AN INVESTIGATION INTO THE INTERACTION EFFECTS OF SIMULTANEOUS PHYSICAL AND COGNITIVE TASK EXECUTION ON PERFORMANCE, PERCEPTUAL AND PHYSICAL RESPONSES

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THESIS

Submitted in fulfilment of the requirements for the Degree Master of Science

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Rhodes University, 2015

Grahamstown, South Africa

ACKNOWLEDGMENTS

Firstly, I would like to thank my supervisor, Miriam Mattison, and co-supervisor Andrew Todd, for their expertise, support, continuous guidance and many of hours of her time in assisting with this project. This help was very much appreciated.

I would also like to thank Rhodes University and the Henderson Scholarship Programme for all the funding during my master’s course, thus making this research project possible.

Lastly, I would like to thank all the participants who gave of their time to take part in this study. Without their involvement this research would not have been possible.

ABSTRACT

Many modern day work environments require some degree of dual tasking, particularly the simultaneous performance of cognitive jobs alongside physical activity. The nature of such tasks is often job dependent and may require cognitive functions such as perception, decision making, memory, or response selection/execution in conjunction to task specific physical requirements. Previous research has indicated a possible relationship between concurrent physical and cognitive demands and task performance, safety and efficiency. However, this research is limited and inconsistent. The current study aimed to identify the interaction, if any, between concurrent physical and mental demands, and determine the impact of sensory modality and stage of information processing on this interaction, with specific focus on the performance, perceptual and physical responses during different types of cognitive tasks performed concurrently with a lifting task.

20 (10 male, 10 female) Rhodes University students participated in this study. Each participant performed 9 test conditions - a physical lifting task, a visual and an auditory memory task, and a visual and an auditory decision making task in isolation, as well as the lifting task concurrently with each of these cognitive tasks. Performance was recorded via accuracy and work output of cognitive tasks and the number of lifts for each condition. Perceptual measures were obtained via the Borg RPE and Subjective Workload Assessment Technique. Spinal kinematics were measured using the Lumbar Motion Monitor, while muscle activity of the Erector Spinae, Rectus Abdominis, Rectus Femoris and Biceps Femoris muscles were recorded using the Biometrix Data Logger surface EMG equipment. Mean results were analysed using a dependent T-test to observe any general interaction, and a Two-way ANOVA for the impact of sensory modality and stage of processing. Individual responses were also considered to gain better understanding of both intra and inter-human variability under the various test conditions.

Results showed a significant decrease in cognitive performance, increased perception of physical effort, time pressure, mental effort and psychological stress under simultaneous physical and mental demands, while no significant differences in physical responses were observed. Further observations included increased dual-task interference during visual and decision-making tasks when combined with physical demands compared to that of auditory and memory tasks respectively. Individual responses showed large variability between individuals indicating the presence of positive, negative and non-responders to concurrent physical and mental demands. Results therefore imply an individual specific interaction between concurrent physical and mental demands that may or may not be detrimental to worker productivity, job error, injury rates and worker well-being, and that the type of cognitive task performed may impact this interaction.

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CHAPTER I:
INTRODUCTION

BACKGROUND TO THE STUDY

Many tasks require some degree of dual-tasking, which is engaging in two activities concurrently (Pellechia, 2010). With rapid advances in technology jobs in a modern day work environment now require the simultaneous processing of a variety of information alongside physical activity, placing high cognitive as well as physical demands on workers (Basahel *et al*., 2012). Although not yet well investigated, there appears to a possible relationship between concurrent physical and cognitive demands, which may impact task performance, perception and movement quality (Basahel *et al*., 2012). Examples of jobs that require physical exertion, as well as concurrent cognitive processing, include, amongst others, operators of manufacturing systems, assembly production lines and heavy machinery, soldiers in combat operations, emergency search and rescue teams, nursing, fire-fighting, aircraft pilots and emergency room medical staff (Perry *et al.*, 2009). Humans have been conventionally classified as having both cognitive and physical subsystems; however, most studies have focused on these systems individually, and particularly little research has investigated the interactions between concurrent physical and mental demands (Bray *et al*., 2011).

One of the central ideas implicated in dual-task performance models is the construct of resources (Hockey, 1997). Resources refer to a limited number of one or more pools of general-purpose processing units capable of performing elementary operations across a range of tasks (Wickens, 1985; Hockey, 1997). The execution of all tasks requires some degree of attention and therefore the use of such resources to a certain extent (Hockey, 1997; Pellechia, 2010). Two key features of the resource construct are of particular importance when considering dual task performance. Firstly, human resources are limited in capacity (Wickens, 2008) and secondly, simultaneous mental operations must compete for available processing units (Hockey, 1997). Therefore, balancing task-workload with attentional resource capacity is crucial for enhancing worker performance (Basahel *et al*., 2012).

The execution of any task requires cognitive processing, and irrespective of whether a task is physical or cognitive in nature, the brain is the organ of mediation (Marras and Hancock, 2013). During a cognitive task, task demands are interpreted by the brain and performance is governed by the ability to process information, which is dictated by the available resources (Wickens, 2008). To perform a physical task, the brain/cognitive system of the worker perceives and processes the task demands and mediates the motor response required for task execution (Asai *et al*., 2013). Since human attentional capacity is limited, dual-task operations must compete for available resources (Hockey, 1997). In respect to the resource construct, most researchers have focused on the effect of concurrent cognitive workloads on attentional resource capacity and research has been centred on the interference between two cognitive tasks (Wickens, 2008). From such studies the Multiple Resource Theory was developed, which suggests that the types of tasks will impact the level of task interference between two tasks (Wickens, 2008). According to this model, interference is dependent upon the extent that tasks share stages of processing, sensory modalities, codes of processing and channels of visual information, as variations of these draw upon different attentional resource pools (Wickens, 2008). The model has however failed to consider the impact of multiple cognitive and physical task demands in any great detail. Consequently, there is a lack of knowledge surrounding the impact of physical workload on attentional resource availability (Basahel *et al.*, 2012).

Since the motor control of a physical task is regulated via cognitive processes, it is possible that an attention demanding second task may influence the control of the motor system, or lead to increased task interference by competing for limited neural resources; impacting both physical and cognitive performance (Brereton and McGill, 1999). Therefore, it is necessary to examine the combined impact of physical and mental workloads on resource allocation and task performance (Basahel *et al.*, 2012).

Previous research into the effects of concurrent physical and mental demands remains limited. Previous investigations have reported alterations in muscle activity, (Brereton and McGill, 1999; Davis *et al*., 2002), increased levels of psychosocial stress (Davis *et al*., 2002; Leyman *et al*., 2004; Bray *et al*., 2011), increased fatigue (Leyman *et al*., 2004; Marcora *et al*., 2009; Bray *et al*., 2011; Pageaux *et al*. 2013), increased perceptions of effort (Bray *et al*., 2011; (Pageaux *et al*. 2013) and decreased levels of performance (Brereton and McGill, 1999; Davis *et al*., 2002; Leyman *et al*., 2004;

Marcora *et al*., 2009; Martin and Bray, 2010; Bray *et al*., 2011; Pageaux *et al*. 2013). However, only a few studies have been done and such alterations were attributed to varying reasons including cognitive distraction (Brereton and McGill, 1999), limited attentional resources (Basahel *et al.*, 2012), increased central fatigue (Bray *et al*., 2011; Marcora *et al*., 2009; Martin and Bray, 2010) or increased muscle tension resulting from increased psychosocial stress (Davis *et al*., 2002 and Leyman *et al*., 2004). As a result of the few investigations and inconsistent reasons for alterations observed, the exact association between cognitive effortful tasks and physical activity still remains unclear, but a general hypothesis that there is a limited brain-based energy resource that governs the performance of tasks requiring cognitive, emotional and physical regulation has become apparent in the literature (Bray *et al*., 2011).

In industrial tasks workers are often exposed to different types of cognitive and physical tasks depending on the work environment and task required (Stork and Schubo, 2010). Workers may be required to use cognitive functions such as perception, decision making, memory, and response selection/execution in conjunction to task specific physical requirements (Hogan, 1991; Perry *et al*., 2009 Safe Work Australia, 2011). Very few studies have explored the impact of different types of cognitive tasks which target these different stages of information processing on task interference with a concurrent physical task. Considering that workers experience combined physical and mental demands in their daily jobs, it has become increasingly important to investigate humans in the full context in which they perform a task by considering the interdependencies between the task environment, individual characteristics, and the cognitive and physical human subsystems (Marras and Hancock, 2013). Developing a greater understanding of how different cognitive functions and demands interact with physical demands to influence performance, perceptual and physical responses can provide the opportunity for improved job design and strategies to increase task performance, worker well-being and decrease the risk of injury (Marras, 2009; Marras and Hancock, 2013).

