any history of musculoskeletal disorders of the upper extremities

If you are interested or would like more information, please contact:
Josephine King
Email: josie.king1992@gmail.com
Cellphone number: 0836113716

The study has been approved by the Rhodes University Human Kinetics and Ergonomics Ethical Standards Committee

APPENDIX B

B.1. RPE BORG SCALE



rating	description
0	NOTHING AT ALL
0.5	VERY, VERY LIGHT
1	VERY LIGHT
2	FAIRLY LIGHT
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	VERY VERY HARD (MAXIMAL)

B. 2. PERMUTATION MATRIX

Table xv: Randomization of 3 Force levels/Duty Cycles: (0.8/25%)

(0.5/40%)

(0.4/50%)

Combination A	Combination B	Combination C	Combination D	Combination E	Combination F
(0.8/25%)	(0.8/25%)	(0.5/40%)	(0.5/40%)	(0.4/50%)	(0.4/50%)
(0.5/40%)	(0.4/50%)	(0.8/25%)	(0.4/50%)	(0.8/25%)	(0.5/40%)
(0.4/50%)	(0.5/40%)	(0.4/50%)	(0.8/25%)	(0.5/40%)	(0.8/25%)

Table xvi: Randomization of 3 Cycle Times: *30 seconds*

60 seconds

120 seconds

Combination (i)	Combination (ii)	Combination (iii)	Combination (iv)	Combination (v)	Combination (vi)
30	30	60	60	120	120
60	120	30	120	30	60
120	60	120	30	60	30

Table xvii: Permutation of above combinations of conditions

	A	B	C	D	E	F
(i)	1	7	13	19	25	31
(ii)	2	8	14	20	26	32
(iii)	3	9	15	21	27	33
(iv)	4	10	16	22	28	34
(v)	5	11	17	23	29	35
(vi)	6	12	18	24	30	36

Example: Participant 1 uses combination A(i); participant 2 performs combination A(ii), participant 3: A(iii)…, participant7: B(i), …, participant 36: F(vi)

APPENDIX C

C.1. ETHICAL CONDERATIONS

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

HUMAN KINETICS & ERGONOMICS
Tel: +27 (0)46 6038471
Fax: +27 (0)46 6038934

02 May 2017

Josephine King – g12K2814@campus.ru.ac.za

Dear Josie King,

Re: Ethical Clearance – Application HKE-2017-01

Your application for ethical clearance for the study provisionally titled *"The effects of different intermittent task parameters during repetitive sub-maximal dynamic exertions on muscle fatigue development"* (reference number HKE-2017-01) has been approved with stipulations by the HKE Ethics Committee.

These stipulations include:

- Permission from Rhodes University Registrar

This permission should be submitted to the HKE Ethics Committee for record keeping purposes.

Any significant changes made to the study and procedures need to be communicated to the HKE Ethics Committee, and another full review may be requested.

Upon completion of your study, please submit a short report indicating whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the HKE Ethics committee should be aware of.

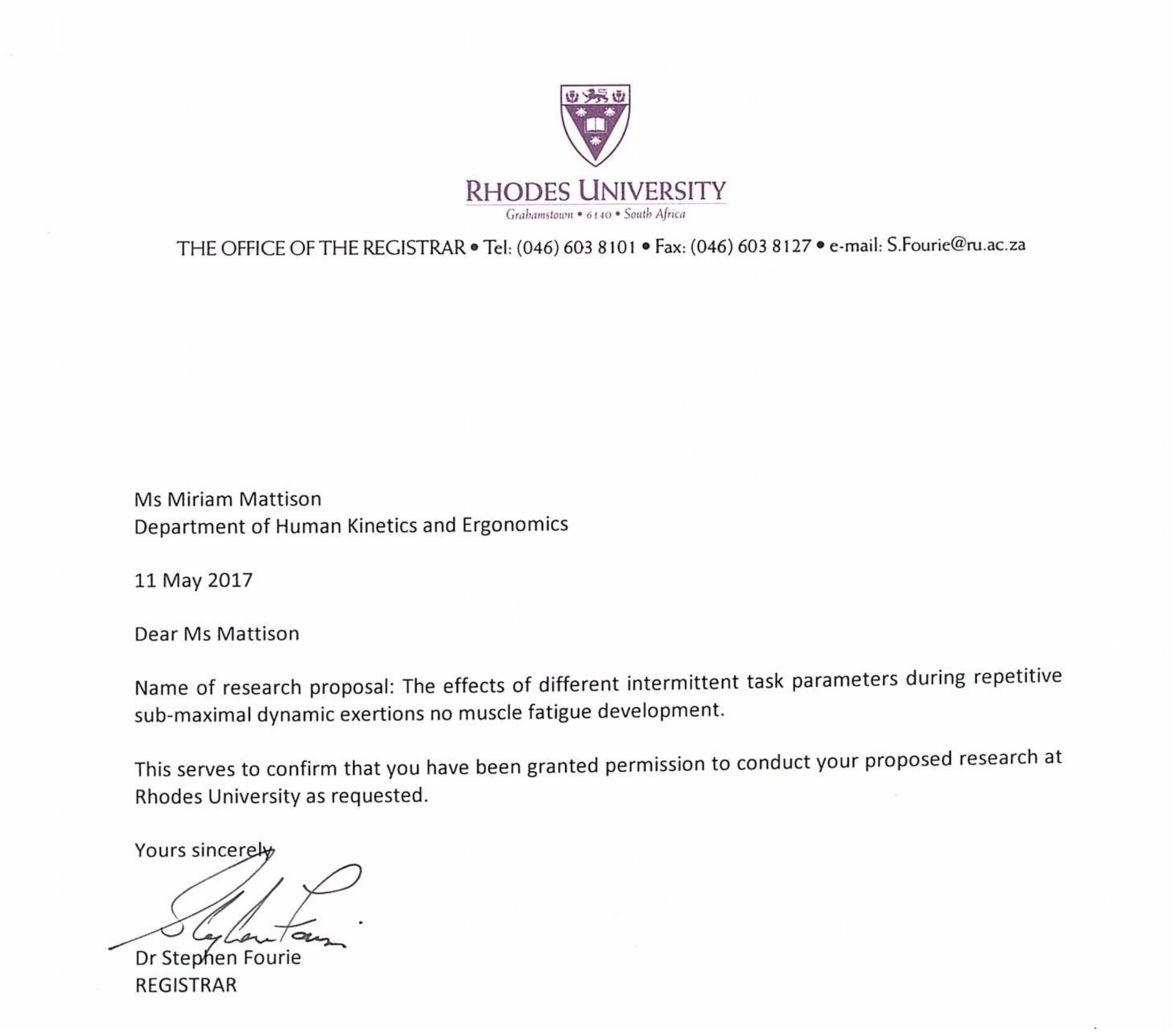
Sincerely,

Miriam Mattison

M.C. Mattison
2017 HKE Ethics Chairperson
Department of Human Kinetics and Ergonomics
Rhodes University; Grahamstown
Tel: + 27-46-603 8468
Cell: +27-82 319 4626
E-mail: m.mattison@ru.ac.za

www.ru.ac.za

C.2. LETTER FROM REGISTRAR



RHODES UNIVERSITY
Grahamstown • 6140 • South Africa
THE OFFICE OF THE REGISTRAR • Tel: (046) 603 8101 • Fax: (046) 603 8127 • e-mail: S.Fourie@ru.ac.za

Ms Miriam Mattison
Department of Human Kinetics and Ergonomics

11 May 2017

Dear Ms Mattison

Name of research proposal: The effects of different intermittent task parameters during repetitive sub-maximal dynamic exertions no muscle fatigue development.

This serves to confirm that you have been granted permission to conduct your proposed research at Rhodes University as requested.

Yours sincerely

Dr Stephen Fourie
REGISTRAR

APPENDIX D

D.1. Biomechanical Measures

D.1.1. Effects of Time

D.1.1.1. Peak Torque

Table xviii: Two-way ANOVA of the pre and post peak torque (Nm)

Effect	Repeated Measures Analysis of Variance (All Data) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 80.0555				
	SS	Degr. of Freedom	MS	F	p
Intercept	1349790	1	1349790	210.6124	0.000000
Error	185858	29	6409		
PRE/POST	2944	1	2944	28.4431	0.000010
Error	3002	29	104		

D.1.1.2. Total Work

Table xix: Two-way ANOVA of the pre and post total work (J)

Effect	Repeated Measures Analysis of Variance (All Data.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 279.6716				
	SS	Degr. of Freedom	MS	F	p
Intercept	9831809	1	9831809	125.7004	0.000000
Error	2268270	29	78216		
PRE/POST	11088	1	11088	13.5593	0.000941
Error	23714	29	818		

D.1.1.3. Average Power

Table xx: Two-way ANOVA of the pre and post average power (watts)

Effect	Repeated Measures Analysis of Variance (All Data) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 93.4996				
	SS	Degr. of Freedom	MS	F	p
Intercept	966377.3	1	966377.3	110.5420	0.000000
Error	253522.9	29	8742.2		
PRE/POST	1029.2	1	1029.2	10.2022	0.003369
Error	2925.5	29	100.9		

D.1.2. Condition Effect

D.1.2.1 Peak Torque

Table xxi: All conditions pre and post values as well as the normalised percentage of the post maximal peak torque from the pre torque.