STATEMENT OF THE PROBLEM

Dual-task work environments require simultaneously executed tasks to compete for available resources, and balancing task-workload with attentional resource capacity is vital for effective task performance. Many occupational tasks place concurrent physical and cognitive demands on workers. A substantial amount of research has investigated the effects of two simultaneous cognitive tasks on resource allocation and performance, but little has focused on the interactive effects of concurrent cognitive and physical demands. Different types of cognitive tasks draw on attentional resources in different ways, and may induce varied levels of strain upon individuals. For example, attentional resources used during different stages of information processing (memory or decision making) are believed to be separate from one another, as are those used during the perception of information through different modalities (visual or auditory). A greater understanding of how different cognitive tasks interact with a common industrial-related physical task could allow for improved strategies to increase task performance and worker well-being. The objective of this research was to identify the extent to which different types of cognitive tasks performed simultaneously with a physical task impact resource allocation and the performance, perceptual and physical responses of participants.

RESEARCH HYPOTHESIS

It was hypothesised that, compared to the physical and cognitive tasks performed in isolation, participants would elicit unfavourable differences in task performance, spinal kinematics, muscle recruitment patterns, and perceptual responses when performing the physical and cognitive tasks concurrently. It was further hypothesised that the stage of information processing (memory or decision making) and the modality through which information is perceived (visual or auditory) would impact these responses.

STATISTICAL HYPOTHESES

The following hypotheses were generated for the study.

Hypothesis 1: General interaction between cognitive and physical demands

This hypothesis investigated whether performing a physical task concurrently with a cognitive task would result an interaction effect. The null hypothesis stated that participants would elicit no differences in selected physical, cognitive and perceptual responses at baseline and those observed during combined physical and cognitive tasks. The alternative hypothesis (Ha) stated that participants would elicit differences in selected responses during the isolated execution of only a physical or a cognitive task and the simultaneous execution of the physical and selected cognitive task.

1) Ho: μR (baseline) = μR (physical + cognitive)

Ha: μR (baseline) ≠ μR (physical + cognitive)

Where: R = Responses in cognitive task performance (quantity, errors), physical responses (e.g. spinal kinematics, electromyography), and perception of effort (ratings of perceived physical exertion, time pressure, mental effort and psychological stress).

“baseline” = either physical or selected cognitive task performed in isolation

“physical + cognitive” = physical lifting task performed in combination with the selected cognitive task

Hypothesis 2: Impact of sensory modality

The second hypothesis investigated whether an interaction effect was dependent on the sensory modality employed during the cognitive task. The null hypothesis stated that selected responses would not differ due to sensory modality employed during the cognitive task. The alternative hypothesis stated that sensory modality would have an impact on the interaction effect.

2a) Memory tasks

Ho: μR (baseline) = μR (physical + visual memory) = μR (physical + auditory memory)

Ha: μR (baseline) ≠ μR (physical + visual memory) ≠ μR (physical + auditory memory)

2b) Decision making tasks

Ho: μR (baseline) = μR (physical + visual decision making) = μR (physical + auditory decision making)

Ha: μR (baseline) ≠ μR (physical + visual decision making) ≠ μR (physical + auditory decision making)

Where: R= Responses in cognitive task performance (quantity, errors), and physical responses (e.g. spinal kinematics, electromyography, ratings of perceived physical exertion).

“baseline” = either physical lifting or selected cognitive task performed in isolation

“physical + visual memory” = physical lifting task performed in combination with the visual memory task

“physical + auditory memory” = physical lifting task performed in combination with the auditory memory task

“physical + visual decision making” = physical lifting task performed in combination with the visual decision making task

“physical + auditory decision making = physical lifting task performed in combination with the auditory decision making task

Hypothesis 3: Impact of stage of information processing

This hypothesis investigated whether the stage of information processing would have an effect on a potential interaction effect. The null hypothesis stated that selected responses would not differ due to the stage of information processing targeted during the cognitive task. The alternative hypothesis stated that sensory modality would have an impact on the interaction effect.

3a) Visual tasks

Ho: μR (baseline) = μR (physical + visual memory) = μR (physical +visual decision making)

Ha: μR (baseline) $\neq$ μR (physical + visual memory) $\neq$ μR (physical +visual decision making)

3b) Auditory tasks

Ho: μR (baseline) = μR (physical + auditory memory) = μR (physical + auditory decision making)

Ha: μR (baseline) ≠ μR (physical + auditory memory) ≠ μR (physical + auditory decision making)

Where: R= Responses in physical task performance, spinal kinematics, electromyography, ratings of perceived physical exertion.

“baseline” = physical lifting/selected cognitive task performed in isolation

“physical + visual memory” = physical lifting task performed in combination with the visual memory task

“physical + visual decision making” = physical lifting task performed in combination with the visual decision making task

“physical + auditory memory” = physical lifting task performed in combination with the auditory memory task

“physical + auditory decision making = physical lifting task performed in combination with the auditory decision making task

CHAPTER II:
REVIEW OF LITERATURE

This chapter reviews the literature relating to the study performed and aims to provide background knowledge regarding task execution, and in particular, the execution of simultaneous tasks. The Multiple Resource Model is then explained in detail as it forms a large basis for this study. Lastly, the chapter considers the different elements of industrial lifting.

TASK EXECUTION

Figure 1 illustrates the most basic model of human information processing adapted from Schmidt and Wrisberg (2008). To perform any operation, humans receive information (“input”), process this information and produce a response (“output” or “motor response”), resulting in the execution of a cognitive or physical task (Schmidt and Wrisberg, 2008). Therefore, all tasks require some degree of cognition, which refers to the mental processes involved in processing information and applying knowledge (Matlin, 2008). It is important to note that for human information processing to take place, a certain amount of concentration is required, and therefore demands attention (Wickens, 1985).

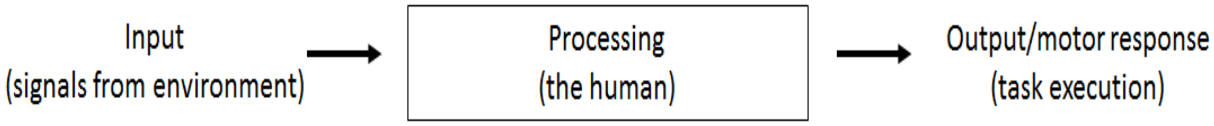


Figure 1: Simplified information processing model (Schmidt and Wrisberg, 2008).

Stages of information processing

The model in Figure 1 can further be expanded, as three discrete stages of processing have been identified through which information must travel from input to output (Schmidt and Wrisberg, 2008). As shown in Figure 2, the individual receives an input stimulus and processing begins. The first stage of processing is the stimulus-identification stage during which an individual recognizes and identifies a stimulus. Once the stimulus has been properly identified and analysed the individual decides what response to initiate during the response-selection stage. This is then followed by the response-programming phase during which the motor system is co-ordinated to achieve the desired movement chosen in the previous stage, and a response (output) is produced (Schmidt and Wrisberg, 2008; Schmidt and Donald, 2011).

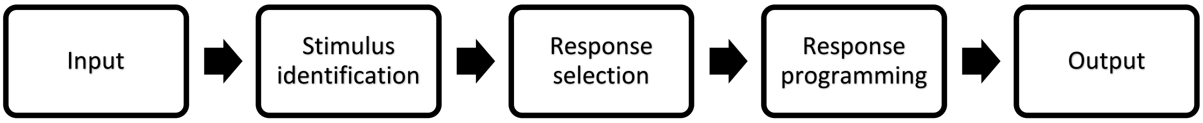


Figure 2: Expanded model of information processing (adapted from Schmidt and Wrisberg, 2008)

This is, however, a highly simplified version of task execution. Under realistic conditions human responses are highly dependent on their individual interpretation of the required task, and it is this “task interpretation” that forms the primary “input” for information processing and response selection (Marras and Hancock, 2013). Figure 3 displays the main factors which influence task perception/interpretation. These include the physical work environment, task workload and the psychosocial environment. The physical work environment refers to the visual, auditory and thermal conditions, as well as any olfactory, tactile and haptic information to which the worker is exposed (Marras and Hancock, 2013). Task workload can be divided into two categories, namely physical demands and cognitive demands (Basahel *et al*., 2010; Marras and Hancock, 2013). Physical workload is defined as the demand on the musculoskeletal, cardiorespiratory and nervous systems of the human body associated with tasks that require physical work (Basahel *et al*., 2010). Physical workload typically considers factors such as energy expenditure, strength, speed, kinematics and kinetics associated with a task (Marras and Hancock, 2013). Mental workload does not have a conventional definition, but is regarded as the amount of attentional resources required to complete a task (Basahel *et al*., 2010). Alternatively, as the amount of time load, mental effort load and psychological stress load associated with given task demands (Nygren, 1991). The psychosocial environment in which the task is performed considers factors such as job satisfaction, job control, level of social support, perceived stress and emotional effort associated with a task (Chany *et al*., 2006; Marras and Hancock, 2013). As Figure 3 depicts, these factors interact with each other to impact the worker's perception/interpretation of the task, making it necessary to investigate this interaction to fully understand human response.