Conditions	Pre-values (Nm)	Post-values (Nm)	Relative value (%) (PostPT/PrePT*100)
30(0.8/25%)	52.70 ±20.21 (38.35%)	45.85 ±19.18 (41.84%)	87 ±19.31 (22.19%)
30(0.5/40%)	51.87 ±20.69 (39.89%)	45.94 ±17.18 (37.40%)	90.61 ±13.61 (15.02%)
30(0.4/50%)	53.22 ±21.75 (40.86%)	49.07 ±20.39 (41.56%)	92.38 ±11.16 (12.08%)
60(0.8/25%)	52.86 ±19.87 (37.59%)	46.29 ±17.66 (38.15%)	88.21 ±15.98 (18.12%)
60(0.5/40%)	51.92 ±21.04 (40.52%)	48.93 ±19.85 (40.57%)	95.77 ±16.62 (17.35%)
60(0.4/50%)	52.53 ±20.79 (39.58%)	50.72 ±21.34 (42.07%)	96.12 ±11.86 (12.34%)
120(0.8/25%)	52.74 ±19.69 (37.34%)	47.63 ±21.25 (44.61%)	89.95 ±21.11 (23.47%)
120(0.5/40%)	51.58 ±19.76 (38.31%)	46.87 ±16.17 (34.49%)	93.78 ±17.70 (18.88%)
120(0.4/50%)	51.57 ±20.33 (39.42%)	47.64 ±18.91 (39.70%)	92.13 ±9.03 (9.8%)

Table xxii: Effect of the dependent factors on the normalised peak torque

Effect	Repeated Measures Analysis of Variance (All Data) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 21.0723				
	SS	Degr. of Freedom	MS	F	p
Intercept	2274019	1	2274019	5121.206	0.000000
Error	12877	29	444		
CT	516	2	258	1.689	0.193693
Error	8867	58	153		
DC/FL	1547	2	773	1.493	0.233214

Error	30049	58	518		
CT*DC/FL	323	4	81	0.788	0.535080
Error	11866	116	102		

D.1.2.2. Total Work

Table xxiii: All conditions pre and post values as well as the normalised percentage of the post maximal total work from the pre work

Conditions	Pre-values (Joules)	Post-values (Joules)	Relative value (%) (PostTW/PreTW*100)
30(0.8/25%)	135.78 ±69.59 (51.25%)	125.09 ±63.48 (50.74%)	92.77 ±14.51 (15.65%)
30(0.5/40%)	136.27 ±68.46 (39.89%)	127.52 ±59.98 (47.03%)	95.37 ±10.50 (11.01%)
30(0.4/50%)	147.22 ±75.17 (51.06%)	142.67 ±72.75 (50.99%)	97.70 ±10.31 (10.55%)
60(0.8/25%)	138.81 ±71.97 (51.85%)	126.19 ±64.69 (51.26%)	91.91 ±13.80 (15.02%)
60(0.5/40%)	135.19 ±67.12 (49.65%)	127.35 ±60.44 (47.46%)	95.79 ±11.05 (11.54%)
60(0.4/50%)	145.39 ±73.10 (50.28%)	141.16 ±69.50 (49.24%)	98.37 ±11.76 (11.95%)
120(0.8/25%)	135.94 ±69.76 (51.32%)	123.65 ±64.54 (52.20%)	90.38 ±15.24 (16.86%)
120(0.5/40%)	135.36 ±68.42 (50.54%)	124.46 ±58.37 (46.90%)	94.29 ±9.97 (10.57%)
120(0.4/50%)	145.21 ±73.91 (50.90%)	135.54 ±64.61 (47.67%)	94.93 ±11.79 (12.42%)

Table xxiv: Effect of the dependent factors on the normalised total work

Effect	Repeated Measures Analysis of Variance (All Data) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 22.5963				
	SS	Degr. of Freedom	MS	F	P
Intercept	2416908	1	2416908	4733.527	0.000000
Error	14807	29	511		
CT	270	2	135	1.663	0.198514
Error	4711	58	81		
DC/FL	1310	2	655	2.530	0.088382
Error	15016	58	259		
CT*DC/FL	54	4	13	0.341	0.849744
Error	4572	116	39		

D.1.2.3. Average Power

Table xxv: All conditions pre and post values as well as the normalised percentage of the post maximal average power from the pre average power

Conditions	Pre-values (Watts)	Post-values (Watts)	Relative value (%) (PostAP/PreAP*100)
30(0.8/25%)	42.70 ±23.66 (55.42%)	39.06 ±20.92 (53.55%)	92.60 ±14.83 (16.02%)
30(0.5/40%)	42.73 ±23.01 (53.85%)	40.21 ±20.21 (50.25%)	96.35 ±10.17 (10.56%)
30(0.4/50%)	46.04 ±24.92 (54.14%)	44.73 ±23.80 (53.21%)	98.26 ±9.25 (9.42%)
60(0.8/25%)	43.45 ±24.02 (55.27%)	39.83 ±22.30 (55.99%)	92.10 ±14.96 (16.25%)
60(0.5/40%)	42.51 ±22.60 (53.17%)	39.73 ±19.85 (49.98%)	95.77 ±12.08 (12.62%)
60(0.4/50%)	45.49 ±24.29 (53.39%)	44.02 ±22.67 (51.51%)	98.54 ±11.56 (11.73%)
120(0.8/25%)	42.25 ±22.91 (54.24%)	39.04 ±22.46 (57.53%)	91.80 ±16.46 (17.93%)
120(0.5/40%)	42.42 ±22.96 (54.14%)	39.14 ±19.65 (50.20%)	95.22 ±11.62 (12.20%)
120(0.4/50%)	45.57 ±24.68 (54.15%)	42.54 ±21.77 (51.16%)	94.95 ±10.91 (11.49%)

Table xxvi: Effect of the dependent factors on the normalised average power

Effect	Repeated Measures Analysis of Variance (All Data.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 23.3356				
	SS	Degr. of Freedom	MS	F	P
Intercept	2440051	1	2440051	4480.853	0.000000
Error	15792	29	545		
CT	160	2	80	1.045	0.358275
Error	4430	58	76		
DC	1230	2	615	2.136	0.127312
Error	16703	58	288		
CT*DC	109	4	27	0.661	0.620608
Error	4763	116	41		

D.2. Physiological Measures

D.2.1. EMG - Percentage of Maximum Voluntary Exertion (%MVE)

Table xxvii: Effect of the dependent factors on the %MVE

Effect	Repeated Measures Analysis of Variance (All Data) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 24.6402				
	SS	Degr. of Freedom	MS	F	p
Intercept	1608441	1	1608441	2649.220	0.000000
Error	17000	28	607		
CT	274	2	137	1.176	0.316055
Error	6515	56	116		
DC/FL	674	2	337	1.540	0.223224
Error	12244	56	219		
CT*DC/FL	230	4	58	0.614	0.653244
Error	10494	112	94		

D.2.2. Root Mean Square

Table xxviii: The normalised RMS measures for 12 seconds at the start in the middle and at the end of the protocol.

	0.00-0.12 mins (mV)	**8.00-8.12 mins (mV)**	**15.48-16.00 mins (mV)**
30(0.8/25%)	26.73 ±12.16 (45.48%)	29.77 ±11.62 (39.02%)	32.38 ±11.83 (36.54%)
30(0.5/40%)	27.10 ±9.59 (35.39%)	27.88 ±9.65 (34.6%)	30.98 ±10.32 (33.31%)
30(0.4/50%)	24.58 ±7.63 (31.03%)	22.93 ±8.44 (36.82%)	23.74 ±8.50 (35.81%)
60(0.8/25%)	28.06 ±12.34 (43.99%)	30.4 ±12.38 (40.74%)	33.87 ±14.40 (42.52%)
60(0.5/40%)	27.99 ±12.42 (44.36%)	26.71 ±12.17 (45.58%)	34.18 ±10.85 (31.74%)
60(0.4/50%)	23.69 ±8.58 (36.2%)	21.36 ±7.79 (36.48%)	26.81 ±10.84 (40.41%)
120(0.8/25%)	26.39 ±12.31 (46.63%)	27.81 ±11.21 (40.31%)	32.23 ±11.56 (35.86%)
120(0.5/40%)	26.55 ±8.20 (30.9%)	25.93 ±8.51 (32.82%)	34.95 ±10.77 (30.81%)
120(0.4/50%)	26.09 ±11.58 (44.37%)	23.80 ±11.42 (47.97%)	31.78 ±11.09 (34.92%)

Table xxix: The effects of RMS on the dependent factors and overtime

Effect	Repeated Measures Analysis of Variance (2017-10-24 All Data - modified) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 35.7821				
	SS	Degr. of Freedom	MS	F	p
Intercept	611746.7	1	611746.7	477.7943	0.000000
Error	35850.0	28	1280.4		
CT	154.4	2	77.2	1.0699	0.349938
Error	4041.0	56	72.2		
DC/FL	3510.3	2	1755.1	3.7296	0.030159
Error	26353.7	56	470.6		
TIME	4163.7	2	2081.9	33.4478	0.000000

Error	3485.6	56	62.2		
CT*DC/FL	717.5	4	179.4	2.5062	0.046066
Error	8016.0	112	71.6		
CT*TIME	602.0	4	150.5	4.5095	0.002047
Error	3738.1	112	33.4		
DC/FL*TIME	627.7	4	156.9	6.4277	0.000108
Error	2734.3	112	24.4		
CT*DC/FL*TIME	196.3	8	24.5	1.3366	0.226394
Error	4111.7	224	18.4		

Table xxx: Post-hoc Tukey test on RMS

Cell No.	Tukey HSD test; variable DV_1 (All Data - modified) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 18.356, df = 224.00																													
	CT	DC/FL	TIME	30(0.8/25%) first 26.727	30(0.8/25%) middle 29.773	30(0.8/25%) last 32.377	30(0.5/40%) first 27.099	30(0.5/40%) middle 27.881	30(0.5/40%) last 30.978	30(0.4/50%) first 24.583	30(0.4/50%) middle 22.932	30(0.4/50%) last 23.744	60(0.8/25%) first 28.056	60(0.8/25%) middle 30.398	60(0.8/25%) last 33.872	60(0.5/40%) first 27.996	60(0.5/40%) middle 26.707	60(0.5/40%) last 34.178	60(0.4/50%) first 23.690	60(0.4/50%) middle 21.359	60(0.4/50%) last 26.811	120(0.8/25%) first 26.390	120(0.8/25%) middle 27.812	120(0.8/25%) last 32.227	120(0.5/40%) first 26.552	120(0.5/40%) middle 25.929	120(0.5/40%) last 34.946	120(0.4/50%) first 26.092	120(0.4/50%) middle 23.803	120(0.4/50%) last 31.779
1	1	1	1		0.569088	0.000183	1.000000	1.000000	0.037683	0.981565	0.136082	0.615351	0.999994	0.183433	0.000021	0.999998	1.000000	0.000021	0.576385	0.000625	1.000000	1.000000	1.000000	0.000341	1.000000	1.000000	0.000021	1.000000	0.657419	0.002190
2	1	1	2	0.569088		0.853027	0.816510	0.996738	0.999999	0.001269	0.000022	0.000047	0.999306	1.000000	0.059779	0.998782	0.554779	0.002393	0.000041	0.000021	0.630471	0.334682	0.994495	0.914689	0.442900	0.120257	0.001356	0.179155	0.000056	0.992407
3	1	1	3	0.000183	0.853027		0.000892	0.017007	0.999983	0.000021	0.000021	0.000021	0.030327	0.993724	0.999940	0.024998	0.000169	0.998487	0.000021	0.000021	0.000260	0.000053	0.013452	1.000000	0.000092	0.000024	0.868950	0.000028	0.000021	1.000000
4	1	2	1	1.000000	0.816510	0.000892		1.000000	0.109580	0.892027	0.048795	0.352820	1.000000	0.389305	0.000022	1.000000	1.000000	0.000021	0.319413	0.000127	1.000000	1.000000	1.000000	0.001618	1.000000	1.000000	0.000021	1.000000	0.391355	0.008930
5	1	2	2	1.000000	0.996738	0.017007	1.000000		0.531488	0.390550	0.003274	0.053424	1.000000	0.891281	0.000052	1.000000	1.000000	0.000028	0.045498	0.000023	1.000000	0.999943	1.000000	0.027868	0.999994	0.994870	0.000021	0.998643	0.063456	0.104354
6	1	2	3	0.037683	0.999999	0.999983	0.109580	0.531488		0.000025	0.000021	0.000021	0.658670	1.000000	0.679033	0.615860	0.035441	0.458246	0.000021	0.000021	0.048785	0.012356	0.481910	0.999998	0.021493	0.002216	0.086512	0.004157	0.000021	1.000000
7	1	3	1	0.981565	0.001269	0.000021	0.892027	0.390550	0.000025		0.999641	1.000000	0.281659	0.000095	0.000021	0.316675	0.983607	0.000021	1.000000	0.440658	0.970309	0.998416	0.437396	0.000021	0.994169	0.999992	0.000021	0.999929	1.000000	0.000021
8	1	3	2	0.136082	0.000022	0.000021	0.048795	0.003274	0.000021	0.999641		1.000000	0.001645	0.000021	0.000021	0.002085	0.142863	0.000021	1.000000	0.999849	0.109600	0.290162	0.004252	0.000021	0.205876	0.604641	0.000021	0.486202	1.000000	0.000021
9	1	3	3	0.615351	0.000047	0.000021	0.352820	0.053424	0.000021	1.000000	1.000000		0.031136	0.000022	0.000021	0.037600	0.629455	0.000021	1.000000	0.936340	0.553744	0.831874	0.065225	0.000021	0.736186	0.976495	0.000021	0.946059	1.000000	0.000021

10	2	1	1	0.999994	0.999306	0.030327	1.000000	1.000000	0.658670	0.281659	0.001645	0.031136		0.947609	0.000095	1.000000	0.999992	0.000037	0.026211	0.000022	0.999998	0.999581	1.000000	0.048177	0.999933	0.983297	0.000022	0.994354	0.037476	0.162454
11	2	1	2	0.183433	1.000000	0.993724	0.389305	0.891281	1.000000	0.000095	0.000021	0.000022	0.947609		0.281122	0.931520	0.175255	0.141323	0.000022	0.000021	0.221896	0.077340	0.861580	0.998058	0.119673	0.018666	0.014220	0.031766	0.000023	0.999987
12	2	1	3	0.000021	0.059779	0.999940	0.000022	0.000052	0.679033	0.000021	0.000021	0.000021	0.000095	0.281122		0.000076	0.000021	1.000000	0.000021	0.000021	0.000021	0.000021	0.000043	0.999668	0.000021	0.000021	1.000000	0.000021	0.000021	0.986472
13	2	2	1	0.999998	0.998782	0.024998	1.000000	1.000000	0.615860	0.316675	0.002085	0.037600	1.000000	0.931520	0.000076		0.999997	0.000033	0.031766	0.000022	0.999999	0.999778	1.000000	0.040149	0.999969	0.988525	0.000022	0.996416	0.045042	0.140394
14	2	2	2	1.000000	0.554779	0.000169	1.000000	1.000000	0.035441	0.983607	0.142863	0.629455	0.999992	0.175255	0.000021	0.999997		0.000021	0.590661	0.000675	1.000000	1.000000	1.000000	0.000314	1.000000	1.000000	0.000021	1.000000	0.671167	0.002028
15	2	2	3	0.000021	0.023093	0.998487	0.000021	0.000028	0.458246	0.000021	0.000021	0.000021	0.000037	0.141323	1.000000	0.000033	0.000021		0.000021	0.000021	0.000021	0.000021	0.000026	0.994912	0.000021	0.000021	1.000000	0.000021	0.000021	0.932302
16	2	3	1	0.576385	0.000041	0.000021	0.319413	0.045498	0.000021	1.000000	1.000000	1.000000	0.026211	0.000022	0.000021	0.031766	0.590661	0.000021		0.950113	0.514637	0.802660	0.055808	0.000021	0.700598	0.968514	0.000021	0.931520	1.000000	0.000021
17	2	3	2	0.000625	0.000021	0.000021	0.000127	0.000023	0.000021	0.440658	0.999849	0.936340	0.000022	0.000021	0.000021	0.000022	0.000675	0.000021	0.950113		0.000419	0.002385	0.000024	0.000021	0.001253	0.013189	0.000021	0.007378	0.918337	0.000021
18	2	3	3	1.000000	0.630471	0.000260	1.000000	1.000000	0.048785	0.970309	0.109600	0.553744	0.999998	0.221896	0.000021	0.999999	1.000000	0.000021	0.514637	0.000419		1.000000	1.000000	0.000487	1.000000	1.000000	0.000021	1.000000	0.596682	0.003046
19	3	1	1	1.000000	0.334682	0.000053	1.000000	0.999943	0.012356	0.998416	0.290162	0.831874	0.999581	0.077340	0.000021	0.999778	1.000000	0.000021	0.802660	0.002385	1.000000		0.999977	0.000087	1.000000	1.000000	0.000021	1.000000	0.860993	0.000545
20	3	1	2	1.000000	0.994495	0.013452	1.000000	1.000000	0.481910	0.437396	0.004252	0.065225	1.000000	0.861580	0.000043	1.000000	1.000000	0.000026	0.055808	0.000024	1.000000	0.999977		0.022296	0.999998	0.996978	0.000021	0.999283	0.077068	0.086802
21	3	1	3	0.000341	0.914689	1.000000	0.001618	0.027868	0.999998	0.000021	0.000021	0.000021	0.048177	0.998058	0.999668	0.040149	0.000314	0.994912	0.000021	0.000021	0.000487	0.000087	0.022296		0.000165	0.000028	0.791407	0.000036	0.000021	1.000000