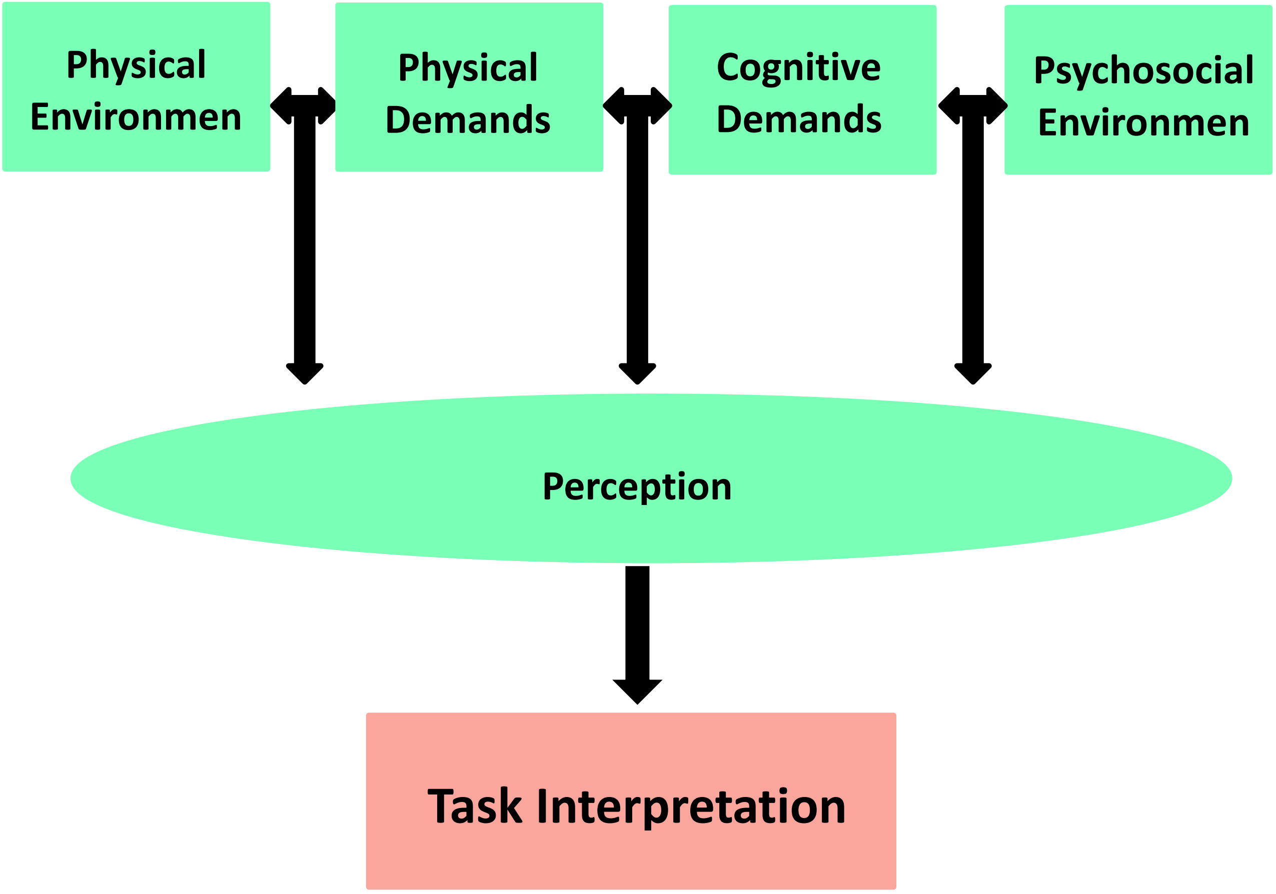


Figure 3: Task interpretation (adapted from Marras and Hancock, 2013)

Humans have been traditionally classified as having a cognitive and a physical subsystem and the majority of ergonomics research has exclusively considered the interplay between either cognitive demands and the work environment, or the physical demands and work environment, but ignored the interconnection between the cognitive and physical systems (Marras and Hancock, 2013). To optimize task performance and worker well-being, research should consider the full context within which the human operates. To achieve this, the interconnection between all the elements that may impact task execution must be considered (Mehta *et al*., 2012).

Cognitive and physical subsystems

Before examining the interaction between concurrent physical and mental demands, the cognitive and physical human subsystems first need to be considered independently. Figure 4 has been adapted from Marras and Hancock, (2013) as it graphically displays the cognitive and physical human subsystems independently from one another during task execution. Although not displayed in the diagram, it is important to keep in mind that, since no human is identical, these processes may be further influenced by individual factors including personality, biomechanical state, genetic factors and experience (Marras and Hancock, 2013). During the execution of a mentally demanding task (utilizing the cognitive subsystem) the task interpretation is considered by the human brain. Task performance is then dictated by the perceived cognitive demands relative to the available cognitive supply, where cognitive supply refers to the amount of attention/mental resources that are available to be dedicated to the task. If cognitive demand exceeds cognitive supply performance is likely to suffer (Marras and Hancock 2013; Mehta and Agnew, 2011). As with the cognitive subsystem, physical task demands/interpretation are processed by the relevant centres in the brain, which then mediate co-ordinated muscle activation and recruitment sequencing in order to produce the intended action - a process known as motor control (Abernethy, 2013; Marras and Hancock 2013). Skeletal muscle is composed of individual muscle fibres, all of which are innervated by an alpha motor neuron. Alpha motor neurons are large lower motor neurons of the brainstem and spinal cord that innervate extrafusal muscle fibres of skeletal muscle and are directly responsible for initiating their contraction. Muscle activation is achieved through the neural recruitment of a motor unit, which consists of a single alpha motor neuron and all the muscle fibres it innervates. Nerve impulses originate in the brain and travel along the motor neurons to activate the motor endplates located on the membrane of every muscle fibre, resulting in contraction. The greater the number of motor units activated the greater the number of fibres contract and the larger the contraction (Tortora and Derrickson, 2009). The brain mediates the number of fibres recruited, duration of activation and the sequence in which different muscles contract (Schmidt and Wrisberg, 2008).

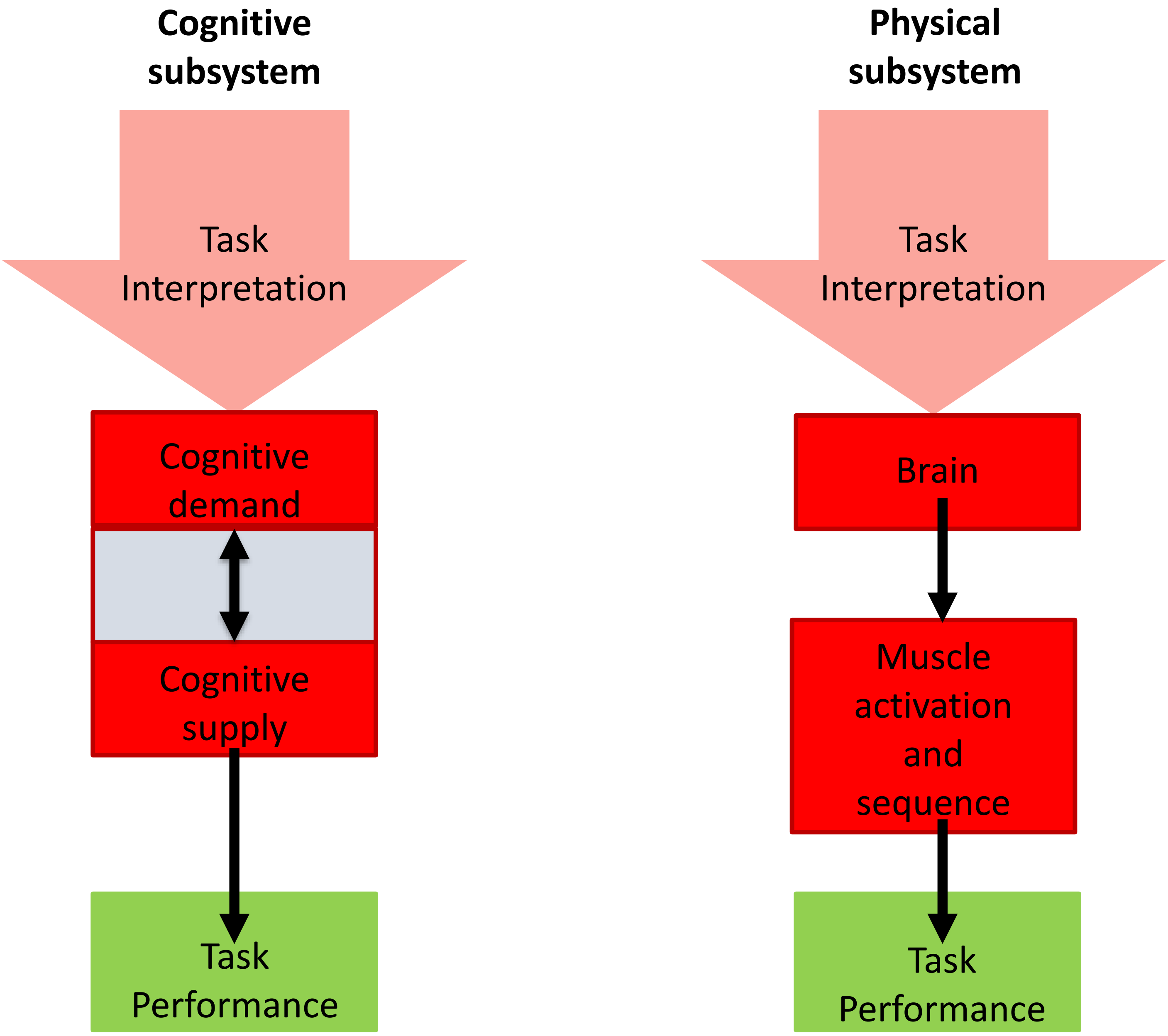


Figure 4: Human cognitive and physical subsystems during task execution (Marras and Hancock, 2013)

Interaction between simultaneous cognitive and physical demands

An important point to take note of from Figure 4 is that all tasks, whether physical or cognitive in nature, require some degree of information processing and the brain is the organ of mediation (Marras and Hancock, 2013). Information processing requires some degree of attention (Wickens, 1985), which is defined as an inferred underlying commodity that enables performance of a task (Smith and Bucholz, 1991) and is crucial for task execution as it is seen as the resource used to select appropriate sources of information and response (Wickens, 1985). Human attentional resources are however limited (Wickens, 2008), and what this essentially means is that if attentional demands exceed that of the individual's attentional capacity, performance is likely to be impaired (MacPherson *et al*., 2004). The safe and efficient operation of complex systems therefore requires that the workload imposed on users does not exceed their capacity (Hertzum and Holmegaard, 2013). Even if capacity is not exceeded, a system design that imposes a high attentional demand allows for less capacity for optimal task performance. This may have important consequences in situations involving dual-tasking, where humans are exposed to numerous sources of cognitive demand and attentional resources must be distributed between the multiple demands (Wickens, 2008). One theory is that of a central cognitive decision and response-selection bottleneck, whose limited capacity constrains the performance of dual-tasks (Schumacher e*t al*., 2001). This is referred to as dual-task interference (Pellechia, 2010). According to the response-selection bottleneck, if an individual is engaged in selecting the response to a stimulus for one cognitive task, then selecting another response to a different stimulus for a second cognitive task will be more difficult and not as much attention will be allocated to the performance of either one or both tasks and performance is likely to be compromised, even if the tasks are relatively simple (Hommel, 1998; Schumacher *et al*., 2001; Johnston and McCann, 2003; Wickens, 2008, Hiraga *et al*., 2009).

In respect to the resource construct and dual-task performance, most research has been centred on the effect of cognitive workloads and the interference between two cognitive/mentally demanding tasks (Wickens, 2008). Since both cognitive and physical tasks require cognition, and therefore draw on the limited attentional resource capacity, it is possible that an interaction may exist between the concurrent performance of physical and cognitive tasks. As each task must compete for the limited available attentional resources (Brainerd and Reyna, 1989; Wickens, 2008), the outcome of performance may depend on the ability to integrate these simultaneous demands (Simoni *et al*., 2013). Many work-related tasks require dual-tasking, involving the integration of mental and physical demands (Perry *et al.*, 2009; Pellechia, 2010; Simoni *et al*., 2013). The level of task interference between different content-related physical and mental tasks is however poorly understood due to the little amount of research that has investigated the impact of physical workload on attentional resource availability (Basahel *et al.*, 2012). Understanding the extent to which two tasks involving both cognitive and motor processes can be performed simultaneously could allow for improved strategies to increase task performance and worker well-being in practical work situations (Schumacher *et al*., 2001; Marras, 2009; Marras and Hancock, 2013).

The hypothesis that there is a limited brain-based energy resource that is responsible for regulating performance of concurrent tasks requiring a combination of mental and physical effort is further supported by research investigating the anatomy of the brain (Bray *et al*., 2011). Studies have identified that tasks requiring concurrent mental, physical as well as emotional effort are regulated in an area of the brain known as anterior cingulate cortex (Bray *et al*., 2011). The anterior cingulate cortex is an area of the human brain that occupies a large fraction of the medial wall of the cerebral hemisphere, in which motor control, homeostatic drive, emotion and cognition converge (Turken and Swick, 1999; Barch *et al*., 2001; Critchley *et al*., 2003; Marcora *et al*., 2009). It has been proposed to be part of the attentional control network of the brain and the neurobiological substrate for executive control of cognitive and motor processes (Turken and Swick, 1999), providing an interface for motor control, drive and cognition (Heckers *et al*., 2004). It has therefore been suggested that the anterior cingulate cortex plays a significant role in behaviour control and the translation of intentions into actions (Paus, 2001). Accumulated evidence from functional imaging studies have indicated the involvement of the anterior cingulate cortex in behavioural functions such as attention-for-action/target selection, motivational assignment, motor response selection, error detection/performance monitoring, competition monitoring, anticipation, working memory, novelty detection and reward assessment (Bush *et al*., 2001). Paus (2001) describes three key features that provide evidence of the link between the anterior cingulate cortex and behavioural control, the first of which is strong projections from the anterior cingulate cortex to the motor cortex and spinal cord, implicating this region in motor control. Secondly, there are direct connections between the anterior cingulate cortex and the prefrontal cortex (PFC), supporting the anterior cingulate cortex's proposed role in cognition. These connections are crucial to dual-task interference between simultaneous cognitive and physical tasks as research shows that physical activity involving motor recruitment is associated with the disengagement of higher order functions of the PFC (Diedrick and Auidffren, 2011). It is believed that this disengagement occurs in order to ensure optimal motor recruitment during physically orientated tasks, and what this essentially means is that cognitive functions will be down-regulated during physical activity (Diedrick and Auidffren, 2011). Furthermore, this down-regulation is believed to be due to the brain's limited resources and perceived as part of the notion of competitive neural processing (Diedrick and Auidffren, 2011). The third feature involves projections from the anterior cingulate cortex to the midline thalamus and brainstem, indicating an important role in arousal/drive.

Despite an increased demand on attentional resources, it has been suggested that dual-task performance increases the amount of psychological stress experienced by individuals (Davis *et al*., 2002). Studies have found that increased stress may lead to increased muscle tension, alterations in muscular activity, biomechanical loading of the musculoskeletal system, and decreased task performance (Davis *et al*., 2002; Schleifer *et al*., 2002). Concurrent mental and physical task demands may interact and exacerbate the stress experienced by individuals (Davis *et al*., 2002). A model created by Schleifer (2002) explains the link between stress and increased muscular tension through the idea that stress causes hyperventilation, which reduces blood CO_2 levels and affects the blood chemistry by increasing pH level in a way that results in elevated muscle tension and enhanced sensitivity to sympathetic activity (Lundberg, 2002). Another model created by Johansson and Sojka (1991) considers the impact of mental stress on muscle spindles, which are important in the coordination of movements and allow for optimal allocation of activity in the muscle (Johansson and Sojka, 1991). It has been suggested that mental stress and elevated sympathetic arousal reduce/eliminate their regulatory functions, resulting in sub-optimal muscular activity/overload (Johansson and Sojka, 1991).

It has also been suggested that increased psychological stress can lead to decreased task performance (Vischer, 2007). Increased anxiety has been linked to impaired functioning of the goal-directed attentional system, exhibited through decreased attentional control. This can lead to adverse effects on information processing efficiency and decreased task performance (Eysenck *et al.*, 2007). In order to compensate for these adverse effects, workers adopt strategies, such as increased effort or an even greater use of attentional resources (Eysenck *et al.*, 2007), which has further been linked to enhanced psychological discomfort, job-related strain and decreased worker motivation (Vischer, 2007).

A link between mental demand and physical perceived effort is also apparent in the literature (Marcora *et al*., 2009; Bray *et al*., 2011). Fatigue associated with motor task performance is considered to consist of two components: peripheral fatigue that occurs at the level of the muscle tissue and central fatigue that occurs in the central nervous system (Gandevia, 2001). Taylor *et al*. (2006) provided evidence that the origin of central fatigue can be traced to the prefrontal areas of the brain associated with emotion, cognition and volition. It is therefore possible that a mentally demanding task performed concurrently with physical workload can lead to increased physical fatigue or perception of effort (Gandevia, 2001; Taylor *et al*., 2006). This is further supported by Mehta and Parasuraman (2014) who observed significant decreases in motor output performance due to mental fatigue. Even if not actually more fatigued, an increased perception of physical exertion can have consequences for task performance and movement quality. Workers may alter movement strategies or work output in an attempt to avoid physical discomfort or possible injury. This is commonly known as "safety seeking behaviour" and is strongly associated with a higher perceived workload (Leeuw *et al*., 2007).