22	3	2	1	1.000000	0.442900	0.000092	1.000000	0.999994	0.021493	0.994169	0.205876	0.736186	0.999933	0.119673	0.000021	0.999969	1.000000	0.000021	0.700598	0.001253	1.000000	1.000000	0.999998	0.000165		1.000000	0.000021	1.000000	0.773150	0.001095
23	3	2	2	1.000000	0.120257	0.000024	1.000000	0.994870	0.002216	0.999992	0.604641	0.976495	0.983297	0.018666	0.000021	0.988525	1.000000	0.000021	0.968514	0.013189	1.000000	1.000000	0.996978	0.000028	1.000000		0.000021	1.000000	0.983330	0.000084
24	3	2	3	0.000021	0.001356	0.868950	0.000021	0.000021	0.086512	0.000021	0.000021	0.000021	0.000022	0.014220	1.000000	0.000022	0.000021	1.000000	0.000021	0.000021	0.000021	0.000021	0.000021	0.791407	0.000021	0.000021		0.000021	0.000021	0.481030
25	3	3	1	1.000000	0.179155	0.000028	1.000000	0.998643	0.004157	0.999929	0.486202	0.946059	0.994354	0.031766	0.000021	0.996416	1.000000	0.000021	0.931520	0.007378	1.000000	1.000000	0.999283	0.000036	1.000000	1.000000	0.000021		0.959284	0.001157
26	3	3	2	0.657419	0.000056	0.000021	0.391355	0.063456	0.000021	1.000000	1.000000	1.000000	0.037476	0.000023	0.000021	0.045042	0.671167	0.000021	1.000000	0.918337	0.596682	0.860993	0.077068	0.000021	0.773150	0.983330	0.000021	0.959284		0.000021
27	3	3	3	0.002190	0.992407	1.000000	0.008930	0.104354	1.000000	0.000021	0.000021	0.000021	0.162454	0.999987	0.986472	0.140394	0.002028	0.932302	0.000021	0.000021	0.003046	0.005445	0.086802	1.000000	0.001095	0.000084	0.481030	0.001557	0.000021	

D.2.3. Median Power Frequency

Table xxxi: The MdPF measures for 12 seconds at the start in the middle and at the end of the protocol.

	0.00-0.12 mins (Hz)	**8.00-8.12 mins (Hz)**	**15.48-16.00 mins (Hz)**
30(0.8/25%)	70.22 ±10.62 (15.12%)	59.43 ±11 (18.50%)	58.84 ±11.10 (18.87%)
30(0.5/40%)	68.10 ±14.17 (20.81%)	64.07 ±12.37 (19.32%)	65.69 ±14.07 (21.42%)
30(0.4/50%)	69.23 ±11.15 (26.49%)	65.67 ±12.10 (18.43%)	69.10 ±17.60 (25.47%)
60(0.8/25%)	68.66 ±11.15 (16.24%)	59.73 ±12.33 (20.64%)	56.33 ±9.31 (16.53%)
60(0.5/40%)	71.01 ±13.95 (19.65%)	67.06 ±14.61 (21.78%)	62.78 ±14.83 (23.62%)
60(0.4/50%)	67.93 ±15.04 (22.14%)	65.18 ±13.73 (21.07%)	69.33 ±14.65 (21.13%)
120(0.8/25%)	71.61 ±16.04 (22.40%)	60.32 ±9.92 (16.44%)	54.02 ±10.34 (19.14%)
120(0.5/40%)	74.51 ±14.73 (19.77%)	62.57 ±16.24 (25.95%)	56.38 ±9.56 (16.96%)
120(0.4/50%)	67.68 ±16.79 (24.81%)	65.16 ±18.32 (28.12%)	56.60 ±12.09 (21.37%)

Table xxxii: The effects of MdPF on the conditions and overtime

	Repeated Measures Analysis of Variance (All Data) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 39.8333				
Effect	SS	Degr. of Freedom	MS	F	P
Intercept	3278883	1	3278883	2066.493	0.000000
Error	44427	28	1587		
CT	897	2	449	4.112	0.021564
Error	6110	56	109		
DC/FL	2631	2	1316	2.307	0.108927
Error	31930	56	570		
TIME	11125	2	5562	27.421	0.000000
Error	11360	56	203		

CT*DC/FL	679	4	170	1.630	0.171663
Error	11662	112	104		
CT*TIME	3287	4	822	9.897	0.000001
Error	9299	112	83		
DC/FL*TIME	2573	4	643	6.833	0.000059
Error	10542	112	94		
CT*DC/FL*TIME	954	8	119	1.482	0.164732
Error	18031	224	80		

Table xxxiii: The post-hoc Tukey test for MdPF

	Tukey HSD test; variable DV_1 (All Data - modified) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 80.494, df = 224.00																													
Cell No.	CT	DC/FL	TIME	30(0.8/25%) first 70.224	30(0.8/25%) middle 59.428	30(0.8/25%) last 58.839	30(0.5/40%) first 68.096	30(0.5/40%) middle 64.067	30(0.5/40%) last 65.692	30(0.4/50%) first 69.229	30(0.4/50%) middle 65.670	30(0.4/50%) last 69.097	60(0.8/25%) first 68.655	60(0.8/25%) middle 59.734	60(0.8/25%) last 56.335	60(0.5/40%) first 71.013	60(0.5/40%) middle 67.063	60(0.5/40%) last 62.779	60(0.4/50%) first 67.934	60(0.4/50%) middle 65.182	60(0.4/50%) last 69.331	120(0.8/25%) first 71.612	120(0.8/25%) middle 60.324	120(0.8/25%) last 54.019	120(0.5/40%) first 74.508	120(0.5/40%) middle 62.573	120(0.5/40%) last 56.378	120(0.4/50%) first 67.679	120(0.4/50%) middle 65.155	120(0.4/50%) last 56.597
1	1	1	1		0.001453	0.000447	1.000000	0.645666	0.979152	1.000000	0.977872	1.000000	1.000000	0.002587	0.000022	1.000000	0.999928	0.237411	1.000000	0.929576	1.000000	1.000000	0.007515	0.000021	0.990053	0.190932	0.000022	0.999999	0.925693	0.000023
2	1	1	2	0.001453		1.000000	0.052977	0.972268	0.609090	0.008918	0.616597	0.011180	0.022952	1.000000	0.999952	0.000298	0.194242	0.999793	0.066431	0.774127	0.007479	0.000094	1.000000	0.862961	0.000021	0.999935	0.999963	0.093256	0.781756	0.999991
3	1	1	3	0.000447	1.000000		0.021916	0.899541	0.407333	0.003120	0.414428	0.003975	0.008699	1.000000	0.999999	0.000096	0.096626	0.997014	0.028229	0.582014	0.002584	0.000039	1.000000	0.956692	0.000021	0.998711	1.000000	0.041402	0.591259	1.000000
4	1	2	1	1.000000	0.052977	0.021916		0.995818	1.000000	1.000000	1.000000	1.000000	1.000000	0.080636	0.000210	0.999985	1.000000	0.882312	1.000000	0.999985	1.000000	0.999524	0.166882	0.000022	0.557945	0.836155	0.000229	1.000000	0.999982	0.000355
5	1	2	2	0.645666	0.972268	0.899541	0.995818		1.000000	0.910917	1.000000	0.931342	0.975713	0.988375	0.174653	0.377281	0.999974	1.000000	0.997756	1.000000	0.892661	0.213839	0.998663	0.005803	0.002837	1.000000	0.183172	0.999250	1.000000	0.231445
6	1	2	3	0.979152	0.609090	0.407333	1.000000	1.000000		0.999474	1.000000	0.999727	0.999979	0.711735	0.018678	0.881474	1.000000	0.999985	1.000000	1.000000	0.999154	0.723784	0.871727	0.000251	0.042889	0.999944	0.020001	1.000000	1.000000	0.028184
7	1	3	1	1.000000	0.008918	0.003120	1.000000	0.910917	0.999474		0.999416	1.000000	1.000000	0.014931	0.000035	1.000000	1.000000	0.544578	1.000000	0.995541	1.000000	1.000000	0.037608	0.000021	0.889880	0.473203	0.000036	1.000000	0.995093	0.000047
8	1	3	2	0.977872	0.616597	0.414428	1.000000	1.000000	1.000000	0.999416		0.999695	0.999976	0.718659	0.019340	0.877018	1.000000	0.999987	1.000000	1.000000	0.999067	0.716906	0.876301	0.000262	0.041548	0.999951	0.020705	1.000000	1.000000	0.029140
9	1	3	3	1.000000	0.011180	0.003975	1.000000	0.931342	0.999727	1.000000	0.999695		1.000000	0.018503	0.000040	1.000000	1.000000	0.590660	1.000000	0.997288	1.000000	0.999999	0.045638	0.000021	0.862426	0.518787	0.000042	1.000000	0.996994	0.000056

10	2	1	1	1.000000	0.022952	0.008699	1.000000	0.975713	0.999979	1.000000	0.999976	1.000000		0.036695	0.000074	1.000000	1.000000	0.737667	1.000000	0.999614	1.000000	0.999980	0.084049	0.000021	0.744870	0.671274	0.000080	1.000000	0.999560	0.000118
11	2	1	2	0.002587	1.000000	1.000000	0.080636	0.988375	0.711735	0.014931	0.718659	0.018503	0.036695		0.999735	0.000552	0.266565	0.999964	0.099610	0.854006	0.012620	0.000167	1.000000	0.785475	0.000021	0.999991	0.999788	0.136426	0.860039	0.999938
12	2	1	3	0.000022	0.999952	0.999999	0.000210	0.174653	0.018678	0.000035	0.019340	0.000040	0.000074	0.999735		0.000021	0.001655	0.546384	0.000290	0.040964	0.000032	0.000021	0.996399	1.000000	0.000021	0.618096	1.000000	0.000485	0.042588	1.000000
13	2	2	1	1.000000	0.000298	0.000096	0.999985	0.377281	0.881474	1.000000	0.877018	1.000000	1.000000	0.000552	0.000021		0.996897	0.095393	0.999956	0.751261	1.000000	1.000000	0.001783	0.000021	0.999571	0.072701	0.000021	0.999811	0.743182	0.000022
14	2	2	2	0.999928	0.194242	0.096626	1.000000	0.999974	1.000000	1.000000	1.000000	1.000000	1.000000	0.266565	0.001655	0.996897		0.990031	1.000000	1.000000	1.000000	0.978162	0.444988	0.000030	0.237578	0.981490	0.001794	1.000000	1.000000	0.002706
15	2	2	3	0.237411	0.999793	0.997014	0.882312	1.000000	0.999985	0.544578	0.999987	0.590660	0.737667	0.999964	0.546384	0.095393	0.990031		0.912247	1.000000	0.509153	0.041801	1.000000	0.046487	0.000224	1.000000	0.561317	0.948077	1.000000	0.637205
16	2	3	1	1.000000	0.066431	0.028229	1.000000	0.997756	1.000000	1.000000	1.000000	1.000000	1.000000	0.099610	0.000290	0.999956	1.000000	0.912247		0.999995	1.000000	0.998988	0.199760	0.000022	0.501389	0.873292	0.000317	1.000000	0.999994	0.000492
17	2	3	2	0.929576	0.774127	0.582014	0.999985	1.000000	1.000000	0.995541	1.000000	0.997288	0.999614	0.854006	0.040964	0.751261	1.000000	1.000000	0.999995		0.993615	0.551200	0.952770	0.000724	0.019641	0.999998	0.043606	0.999999	1.000000	0.059567
18	2	3	3	1.000000	0.007479	0.002584	1.000000	0.892661	0.999154	1.000000	0.999067	1.000000	1.000000	0.012620	0.000032	1.000000	1.000000	0.509153	1.000000	0.993615		1.000000	0.032281	0.000021	0.908454	0.438793	0.000033	1.000000	0.993011	0.000041
19	3	1	1	1.000000	0.000094	0.000039	0.999524	0.213839	0.723784	1.000000	0.716906	0.999999	0.999980	0.000167	0.000021	1.000000	0.978162	0.041801	0.998988	0.551200	1.000000		0.000543	0.000021	0.999987	0.030721	0.000021	0.997089	0.541930	0.000021
20	3	1	2	0.007515	1.000000	1.000000	0.166882	0.998663	0.871727	0.037608	0.876301	0.045638	0.084049	1.000000	0.996399	0.001783	0.444988	1.000000	0.199760	0.952770	0.032281	0.000543		0.595096	0.000022	1.000000	0.996938	0.259959	0.955567	0.998746
21	3	1	3	0.000021	0.862961	0.956692	0.000022	0.005803	0.000251	0.000021	0.000262	0.000021	0.000021	0.785475	1.000000	0.000021	0.000030	0.046487	0.000022	0.000724	0.000021	0.000021	0.595096		0.000021	0.062207	1.000000	0.000023	0.000761	0.999999

22	3	2	1	0.990053	0.000021	0.0000021	0.557945	0.002837	0.042889	0.889880	0.041548	0.862426	0.744870	0.000021	0.0000021	0.999571	0.237578	0.0000224	0.501389	0.019641	0.908454	0.999987	0.000022	0.000021		0.000150	0.000021	0.415219	0.018823	0.000021
23	3	2	2	0.190932	0.999935	0.998711	0.836155	1.000000	0.999944	0.473203	0.999951	0.518787	0.671274	0.999991	0.618096	0.072701	0.981490	1.000000	0.873292	0.999998	0.438793	0.030721	1.000000	0.062207	0.000150		0.632793	0.920131	0.999999	0.705820
24	3	2	3	0.000022	0.999963	1.000000	0.000229	0.183172	0.020001	0.000036	0.020705	0.000042	0.000080	0.999788	1.000000	0.000021	0.001794	0.561317	0.000317	0.043606	0.000033	0.000021	0.996938	1.000000	0.000021	0.632793		0.000529	0.045320	1.000000
25	3	3	1	0.999999	0.093256	0.041402	1.000000	0.999250	1.000000	1.000000	1.000000	1.000000	1.000000	0.136426	0.000485	0.999811	1.000000	0.948077	1.000000	0.999999	1.000000	0.997089	0.259959	0.000023	0.415219	0.920131	0.000529		0.999999	0.000843
26	3	3	2	0.925693	0.781756	0.591259	0.999982	1.000000	1.000000	0.995093	1.000000	0.996994	0.999560	0.860039	0.042588	0.743182	1.000000	1.000000	0.999994	1.000000	0.993011	0.541930	0.955567	0.000761	0.018823	0.999999	0.045320	0.999999		0.061805
27	3	3	3	0.000023	0.999991	1.000000	0.000355	0.231445	0.028184	0.000047	0.029140	0.000056	0.000118	0.999938	1.000000	0.000022	0.002706	0.637205	0.000492	0.059567	0.000041	0.000021	0.998746	0.999999	0.000021	0.705820	1.000000	0.000843	0.061805	

D.2.4. Mean Power Frequency

Table xxxiv: The MnPF measures for 12 seconds at the start in the middle and at the end of the protocol.

	0.00-0.12 mins (Hz)	8.00-8.12 mins (Hz)	15.48-16.00 mins (Hz)
30(0.8/25%)	96.18 ±11.81 (12.28%)	83.54 ±10.97 (13.13%)	82 ±11.93 (14.55%)
30(0.5/40%)	95.38 ±11.74 (12.31%)	91.37 ±9.81 (10.73%)	90.61 ±12.22 (13.49%)
30(0.4/50%)	98.73 ±14.34 (14.53%)	95.89 ±12.24 (12.76%)	98.56 ±16.33 (16.57%)
60(0.8/25%)	94.08 ±13.76 (14.63%)	82.55 ±12.55 (15.20%)	80.78 ±12.54 (15.52%)
60(0.5/40%)	97.67 ±12.30 (12.59%)	92.58 ±11.58 (12.50%)	89.65 ±13.02 (14.53%)
60(0.4/50%)	97.92 ±14.31 (14.61%)	95.38 ±12.97 (13.60%)	97.74 ±14.18 (14.51%)
120(0.8/25%)	95.90 ±15.08 (15.73%)	84.06 ±8.87 (10.55%)	77.57 ±9.33 (12.03%)
120(0.5/40%)	98.59 ±12.93 (13.12%)	88.86 ±13.40 (15.08%)	79.68 ±10.12 (12.70%)
120(0.4/50%)	97.84 ±15.05 (15.39%)	95.14 ±14.74 (15.50%)	83.46 ±11.47 (13.75%)

Table xxxv: The effects of MnPF on the conditions and overtime

	Repeated Measures Analysis of Variance (All Data) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 46.6467				
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	6508962	1	6508962	2991.373	0.000000
Error	60926	28	2176		
CT	1858	2	929	15.328	0.000005
Error	3394	56	61		
DC/FL	11437	2	5719	16.771	0.000002
Error	19095	56	341		
TIME	14308	2	7154	53.418	0.000000
Error	7500	56	134		

CT*DC/FL	748	4	187	2.791	0.029684
Error	7502	112	67		
CT*TIME	3672	4	918	15.444	0.000000
Error	6657	112	59		
DC/FL*TIME	2903	4	726	12.550	0.000000
Error	6477	112	58		
CT*DC/FL*TIME	833	8	104	2.218	0.027107
Error	10511	224	47		

Table xxxvi: Post-hoc Tukey test for MnPF

Tukey HSD test; variable DV_1 (All Data - modified) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 46.924, df = 224.00