Given the above-mentioned theory, it is plausible to presume a link between concurrent physical and mental demands, but this link has not been extensively explored and only a few studies have investigated this topic. The studies conducted on the effects of concurrent physical and mental demands have reported inappropriate muscle recruitment and movement patterns (Brereton and McGill, 1999; Davis *et al*., 2002), increased levels of psychosocial stress (Davis *et al*., 2002; Leyman *et al*., 2004; Bray *et al*., 2011), increased central fatigue (Leyman *et al*., 2004; Marcora *et al*., 2009; Bray *et al*., 2011), increased perceptions of effort (Bray *et al*., 2011) and decreased levels of performance (Brereton and McGill, 1999; Davis *et al*., 2002; Leyman *et al*., 2004; Marcora *et al*., 2009; Martin and Bray, 2010; Bray *et al*., 2011). The alterations observed in these studies were attributed to a variety of reasons including cognitive distraction (Brereton and McGill, 1999), limited attentional resources (Basahel *et al.*, 2012), increased central fatigue (Bray *et al*., 2011; Marcora *et al*., 2009; Martin and Bray, 2010) or increased muscle tension resulting from increased psychosocial stress (Davis *et al*., 2002 and Leyman *et al*., 2004). A contradicting study by Pageaux *et al*. (2013), however, indicated no interaction between mental effort and neuro-muscular function, and attributed any negative impact on performance to a higher perception of effort rather than impaired muscular recruitment patterns. Given that research surrounding cognitive-physical task interaction is both limited and inconsistent, the exact association between cognitive effortful tasks and physical activity still remains unclear (Bray *et al*., 2011).

A strong link between motor control and injury has also been identified in the literature (Gorelick *et al*., 2002; Radwin *et al*., 2002; Solomonow, 2003; Olson, 2010), making it critical to investigate possible changes in motor control due to mental workload in order to evaluate occupational demands and possible risk of injury (Mehta *et al*, 2012). Work-related musculoskeletal disorders (WMSDs) are currently regarded as one of the most costly health care problems facing society (Marras, 2000). Of these WMSDs, lower back disorders (LBDs) are regarded as the most common and expensive disorders (Marras, 2000). Up to 80% of adults will experience lower back pain during their life time, of which a large proportion is attributed to occupational forces (Marras, 2000). Regular physical job demands often result from manual materials handling (MMH). MMH refers to the transporting or supporting of any load, and occurs in almost all work environments from factories and warehouses to offices (European Agency for Safety and Health at Work, 2007). In MMH industries lifting remains the most common task associated with work related low back injuries (Marras and Granata, 1995). The types of physical demands that workers are exposed to often differ depending on the content of the task required, as well as the work environment in which the task is performed (Stork and Schubo, 2010). Many occupational-related physical tasks are multi-dimensional in nature, but have two primary components: muscular strength and endurance, and movement quality (Hogan, 1991). Lifting is regarded as a complex physical task that requires both strength, endurance in the case of repetitive lifting and coordination (Wrigley *et al*., 2005). Muscular strength is the capacity of a muscle to generate tension and overcome an opposing force, endurance is the ability to maintain or repeatedly produce this force and co-ordination is the capacity of an individual to use the brain and nervous system together with the locomotor system to execute smooth and precise movements (Merino and Briones, 2007). Co-ordination is crucial in determining the accuracy and effectiveness of a movement (Hogan, 1991).

The majority of over-exertion injuries occur as a result of lifting tasks and they are currently the leading cause of work related low back pain (Wrigley *et al*., 2005). Lifting tasks can lead to excessive compressive forces on the spine due to increased muscle moment generation requirements (Anderson and Chaffin, 1986). Lifting an external load imposes a moment on the spine, which is then counter-balanced by an opposite moment produced by the trunk muscles; this muscle activity exerts compressive and anterior-posterior and lateral shearing forces onto the spine, particularly at the L5/S1 joint (Davis and Marras, 2000). It is these forces that are believed to lead to LBDs (Marras and Granata, 1995).

The cause of work-related LBDs is believed to be multifactorial in nature and to be triggered by a complex interaction of physical/biomechanical work factors, psychosocial stress and organizational factors and individual characteristics (Waters *et al.*, 2006). Epidemiological studies have indicated that between 11% and 80% of all low back injuries are related to physical/biomechanical factors (Marras, 2009). However, in addition to these biomechanical factors, epidemiological studies indicate that between 14% and 63% of low back injuries are attributable to work psychosocial and organizational factors (Marras, 2009). Evidence suggests that increased psychological stress negatively influences muscle recruitment patterns and could increase the risk of injury (Davis *et al*., 2002). Psychosocial and organizational factors that have been shown to influence the development of low back pain include job satisfaction, perceived effort, supervisor support, safety climate, work related stress and monotony of work tasks (Manchikanti, 2000). Such factors have been shown to contribute to injury causation through accentuation of the load placed on the tissues (Waters *et al.*, 2006). Increased psychosocial stress and perception of effort have been linked to decreased pain thresholds and tolerance to loading, this ultimately results in altered movement patterns and unfavourable changes in muscle recruitment patterns which exert more force on the musculoskeletal structures and surrounding tissues (Marras, 2005).

With the precipitation of LBDs resulting from a multivariate interaction, defining a single mechanism of injury is very difficult, but it is believed that injury occurs when a stress placed on the body exceeds the internal tolerance of the musculoskeletal tissues for mechanical strain, resulting in tissue damage, pain, impairment or injury (Radwin *et al*., 2002). To date the “tissue-load tolerance” model has dominated research in the latter part of the last century and still has wide support (McGill, 2010). This model provides a biomechanical explanation of musculoskeletal injury low and presents a tool for quantifying a harmful level of risk exposure in the workplace (Brereton and

McGill, 1999; Marras, 2000). According to this model injury occurs when a stress placed on the body exceeds the internal tolerance of the musculoskeletal tissues for mechanical strain, resulting in tissue damage, pain, impairment or injury (Radwin *et al*., 2002). Figure 5 depicts this relationship, which assumes that during a work task a specific and quantifiable load is placed on the structures of the spine and that injury can be expected to occur if this load exceeds the threshold or tolerance level for tissue damage. The safety margin where injury would not be expected is the difference between the tolerance threshold and spinal load (Marras 2000, Brereton and McGill, 1999, Kudryk, 2008). This model provides a useful mechanism for controlling risk by evaluating the imposed load relative to the structural tolerance of the spine (Marras 2000).

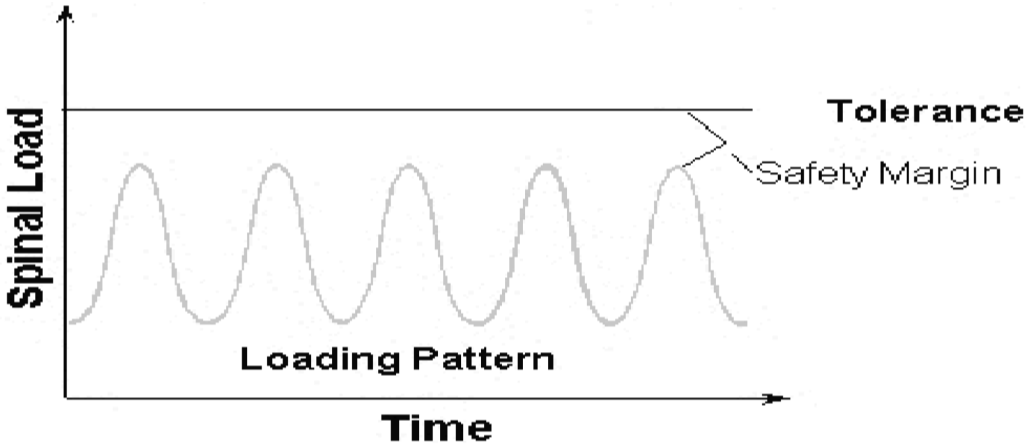


Figure 5: Biomechanical model for injury displaying the load-tolerance relationship (Marras, 2000)

This relationship is however more complex than depicted in Figure 5. Throughout the work-day, the load-tolerance relationship is affected by several factors including, but not limited to task repetition, duration, frequency, time of day, worker technique, psychosocial factors and individual characteristics (Marras, 2000, Marras *et al*., 2006). A more realistic model given the variable nature of the modern workplace is shown depicted in Figure 6 . This diagram demonstrates how initially when a relatively high load is placed on the tissues injury may not occur, whereas over time a considerably lower load placed can result in injury dues to the reduction in tissue tolerance (Marras, 2000).