Cell No.	CT	DC/FL	TIME	30(0.8/25%) first 96.177	30(0.8/25%) middle 83.543	30(0.8/25%) last 82.001	30(0.5/40%) first 95.376	30(0.5/40%) middle 91.373	30(0.5/40%) last 90.610	30(0.4/50%) first 98.728	30(0.4/50%) middle 95.895	30(0.4/50%) last 98.565	60(0.8/25%) first 94.084	60(0.8/25%) middle 82.550	60(0.8/25%) last 80.781	60(0.5/40%) first 97.671	60(0.5/40%) middle 92.580	60(0.5/40%) last 89.647	60(0.4/50%) first 97.921	60(0.4/50%) middle 95.376	60(0.4/50%) last 97.743	120(0.8/25%) first 95.898	120(0.8/25%) middle 84.063	120(0.8/25%) last 77.569	120(0.5/40%) first 98.592	120(0.5/40%) middle 88.859	120(0.5/40%) last 79.682	120(0.4/50%) first 97.835	120(0.4/50%) middle 95.137	120(0.4/50%) last 83.462
1	1	1	1		0.000021	0.000021	1.000000	0.599971	0.276753	0.999804	1.000000	0.999941	0.999996	0.000021	0.000021	1.000000	0.966698	0.062402	1.000000	1.000000	1.000000	1.000000	0.000021	0.000021	0.999927	0.012905	0.000021	1.000000	1.000000	0.000021
2	1	1	2	0.000021		1.000000	0.000021	0.003989	0.021955	0.000021	0.000021	0.000021	0.000023	1.000000	0.999233	0.000021	0.000181	0.128532	0.000021	0.000021	0.000021	0.000021	1.000000	0.157243	0.000021	0.372113	0.927587	0.000021	0.000021	1.000000
3	1	1	3	0.000021	1.000000		0.000021	0.000080	0.000557	0.000021	0.000021	0.000021	0.000021	1.000000	1.000000	0.000021	0.000022	0.006150	0.000021	0.000021	0.000021	0.000021	0.999997	0.759363	0.000021	0.033464	0.999966	0.000021	0.000021	1.000000
4	1	2	1	1.000000	0.000021	0.000021		0.896805	0.616853	0.986148	1.000000	0.992983	1.000000	0.000021	0.000021	0.999972	0.999059	0.223677	0.999812	1.000000	0.999950	1.000000	0.000021	0.000021	0.992094	0.063874	0.000021	0.999899	1.000000	0.000021
5	1	2	2	0.599971	0.003989	0.000080	0.896805		1.000000	0.011893	0.723323	0.016911	0.999438	0.000316	0.000022	0.093589	1.000000	1.000000	0.060328	0.896805	0.082733	0.722183	0.013096	0.000021	0.015958	0.999849	0.000021	0.070446	0.944538	0.003282
6	1	2	3	0.276753	0.021955	0.000557	0.616853	1.000000		0.001984	0.385140	0.002957	0.978081	0.002288	0.000035	0.022207	0.999999	1.000000	0.013067	0.616853	0.019112	0.383992	0.060441	0.000021	0.002768	1.000000	0.000022	0.015736	0.720898	0.018525
7	1	3	1	0.999804	0.000021	0.000021	0.986148	0.011893	0.001984		0.998835	1.000000	0.671355	0.000021	0.000021	1.000000	0.119789	0.000162	1.000000	0.986148	1.000000	0.998853	0.000021	0.000021	1.000000	0.000034	0.000021	1.000000	0.967366	0.000021
8	1	3	2	1.000000	0.000021	0.000021	1.000000	0.723323	0.385140	0.998835		0.999566	1.000000	0.000021	0.000021	1.000000	0.988039	0.101829	0.999998	1.000000	1.000000	1.000000	0.000021	0.000021	0.999484	0.023429	0.000021	0.999999	1.000000	0.000021
9	1	3	3	0.999941	0.000021	0.000021	0.992983	0.016911	0.002957	1.000000	0.999566		0.740071	0.000021	0.000021	1.000000	0.154560	0.000247	1.000000	0.992983	1.000000	0.999574	0.000021	0.000021	1.000000	0.000042	0.000021	1.000000	0.981523	0.000021

10	2	1	1	0.999996	0.000023	0.000021	1.000000	0.999438	0.978081	0.671355	1.000000	0.740071		0.000021	0.000021	0.967770	1.000000	0.757206	0.932048	1.000000	0.959426	1.000000	0.000029	0.000021	0.728998	0.410380	0.000021	0.946589	1.000000	0.000022
11	2	1	2	0.000021	1.000000	1.000000	0.000021	0.000316	0.002288	0.000021	0.000021	0.000021	0.000021		1.000000	0.000021	0.000029	0.020615	0.000021	0.000021	0.000021	0.000021	1.000000	0.518881	0.000021	0.091773	0.998584	0.000021	0.000021	1.000000
12	2	1	3	0.000021	0.999233	1.000000	0.000021	0.000022	0.000035	0.000021	0.000021	0.000021	0.000021	1.000000		0.000021	0.000021	0.000283	0.000021	0.000021	0.000021	0.000021	0.989565	0.992234	0.000021	0.002188	1.000000	0.000021	0.000021	0.999536
13	2	2	1	1.000000	0.000021	0.000021	0.999972	0.093589	0.022207	1.000000	1.000000	1.000000	0.967770	0.000021	0.000021		0.468737	0.002498	1.000000	0.999972	1.000000	1.000000	0.000021	0.000021	1.000000	0.000326	0.000021	1.000000	0.999826	0.000021
14	2	2	2	0.966698	0.000181	0.000022	0.999059	1.000000	0.999999	0.119789	0.988039	0.154560	1.000000	0.000029	0.000021	0.468737		0.997984	0.361773	0.999059	0.436871	0.987905	0.000735	0.000021	0.148275	0.951145	0.000021	0.397430	0.999795	0.000148
15	2	2	3	0.062402	0.128532	0.006150	0.223677	1.000000	1.000000	0.000162	0.101829	0.000247	0.757206	0.020615	0.000283	0.002498	0.997984		0.001346	0.223677	0.002093	0.101363	0.270646	0.000021	0.000230	1.000000	0.000030	0.001668	0.304288	0.112781
16	2	3	1	1.000000	0.000021	0.000021	0.999812	0.060328	0.013067	1.000000	0.999998	1.000000	0.932048	0.000021	0.000021	1.000000	0.361773	0.001346		0.999812	1.000000	0.999998	0.000021	0.000021	1.000000	0.000170	0.000021	1.000000	0.999123	0.000021
17	2	3	2	1.000000	0.000021	0.000021	1.000000	0.896805	0.616853	0.986148	1.000000	0.992983	1.000000	0.000021	0.000021	0.999972	0.999059	0.223677	0.999812		0.999950	1.000000	0.000021	0.000021	0.992094	0.063874	0.000021	0.999899	1.000000	0.000021
18	2	3	3	1.000000	0.000021	0.000021	0.999950	0.082733	0.019112	1.000000	1.000000	1.000000	0.959426	0.000021	0.000021	1.000000	0.436871	0.002093	1.000000	0.999950		1.000000	0.000021	0.000021	1.000000	0.000270	0.000021	1.000000	0.999714	0.000021
19	3	1	1	1.000000	0.000021	0.000021	1.000000	0.722183	0.383992	0.998853	1.000000	0.999574	1.000000	0.000021	0.000021	1.000000	0.987905	0.101363	0.999998	1.000000	1.000000		0.000021	0.000021	0.999493	0.023297	0.000021	0.999999	1.000000	0.000021
20	3	1	2	0.000021	1.000000	0.999997	0.000021	0.013096	0.060441	0.000021	0.000021	0.000021	0.000029	1.000000	0.989565	0.000021	0.000735	0.270646	0.000021	0.000021	0.000021	0.000021		0.066527	0.000021	0.603042	0.778910	0.000021	0.000022	1.000000
21	3	1	3	0.000021	0.157243	0.759363	0.000021	0.000021	0.000021	0.000021	0.000021	0.000021	0.000021	0.518881	0.992234	0.000021	0.000021	0.000021	0.000021	0.000021	0.000021	0.000021	0.066527		0.000021	0.000021	0.999995	0.000021	0.000021	0.177454

22	3	2	1	0.999927	0.000021	0.000021	0.992094	0.015958	0.002768	1.000000	0.999484	1.000000	0.728998	0.000021	0.000021	1.000000	0.148275	0.002230	1.000000	0.992094	1.000000	0.999493	0.000021	0.000021		0.000040	0.000021	1.000000	0.979581	0.000021
23	3	2	2	0.012905	0.372113	0.033464	0.063874	0.999849	1.000000	0.000034	0.023429	0.000042	0.410380	0.091773	0.002188	0.000326	0.951145	1.000000	0.000170	0.063874	0.000270	0.023297	0.603042	0.000021	0.000040		0.000127	0.000212	0.096818	0.339457
24	3	2	3	0.000021	0.927587	0.999966	0.000021	0.000021	0.000022	0.000021	0.000021	0.000021	0.000021	0.998584	1.000000	0.000021	0.000021	0.000030	0.000021	0.000021	0.000021	0.000021	0.778910	0.999995	0.000021	0.000127		0.000021	0.000021	0.942037
25	3	3	1	1.000000	0.000021	0.000021	0.999899	0.070446	0.015736	1.000000	0.999999	1.000000	0.946589	0.000021	0.000021	1.000000	0.397430	0.001668	1.000000	0.999899	1.000000	0.999999	0.000021	0.000021	1.000000	0.000212	0.000021		0.999482	0.000021
26	3	3	2	1.000000	0.000021	0.000021	1.000000	0.944538	0.720898	0.967366	1.000000	0.981523	1.000000	0.000021	0.000021	0.999826	0.999795	0.304288	0.999123	1.000000	0.999714	1.000000	0.000022	0.000021	0.979581	0.096818	0.000021	0.999482		0.000021
27	3	3	3	0.000021	1.000000	1.000000	0.000021	0.003282	0.018525	0.000021	0.000021	0.000021	0.000022	1.000000	0.999536	0.000021	0.000148	0.112781	0.000021	0.000021	0.000021	0.000021	1.000000	0.177454	0.000021	0.339457	0.942037	0.000021	0.000021	

D.3. Perceptual Measures

D.3.1 Ratings of Perceived Exertions

Table xxxvii: The mean, standard deviation, and coefficient of variance for each condition and throughout time