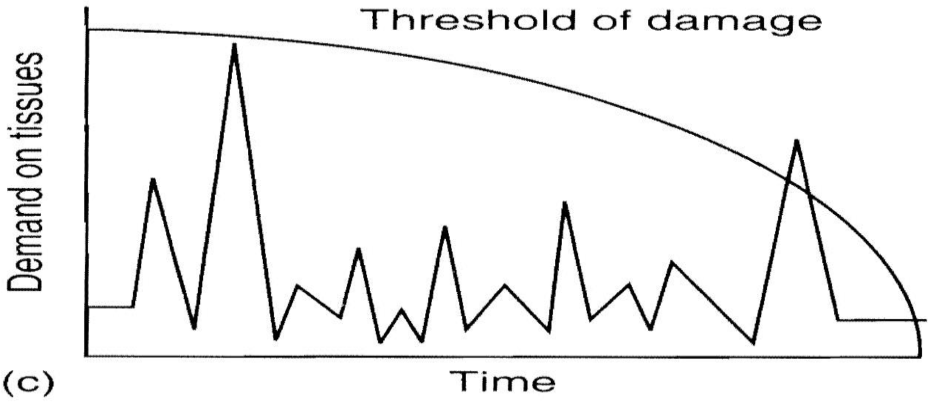


Figure 6: Variable nature of load-tolerance relationship over time (Marras, 2000)

During periods of loading the forces applied to the tissues are strongly influenced by how the motor control system chooses postures and movements to support these loads (Brereton and McGill, 1999). Alternative muscle recruitment strategies, such as changes in the timing, duration and degree of muscle activation, as well as the muscles recruited, result in unnatural movements and increased loading of tissues (D’hooge *et al*., 2012). This is often associated with a non-optimal redistribution of stress and tissue overload (Brereton and McGill, 1999). Under dynamic conditions the risk of injury is increased and dynamic action of the trunk greatly affects the ability of a worker to perform lifting tasks (Marras, 2009). Increased trunk moments, asymmetrical movements, velocities and accelerations result in increased trunk muscle co-activity and muscular force, intra-abdominal pressure and spinal loading (Davis and Marras, 2000). Movement quality is therefore crucial to lifting. Analysing spinal kinematics and muscle activity provides a way to track the coordinated patterns and variation of dynamic movements during a lifting task (Wrigley *et al*., 2005).

In typical work environments the manipulation of materials is often performed at a rapid work output and requires some degree of mental concentration from workers through decision making tasks such as distinguishing between and sorting of materials, or continuous vigilance and motor control in order to precisely place loads. Biomechanical, physiological and psychosocial risk factors have dominated research surrounding the risk of WMSDs providing an understanding of the major risk factors that influence the load-tolerance relationship of human tissue and risk of injury (Marras, 2009). However, the impact of the interactive effects of concurrent cognitive and physical demands on these risk factors for injury remains virtually unexplored (Marras, 2009). Since motor control is regulated by the cognitive system there is a possible link between concurrent physical and mental demands and the risk of injury. This interaction could negatively impact work parameters such as, force levels, muscles employed, kinematics, trunk dynamics, task perception and psychological stress, possibly placing workers at a higher risk for injury development (Davis *et al*., 2002; Mehta *et al*., 2012). Understanding how cognitive demands interact with other risk factors to influence the load-tolerance relationship will allow for work-related risk to be better quantified and improved preventative strategies (Marras and Hancock, 2013).

MULTIPLE RESOURCE THEORY

Wickens (1985) proposed a Multiple Attentional Resource Model in relation to dual-task performance, which explains the extent to which two tasks can be carried out concurrently, and accounts for differences in dual-task interference based on task content. This model is the dominant theory behind explaining dual-task performance, but is centred on the interference between simultaneous mental demands. It states that performance is directly proportional to the allocation of resources (Mehta and Agnew, 2011) and addresses the idea that each individual has separate and different resources for different types of mental demands, all of which are characterized by different capacity limits (Wickens, 2008). According to the Multiple Resource Model the level of task interference will depend on the extent that two tasks require common attentional resources (Smith and Bucholz, 1991). These separate resources are defined in terms of four different dimensions as illustrated in Figure 7, namely the stages of information processing, codes of processing information, perceptual modalities and visual channels (Wickens, 2008).

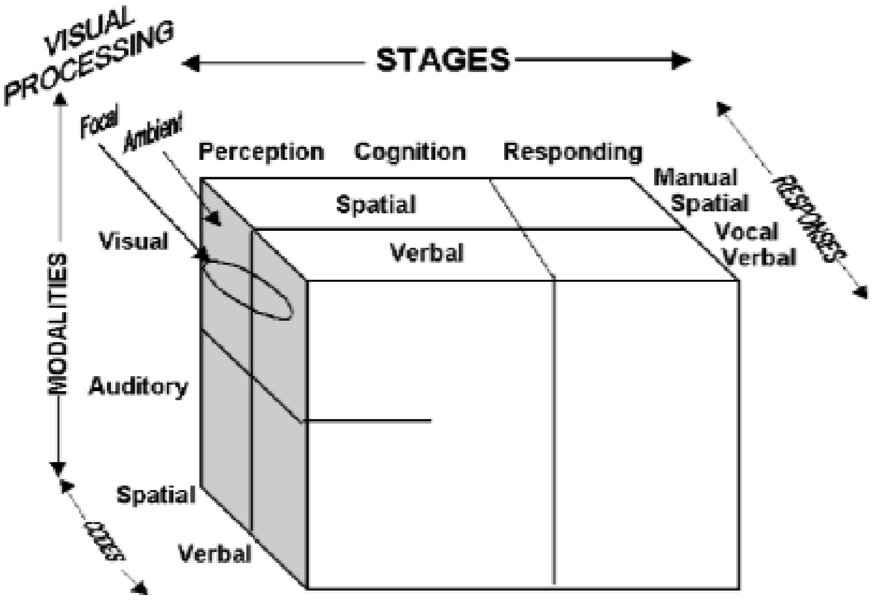


Figure 7: Wickens' Multiple Resource Model (Wickens, 2008)

Stages of information processing and memory

The stages of information processing displayed in Figure 7 are the same as those explained earlier and displayed in Figure 2 . The processes involved in information processing can be stored in the central nervous system and most instances of perception, response selection and movement production draw on information from previous experiences (Schmidt and Donald, 2011); in other words, information stored in memory (Schmidt and Wrisberg, 2008). Memory is viewed as the storage and retrieval of information (Huitt, 2003) and plays a crucial role during information processing, as is illustrated in Wickens' Model of Information Processing, shown in Figure 8. Wickens (2008) proposed that the resources underlying perceptual and working memory activities differ from those responsible for response selection and execution.

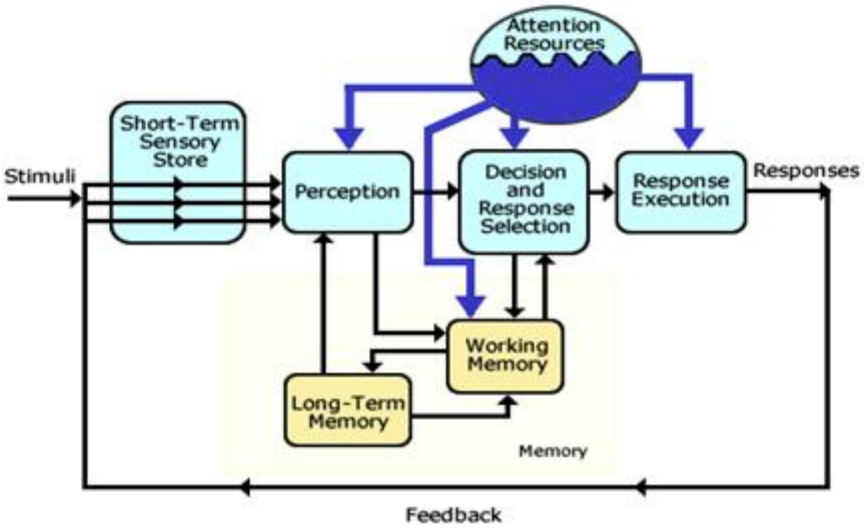


Figure 8: Wickens' information processing model (Wickens, 2002)

According to this model, information is stored and accessed in three distinct memory systems (Wickens, 2002; Huitt 2003) with the first type of memory being the short-term sensory store (STSS). In any environment numerous streams of sensory information enter the STSS via auditory, visual, tactile or kinesthetic modalities, and are held until the individual identifies them or they are replaced by new incoming information (Huitt 2003).

From the STSS a selective attention mechanism perceives certain information and allows it to be stored temporarily in the working memory, also termed short-term memory (D'Esposito *et al*., 1995). Working memory can be thought of as a temporary work space where information is stored and manipulated in order to carry out complex cognitive activities and response selection (Wickens, 2002; Schmidt and Wrisberg, 2008; Gathercole and Alloway, 2007). It is divided into three subcomponents: the central executive, the visuospatial sketchpad and the phonological loop (Ericsson and Kintsch, 1995). The central executive component is thought to be involved in the attention-controlling system, and responsible for directing attention as well as coordinating the activities of the visuospatial sketchpad and phonological loop (Morris and Jones, 1990). The visuospatial sketchpad stores and processes information in visual or spatial form (Wen *et al.*, 2011), manipulates visual images and maintains visual information in the short-term memory (Bruyer and Scailquin, 1997), while the phonological loop stores and processes speech-based information (Buchsbaum and D'Esposito, 2008).

The third component of memory is the long-term memory, which permanently stores well-learned information (Schmidt and Wrisberg, 2008). Information regarding prior experiences and knowledge, emotional state and values can easily be recalled from this memory store and impact individuals' perceptions and response selections (Wickens, 2002).

Codes of processing information

The codes of processing displayed in Figure 7 refer to the type of information being processed and expressed (Wickens, 2008). Information can either be processed or expressed spatially or verbally (Stadler, 1984) and tasks may either be purely verbal or spatial in nature or a combination of the two (Proctor and Reeve, 1989). Verbal tasks are defined as tasks that require the use of language or symbols and would include processing text or speech (Proctor and Reeve, 1989). Spatial tasks require the judgement and integration concerning orientation and translation, such as sound localisation and processing analogue pictures (Proctor and Reeve, 1989). According to Wickens (2008), spatial activity requires the use of different attentional resources to verbal/linguistic activity. Therefore, perception and processing of verbal and spatial as well as manual (spatial) and vocal (verbal) responses will target different resource pools.

Perceptual modalities

Environments contain enormous amounts of information which humans must perceive, decipher and choose between what information is relevant and which is irrelevant (Ohno, 1991). The modalities refer to the human channels through which information is perceived (Schumacher *et al*., 2001). The human input modalities relate specifically to the sensory organ through which information is received, and includes the visual (eyes), auditory (ears/sound), tactile (touch), olfactory (nose), gustatory (tongue) and vestibular (balance) systems (Schumacher *et al*., 2001). However, as shown in Figure 7, the Multiple Resource Model only distinguishes between visual and auditory modalities and it is proposed that visual and auditory perception draw on different pools of attentional resources (Wickens, 2008).

Visual channels

Wickens' Multiple Resource Model also distinguishes between two visual channels, which target different resource pools: focal and ambient, and which are nested within processing of visual information. The visual system is critically important in perceiving stimuli, and focal and ambient vision differ in terms of their roles in environmental perception, as well as the attentional resources they demand (Ohno, 1991; Wickens, 2008). Focal vision is responsible for detailed examination including tasks such as object recognition and high acuity perception such as reading texts and symbols (Wickens, 2008). Ambient vision on the other hand refers to the entire visual field and supports the perception of orientation, movement and direction; playing a crucial role in guiding larger movements (Ohno, 1991; Wickens, 2008).

Research surrounding this model has focused on the interaction between two cognitively demanding tasks and very little is known about how a physical task may target different resource pools; as well as how a physical task may interact with different types cognitive tasks (Basahel *et al*., 2012). Investigating this interaction could allow for improved task design in dual-task scenarios involving both cognitive and physical demands.

CONCLUSION

In conclusion, many occupational tasks place simultaneous physical and cognitive demands on workers and, whether physical or cognitive in nature, the execution of any task involves some degree of cognition (Marras and Hancock, 2013). All tasks therefore demand attention, which remains a limited resource in humans (Wickens, 1985) and simultaneous tasks, whether physical or cognitive, must compete for available attentional resources and it is likely that the performance of one or both tasks may suffer (Brainerd and Reyna, 1989; Wickens, 2008). A substantial amount of research has investigated the effects of two simultaneous cognitive tasks on resource allocation and performance, but little has focused on the interactive effects of concurrent cognitive and physical demands and the impact their level of interference may have on performance, perceptual and physical/movement quality responses. Given the strong link between movement quality and the risk of injury, understanding how cognitive demands interact with physical demands may provide further insight into not only worker performance, but worker well-being and risk of injury (Marras, 2009; Marras and Hancock, 2013). Further, different types of cognitive tasks have been found to draw on separate attentional resource pools, resulting in a task-dependent level of interference. For example, attentional resources used during memory tasks are believed to differ from those during decision making tasks, as do those used during the perception of information through different modalities i.e. visual or auditory (Wickens, 2008). The impact of physical task demands on resource allocation still remains unclear and it is possible that some types of cognitive tasks may result in greater or less interference than others (Basahel *et al*., 2012). Given that workers are exposed to a variety of different cognitive demands (Stork and Schubo, 2010), it is necessary to not only understand how physical and cognitive tasks interact, but how physical demands interact with different types of cognitive demands, in order to allow for improved strategies to increase task performance and worker well-being under dual-task conditions.

CHAPTER III:

METHODOLOGY

This study investigated the impact of possible dual-task interference during concurrent physical and cognitive task execution. Specifically, the study examined the varying effects of different types of cognitive tasks combined with a physical lifting task on task performance, movement quality and perceptual measures.

This chapter describes the methodological investigations, highlighting the selection of the experimental design, its independent and dependent variables, selection of participants, permutations of conditions, ethical considerations, experimental protocol and analysis of data.

EXPERIMENTAL DESIGN

A repeated measures design was selected for the current study as it allowed for the comparison between the physical and cognitive tasks performed in isolation and concurrently with one another. The independent variable of interest for the current study was the work task performed. Nine work tasks were selected as independent variables and included five baseline tasks (one physical task and four different cognitive tasks, which were each performed in isolation) and four dual-task scenarios (each cognitive task performed simultaneously with the physical task). Performance, perceptual and physical responses were selected as dependent variables of interest. Responses were compared between baseline and dual-task work conditions to observe firstly, if any general interaction between concurrent physical and cognitive demands occurred, and secondly, if sensory modality or stage of processing impacted this interaction.

To observe for general dual-task interference responses from each baseline task were compared to those from the corresponding dual-task scenario (Table i). Shaded blocks represent conditions that were not compared.

Table i: Design matrix utilised to observe general dual-task interference (white cells indicate conditions compared to one another)

	Physical + visual memory	Physical + auditory memory	Physical + visual decision-making	Physical + auditory decision-making
Physical baseline				
Visual memory baseline		▨	▨	▨
Auditory memory baseline	▨		▨	▨
Visual decision-making baseline	▨	▨		▨
Auditory decision-making baseline	▨	▨	▨	

To observe the impact of sensory modality on dual-task interference the combined responses from both visual dual tasks were compared to the combined responses from both auditory dual-tasks. Likewise, to observe the impact of stage of information on dual-task interference the combined responses from memory dual tasks were compared to the combined responses from both decision-making dual-tasks.

Selection of independent variables

The cognitive tasks selected for the current study included 1) a visual memory task, 2) an auditory memory task, 3) a visual decision making task, and 4) an auditory decision making task, while the physical task was a repetitive lifting and lowering protocol. The justification for the selection of these conditions is provided below.

Selection of cognitive tasks

Each cognitive task was chosen based on specific characteristics, which were aimed at targeting the recruitment of specific neural resources associated with specific stages of information processing (perceptual / memory and decision making), as well as the modalities through which information is processed (visual and auditory). Their selection was based on the Multiple Resource Model developed by Wickens (2008) since resources used for perception and memory are believed to differ from those used during decision making; as are those used for the processing of visual and auditory information. Two main factors were considered when selecting the specific features of the cognitive tasks, participant responses and task complexity:

All responses to the cognitive tests were required to be vocal and in English. This was done for two reasons. Firstly, to control the type of neural resources recruited during the response execution stage of information processing. According to Wickens (2008) manual and vocal responses target different attentional resources. The impact of different types of response executions is beyond the scope of this project as the focus was limited to investigating the impact of different sensory modalities and stages of information processing. Secondly, since, during the dual-task test conditions, participants were required to perform a continuous physical task in combination with the cognitive tasks, the protocol required that all cognitive tasks did not disrupt the continuous movement of the physical task (for example, having to let go of the object lifted in order to execute a motor response for the cognitive task). Consequently, all cognitive tasks chosen allowed for verbal responses.

Given that task complexity impacts the demand placed on attentional resources (Wickens, 2008) an effort was made to match all cognitive tasks in complexity, when performed in isolation. This was carried out by analysing perceptual ratings of difficulty and heart rate variability responses during a variety of cognitive tasks performed in explorative studies. Heart rate variability was measured using a Suunto heart rate monitor. Results indicated no significant difference ($p>0.05$) in perceived effort ratings or heart rate variability between all cognitive tasks selected for the current study. Heart rate variability was selected as a measure as it has gained widespread acceptance as a measure of mental effort (Irwin e*t al*., 1998). Heart rate variability has been described as the variation over time of the period between consecutive heart beats (Acharya *et al*., 2005), as well as the degree of fluctuations around the mean heart rate (Karim *et al*., 2011). Many researchers have suggested that heart rate variability is associated with cognitive demand and that it is sensitive to changes in mental effort (Mulder and Mulder, 1981; Veldman *et al*., 1992; Luft *et al*., 2009). Decreased heart rate variability is an indicator of increased mental effort and thought to result from increased stress and increased concentration demands (Elliot *et al*., 2011). This theory was used for the selection of the cognitive tasks used for the current study.