	4 minutes	8 minutes	12 minutes	16 minutes
30(0.8/25%)	3.28 ±1.65 (50.22%)	4.33 ±1.60 (37.03%)	4.9 ±1.86 (38.03%)	5.27 ±2.05 (38.92%)
30(0.5/40%)	1.75 ±1.17 (66.58%)	2.32 ±1.41 (60.91%)	2.78 ±1.75 (62.71%)	3.12 ±1.98 (63.43%)
30(0.4/50%)	1.45 ±0.96 (66.14%)	1.78 ±1.19 (66.95%)	1.92 ±1.42 (74.13%)	2.15 ±1.61 (74.84%)
60(0.8/25%)	3.63 ±1.63 (44.89%)	4.63 ±1.71 (36.94%)	5.03 ±1.87 (37.07%)	5.33 ±1.9 (35.62%)
60(0.5/40%)	2 ±1.07 (53.74%)	2.67 ±1.49 (55.78%)	3.1 ±1.6 (51.6%)	3.47 ±1.83 (52.75%)
60(0.4/50%)	1.8 ±1.42 (63.43%)	2.08 ±1.25 (60.15%)	2.28 ±1.43 (62.65%)	2.6 ±1.52 (58.33%)
120(0.8/25%)	3.93 ±1.6 (40.58%)	4.9 ±1.86 (38.03%)	5.6 ±2.14 (38.27%)	5.93 ±2.35 (39.57%)
120(0.5/40%)	2.53 ±1.19 (46.92%)	3.47 ±1.75 (50.52%)	4.17 ±2.26 (54.16%)	4.72 ±2.46 (52.21%)
120(0.4/50%)	2.37 ±1.42 (59.99%)	3. 13 ±1.72 (54.79%)	3.63 ±2.01 (55.27%)	3.83 ±2.18 (56.94%)

Table xxxviii: Effect of the dependent factors on RPE throughout time

	Repeated Measures Analysis of Variance (Spreadsheet1_(Recovered)) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 7.4205				
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	12383.01	1	12383.01	224.8863	0.000000
Error	1596.84	29	55.06		
CT	231.70	2	115.85	35.8458	0.000000
Error	187.45	58	3.23		
DC/FL	1040.21	2	520.11	47.6823	0.000000

Error	632.65	58	10.91		
TIME	349.91	3	116.64	59.7635	0.000000
Error	169.79	87	1.95		
CT*DC/FL	21.81	4	5.45	2.6618	0.036065
Error	237.58	116	2.05		
CT*TIME	11.77	6	1.96	4.8378	0.000136
Error	70.53	174	0.41		
DC/FL*TIME	24.86	6	4.14	12.3468	0.000000
Error	58.39	174	0.34		
CT*DC/FL*TIME	4.30	12	0.36	1.3975	0.164777
Error	89.20	348	0.26		

Table xxxix: Post-hoc analysis Tukey test for RPE

Cell No.	Tukey HSD test; variable DV_1 (All Data - modified) Approximate Probabilities for Post Hoc Tests Error: Within MSE = .25633, df = 348.00																																						
	C-T	DC/FL	TIME	30 (0.8/25%) min 4 3.2833	30 (0.8/25%) min 8 4.3333	30 (0.8/25%) min 12 4.9000	30 (0.8/25%) min 16 5.2667	30 (0.5/40%) min 4 1.7500	30 (0.5/40%) min 8 2.3167	30 (0.5/40%) min 12 2.7833	30 (0.5/40%) min 16 3.1167	30 (0.4/50%) min 4 1.4500	30 (0.4/50%) min 8 1.7833	30 (0.4/50%) min 12 1.9167	30 (0.4/50%) min 16 2.1500	60 (0.8/25%) min 4 3.6333	60 (0.8/25%) min 8 4.6333	60 (0.8/25%) min 12 5.0333	60 (0.8/25%) min 16 5.3333	60 (0.5/40%) min 4 2.0000	60 (0.5/40%) min 8 2.6667	60 (0.5/40%) min 12 3.1000	60 (0.5/40%) min 16 3.4667	60 (0.4/50%) min 4 1.8000	60 (0.4/50%) min 8 2.0833	60 (0.4/50%) min 12 2.2833	60 (0.4/50%) min 16 2.6000	120(0.8/25%) min 4 3.9333	120(0.8/25%) min 8 4.9000	120(0.8/25%) min 12 5.6000	120(0.8/25%) min 16 5.9333	120(0.5/40%) min 4 2.5333	120(0.5/40%) min 8 3.4667	120(0.5/40%) min 12 4.1667	120(0.5/40%) min 16 4.7167	120(0.4/50%) min 4 2.3667	120(0.4/50%) min 8 3.1333	120(0.4/50%) min 12 3.6333	120(0.4/50%) min 16 3.8333
1	1	1	1		0.000034	0.000034	0.000034	0.000034	0.000034	0.052187	0.999999	0.000034	0.000034	0.000034	0.000034	0.735615	0.000034	0.000034	0.000034	0.000034	0.013337	0.999994	0.999994	0.000034	0.000034	0.000034	0.000128	0.000401	0.000034	0.000034	0.000034	0.000038	0.999994	0.000034	0.000034	0.000034	1.000000	0.735615	0.012445
2	1	1	2	0.000034		0.073357	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000080	0.942660	0.000080	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.418681	0.073357	0.000034	0.000034	0.000034	0.000034	0.999999	0.524740	0.000034	0.000034	0.000080	0.052187
3	1	1	3	0.000034	0.073357		0.633132	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.988823	1.000000	0.238661	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	1.000000	0.000080	0.000034	0.000034	0.000034	0.000044	0.999994	0.000034	0.000034	0.000034	0.000034
4	1	1	4	0.000034	0.000034	0.633132		0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000733	0.998901	1.000000	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.633132	0.824353	0.000222	0.000034	0.000034	0.000034	0.012445	0.000034	0.000034	0.000034	0.000034
5	1	2	1	0.000034	0.000034	0.000034	0.000034		0.073357	0.000034	0.000034	0.942660	1.000000	0.999999	0.418681	0.000034	0.000034	0.000034	0.000034	0.996135	0.000034	0.000034	0.000034	1.000000	0.824353	0.020580	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.013337	0.000034	0.000034	0.000034
6	1	2	2	0.000034	0.000034	0.000034	0.000034	0.073357		0.118648	0.000034	0.000034	0.020580	0.418681	0.999999	0.000034	0.000034	0.000034	0.000034	0.893918	0.735615	0.000034	0.000034	0.033193	0.989901	1.000000	0.972740	0.000034	0.000034	0.000034	0.000034	0.999751	0.000034	0.000034	0.000034	1.000000	0.000034	0.000034	0.000034

7	1	2	3	0.052187	0.000034	0.000034	0.000034	0.000034	0.118648		0.824353	0.000034	0.000034	0.000034	0.007333	0.000034	0.000034	0.000034	0.000034	0.000034	1.000000	0.893918	0.000128	0.000034	0.000080	0.052187	0.999994	0.000034	0.000034	0.000034	0.000034	0.996135	0.000128	0.000034	0.000034	0.321834	0.735615	0.000034	0.000034
8	1	2	4	0.999999	0.000034	0.000034	0.000034	0.000034	0.000034	0.824353		0.000034	0.000034	0.000034	0.000034	0.003193	0.000034	0.000034	0.000034	0.000034	0.171022	1.000000	0.735615	0.000034	0.000034	0.000034	0.003193	0.000034	0.000034	0.000034	0.000034	0.004259	0.735615	0.000034	0.000034	0.000038	1.000000	0.033193	0.000056
9	1	3	1	0.000034	0.000034	0.000034	0.000034	0.942660	0.000034	0.000034	0.000034		0.824353	0.118648	0.000080	0.000034	0.000034	0.000034	0.000034	0.012445	0.000034	0.000034	0.000034	0.735615	0.007333	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034
10	1	3	2	0.000034	0.000034	0.000034	0.000034	1.000000	0.020580	0.000034	0.000034	0.824353		1.000000	0.633132	0.000034	0.000034	0.000034	0.000034	0.999751	0.000034	0.000034	0.000034	1.000000	0.942660	0.052187	0.000034	0.000034	0.000034	0.000034	0.000034	0.000038	0.000034	0.000034	0.000034	0.004259	0.000034	0.000034	0.000034
11	1	3	3	0.000034	0.000034	0.000034	0.000034	0.999999	0.418681	0.000034	0.000034	0.118648	1.000000		0.998901	0.000034	0.000034	0.000034	0.000034	1.000000	0.000038	0.000034	0.000034	1.000000	0.999999	0.633132	0.000128	0.000034	0.000034	0.000034	0.000034	0.001337	0.000034	0.000034	0.000034	0.171022	0.000034	0.000034	0.000034
12	1	3	4	0.000034	0.000034	0.000034	0.000034	0.418681	0.999999	0.007333	0.000034	0.000080	0.633132	0.998901		0.000034	0.000034	0.000034	0.000034	1.000000	0.003193	0.000034	0.000034	0.735615	1.000000	1.000000	0.171022	0.000034	0.000034	0.000034	0.000034	0.524740	0.000034	0.000034	0.000034	0.999751	0.000034	0.000034	0.000034
13	2	1	1	0.735615	0.000080	0.000034	0.000034	0.000034	0.000034	0.000034	0.003193	0.000034	0.000034	0.000034	0.000034		0.000034	0.000034	0.000034	0.000034	0.000034	0.020580	0.999999	0.000034	0.000034	0.000034	0.000034	0.942660	0.000034	0.000034	0.000034	0.000034	0.999999	0.020580	0.000034	0.000034	0.052187	1.000000	0.999956
14	2	1	2	0.000034	0.942660	0.988823	0.007333	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034		0.418681	0.000080	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000080	0.988823	0.000034	0.000034	0.000034	0.000034	0.118648	1.000000	0.000034	0.000034	0.000034	0.000034
15	2	1	3	0.000034	0.000080	1.000000	0.998901	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.418681		0.942660	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	1.000000	0.007357	0.000034	0.000034	0.000034	0.000034	0.893918	0.000034	0.000034	0.000034	0.000034

16	2	1	4	0.000034	0.000034	0.238661	1.000000	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000080	0.942660		0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.000034	0.238661	0.988823	0.002425	0.000034	0.000034	0.000034	0.001337	0.000034	0.000034	0.000034	0.000034
17	2	2	1	0.000034	0.000034	0.000034	0.000034	0.996135	0.893918	0.000034	0.000034	0.012445	0.999751	1.000000	1.000000	0.000034	0.000034	0.000034	0.000034		0.000222	0.000034	0.000034	0.999956	1.000000	0.972740	0.002425	0.000034	0.000034	0.000034	0.000034	0.020580	0.000034	0.000034	0.000034	0.633132	0.000034	0.000034	0.000034
18	2	2	2	0.001337	0.000034	0.000034	0.000034	0.000034	0.735615	1.000000	0.171022	0.000034	0.000034	0.000038	0.033193	0.000034	0.000034	0.000034	0.000034	0.000222		0.238661	0.000034	0.000034	0.004259	0.524740	1.000000	0.000034	0.000034	0.000034	0.000034	1.000000	0.000034	0.000034	0.000034	0.942660	0.118648	0.000034	0.000034
19	2	2	3	0.999994	0.000034	0.000034	0.000034	0.000034	0.000034	0.893918	1.000000	0.000034	0.000034	0.000034	0.000034	0.020580	0.000034	0.000034	0.000034	0.000034	0.238661		0.633132	0.000034	0.000034	0.000034	0.052187	0.000034	0.000034	0.000034	0.000034	0.007357	0.633132	0.000034	0.000034	0.000044	1.000000	0.020580	0.000044
20	2	2	4	0.999994	0.000034	0.000034	0.000034	0.000034	0.000034	0.000128	0.735615	0.000034	0.000034	0.000034	0.000034	0.999999	0.000034	0.000034	0.000034	0.000034	0.000034	0.633132		0.000034	0.000034	0.000034	0.000034	0.118648	0.000034	0.000034	0.000034	0.000034	1.000000	0.000080	0.000034	0.000034	0.824353	0.999999	0.633132
21	2	3	1	0.000034	0.000034	0.000034	0.000034	1.000000	0.033193	0.000034	0.000034	0.735615	1.000000	1.000000	0.735615	0.000034	0.000034	0.000034	0.000034	0.999956	0.000034	0.000034	0.000034		0.972740	0.079828	0.000034	0.000034	0.000034	0.000034	0.000034	0.000044	0.000034	0.000034	0.000034	0.007357	0.000034	0.000034	0.000034
22	2	3	2	0.000034	0.000034	0.000034	0.000034	0.824353	0.998901	0.000080	0.000034	0.000733	0.942660	0.999999	1.000000	0.000034	0.000034	0.000034	0.000034	1.000000	0.004259	0.000034	0.000034	0.972740		0.999956	0.033193	0.000034	0.000034	0.000034	0.000034	0.171022	0.000034	0.000034	0.000034	0.972740	0.000034	0.000034	0.000034
23	2	3	3	0.000034	0.000034	0.000034	0.000034	0.020580	1.000000	0.052187	0.000034	0.000034	0.052187	0.633132	1.000000	0.000034	0.000034	0.000034	0.000034	0.972740	0.524740	0.000034	0.000034	0.079828	0.999956		0.893918	0.000034	0.000034	0.000034	0.000034	0.996135	0.000034	0.000034	0.000034	1.000000	0.000034	0.000034	0.000034
24	2	3	4	0.000128	0.000034	0.000034	0.000034	0.000034	0.972740	0.999994	0.033193	0.000034	0.000034	0.000128	0.171022	0.000034	0.000034	0.000034	0.000034	0.002425	1.000000	0.052187	0.000034	0.000034	0.033193	0.893918		0.000034	0.000034	0.000034	0.000034	1.000000	0.000034	0.000034	0.000034	0.998901	0.020580	0.000034	0.000034

25	3	1	1	0.0000401	0.4186811	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.9426660	0.0000080	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.1186648	0.0000034	0.0000034	0.0000034	0.0000034		0.0000034	0.000000034	0.000000034	0.0000034	0.1186648	0.998901	0.000000034	0.0000034	0.0000034	0.942660	1.000000
26	3	1	2	0.0000034	0.0007357	1.0000000	0.6331132	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.9888823	1.0000000	0.2386661	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034		0.000000080	0.000000034	0.0000034	0.0000034	0.000000044	0.999994	0.0000034	0.0000034	0.000000034	0.000000034
27	3	1	3	0.0000034	0.0000034	0.0000080	0.8243353	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0007357	0.9888823	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000080		0.824353	0.0000034	0.0000034	0.000000034	0.000000034	0.0000034	0.0000034	0.000000034	0.000000034
28	3	1	4	0.0000034	0.0000034	0.0000034	0.0000222	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0002425	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.824353		0.0000034	0.0000034	0.000000034	0.000000034	0.0000034	0.0000034	0.000000034	0.000000034
29	3	2	1	0.0000038	0.0000034	0.0000034	0.0000034	0.0000034	0.9997751	0.9961135	0.0004259	0.0000034	0.0000038	0.0001337	0.5247740	0.0000034	0.0000034	0.0000034	0.0000034	0.0020580	1.0000000	0.0007357	0.0000034	0.0000044	0.1710222	0.9961135	1.0000000	0.0000034	0.0000034	0.000000034	0.000000034		0.0000034	0.000000034	0.000000034	0.9999999	0.0002425	0.000000034	0.000000034
30	3	2	2	0.9999994	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000128	0.7356615	0.0000034	0.0000034	0.0000034	0.0000034	0.9999999	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.6331132	1.0000000	0.0000034	0.0000034	0.0000034	0.0000034	0.1186648	0.0000034	0.000000034	0.000000034	0.0000034		0.000000080	0.000000034	0.0000034	0.8243353	0.999999	0.633132
31	3	2	3	0.0000034	0.9999999	0.0000044	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0020580	0.1186648	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000080	0.0000034	0.0000034	0.0000034	0.0000034	0.9989901	0.0000044	0.000000034	0.000000034	0.0000034	0.0000080		0.0012445	0.0000034	0.0000034	0.0020580	0.824353
32	3	2	4	0.0000034	0.5247740	0.9999994	0.0012445	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	1.0000000	0.8939918	0.0001337	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.9999994	0.000000034	0.000000034	0.0000034	0.0000034	0.0012445		0.0000034	0.0000034	0.000000034	0.000000034
33	3	3	1	0.0000034	0.0000034	0.0000034	0.0000034	0.0001337	1.0000000	0.3218344	0.0000038	0.0000034	0.0004259	0.1710222	0.9997751	0.0000034	0.0000034	0.0000034	0.0000034	0.6331132	0.9426660	0.0000044	0.0000034	0.0007357	0.9727740	1.0000000	0.9989901	0.0000034	0.0000034	0.000000034	0.000000034	0.9999999	0.0000034	0.000000034	0.000000034		0.0000036	0.000000034	0.000000034

34	3	3	2	1.0000000	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.7356115	1.0000000	0.0000034	0.0000034	0.0000034	0.0000034	0.0521187	0.0000034	0.0000034	0.0000034	0.0000034	0.1186648	1.0000000	0.8243353	0.0000034	0.0000034	0.0000034	0.0020580	0.0000034	0.0000034	0.000034	0.000034	0.0024245	0.8243353	0.000034	0.000034	0.0000036		0.052187	0.000080
35	3	3	3	0.7356115	0.0000080	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0033193	0.0000034	0.0000034	0.0000034	0.0000034	1.0000000	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0020580	0.9999999	0.0000034	0.0000034	0.0000034	0.0000034	0.9426660	0.0000034	0.000034	0.000034	0.0000034	0.9999999	0.020580	0.000034	0.0000034	0.0521187		0.999956
36	3	3	4	0.0012445	0.0521187	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000056	0.0000034	0.0000034	0.0000034	0.0000034	0.9999956	0.0000034	0.0000034	0.0000034	0.0000034	0.0000034	0.0000044	0.6331132	0.0000034	0.0000034	0.0000034	0.0000034	1.0000000	0.0000034	0.000034	0.000034	0.0000034	0.6331132	0.824353	0.000034	0.0000034	0.0000080	0.999956	