Visual and auditory decision making tasks

Decision-making tasks were selected as neuroimaging studies have implicated the anterior cingulate cortex during the performance of decision making tasks (Swick and Jovanic, 2002). Studies show that the anterior cingulate cortex is activated during conflict detection and response selection, as well as directing attentional focus on relevant stimuli (Weissman *et al*., 2005). This is of importance as the anterior cingulate cortex is the area of the brain in which motor control, homeostatic drive, emotion and cognition converge (Turken and Swick; 1999; Critchley *et al*., 2003; Marcora *et al*., 2009). The decision-making stage of information processing was therefore chosen in an attempt to target the area of the brain where motor control and cognition converge.

Both the visual and auditory decision making tasks were selected based on an n-Alternative-Forced-Choice recognition paradigm as described by Wigget and Davies (2010). These tasks required participants to recognize stimuli and then to decide on the appropriate response from n alternatives (Wigget and Davies, 2010; Insabato *et al*., 2014). Choosing between given alternatives represents a large class of real world decision-making problems faced by humans (De Lucia *et al*., 2010; Poulakakis *et al*., 2010) and such paradigms are a common tool used for investigating decision-making processes (Kristi *et al*., 2010; Poulakakis *et al*., 2010; Yu, 2014).

The visual decision making task selected was the incongruent Stroop-colour word test. The Stroop test is widely used in cognitive studies and has long been considered an index for cognitive control (Fellows and Farah, 2005; Swick and Jovanic, 2002). This test was considered appropriate for the current study as it has been associated with mental demands (Fredericks *et al*., 2005; MacDonell and Keir, 2005). Specifically, the incongruent condition was chosen for this task as studies have indicated that the cognitive processes involved in completing the test include conflict detection and resolution, forcing the participant to make a decision (Weissman *et al*., 2005).

During this task participants were presented with a table containing a variety of colour names displayed in an incongruent ink colour, for example “yellow” printed in blue ink. This was displayed using a Powerpoint slideshow on a computer monitor placed in front of the participants directly in their line of vision. Each block was 15mm x 30mm as deemed acceptable during pilot studies. Participants were instructed to call out the colour of the ink in which the text was written. It was requested that this response was loud, continuous, and from left to right, starting with the top row and moving downwards for the 3-minute duration of the condition. Once one table was completed, the researcher immediately presented participants with a new slide (lined up in the slideshow), which contained a new table with a different set of colour names. An example of the display presented to participants is shown below in Figure 9.

RED	YELLOW	BLUE	GREEN	BLACK
PINK	ORANGE	BROWN	GRAY	PURPLE
GREEN	GRAY	BLACK	BLUE	YELLOW
GRAY	BROWN	PINK	ORANGE	BLUE
YELLOW	RED	GREEN	BLACK	GRAY
BLACK	BROWN	PURPLE	ORANGE	PINK
PURPLE	BLACK	YELLOW	RED	GREEN
ORANGE	PINK	BROWN	GRAY	PURPLE

Figure 9: Example of the incongruent version of the Stroop Test

A sound categorisation task was selected as the auditory decision making task. Humans are constantly exposed to environments where fast and accurate identification of sounds are essential for communication and navigation of tasks, and the process of which implies making choice i.e. making a decision (De Lucia *et al*., 2012). A sound categorisation task was therefore selected as it required participants to engage in decision-making. During this task participants were played a variety of sounds produced either by humans (for example, sneezing, coughing or talking), musical instruments (such as the banjo, piano and trumpet), animals (for example, lion, monkey or snake) or environmental sounds (such as thunder, a flowing river or the ocean). Participants were asked to identify which category the sound belonged to. Four sound categories were specifically chosen as exploratory studies found that these allowed the complexity of this task to be matched to that of the visual Stroop task.

Sounds were selected from an on-line-library (http://marcellm.people.cofc.edu/confrontation%20sound%20naming/confront.htm) containing a database of everyday, nonverbal, digitized sounds that has been developed by Marcell *et al*. (2000) for the use in auditory naming applications. The database contains 120 sounds of varying lengths which were selected based on normative data, gathered from several studies performed on university students regarding the impact of familiarity, complexity, pleasantness and duration, on naming accuracy (Marcell *et al*., 2000). Results showed that naming accuracy was correlated with familiarity and complexity, but not with pleasantness or duration; therefore, all sounds selected for the current study were had similar familiarity and complexity ratings. This ensured that the most familiar sounds were selected for the current study and minimized the impact of unknown sounds on the accuracy/performance of the task.

Sounds were played in random order to the participants and they were requested to classify each sound into one of four categories, namely, musical instruments, human sounds, animal sounds or environmental sounds directly after hearing it. This was done continuously for the three-minute duration of the condition. No sound was repeated to the same participant to ensure there was no learning effect. All sounds were played through a computer with sound settings of a bit depth of 24 bit, audio output of 100 percent, and sampling rate of 48000 Hz. This was done to ensure that the sounds were played at a consistent volume for all participants.

Visual and auditory memory task

The visual and auditory memory tasks were selected to specifically target the neural resources involved in the perceptual and working memory processes of information processing (Wickens, 2002). As with the decision making tasks, the anterior cingulate cortex has been implicated in memory consolidation and the formation of memories regarding new information (Einarsson and Nader, 2012).

Both the visual and auditory memory tasks required participants to recall a seven-digit number. Numbers and words were originally considered for both tasks as they were both compatible with the visual and auditory conditions. Numbers were chosen as opposed to words as they were perceived as more neutral by participants during exploratory studies, whereas participants tended to associate certain words with personal experiences and found it easier to remember some words better than others. For the same reason, all numbers were displayed in black ink on a white background which allowed for good contrast and easy reading. Any interference from individual preferences or emotional association with specific colours or words was therefore minimized as colour and certain words have been found to trigger different emotions in individuals and therefore impact visual communication (Takahashi and Kawabata, 2013). It was decided that seven digit numbers would be displayed to participants since exploratory studies indicated that this resulted in no significant difference in complexity to both the visual and auditory decision making tasks in terms of heart rate variability responses as well as perceived difficulty.

During the visual memory task numbers were displayed in a likewise manner to the Stroop task using a Powerpoint slideshow on the same computer monitor. Numbers were displayed for 15 seconds, followed by the presentation of a blank slide. Participants were required to wait quietly for 30 seconds before being requested to recall the numbers vocally to the best of their ability. A lag period of thirty seconds was selected as it has been suggested that this is the duration of short-term memory (Wickens, 1985). After this, a new set of numbers was displayed and the same procedure repeated continuously for the 3-minute duration of the task. The same procedure was followed for the auditory memory task, except the numbers were read out to the participant by the researcher as opposed to being visually displayed. During this time the researcher ensured that background noise was limited and placed great emphasis on pronouncing the numbers loudly and clearly.

Selection of the physical task

A repetitive self-paced lifting and lowering task was as the physical task for the current study. Regular physical job demands often result from manual materials handling (MMH). MMH refers to the transporting or supporting of any load, and occurs in almost all work environments from factories and warehouses to offices (European Agency for Safety and Health at Work, 2007). In MMH industries lifting continues to dominate the risk for development of LBDs (Marras *et al*., 2006) and remains the most common task associated with work related injuries (Wrigley *et al*., 2009). The following variables were controlled to standardize to the protocol, reduce unwanted variance as far as possible and minimize the level of fatigue associated with the lifting task. It is understood that under fatiguing conditions, the motor control system of the body will adapt, often resulting in the performance of inappropriate muscle sequencing, (Brereton and McGill, 1999). Changes include the activation of secondary muscles or the alterations in recruitment of primary muscles, such as, changes in the timing, duration and degree of muscle activation (Gorelick *et al*., 2002; Radwin *et al*., 2002; Olson, 2010). These alternative muscle recruitment strategies, or substitution patterns, are an attempt to redistribute stress and replace or compensate for fatigued tissues (Brereton and McGill, 1999). It was therefore important to minimize the level of fatigue associated with the lifting task during this study to ensure that any alterations in movement and muscle recruitment patterns observed during the protocol could be attributed to the addition of a cognitive task rather than muscle fatigue.

Lifting frequency

A self-paced task was chosen as opposed to a controlled paced task for several reasons. Firstly, a self-paced task minimized the cognitive workload associated with the physical activity as participants were not required to concentrate on a metronome. Participants indicated during exploratory studies that a metronome was highly distracting when trying to perform the cognitive tests. Secondly, a self-paced task allowed for measures of physical performance by examining the number of lifts performed under each test condition. Participants were instructed to lift at the rate they would adopt during an eight-hour work shift. Thirdly, a self-paced task allowed for task demands to be matched to individual capability levels thereby minimizing variability in muscle fatigue. Lastly, in realistic work environments, many jobs allow workers to select their own work pace (Lee and Mattison, 2012).

Placement of box and lifting height:

The box was originally positioned at knee height and 5cm in front of the participants' ankles. Knee height was chosen as research has shown that from knee height and above participants tend to adopt more of a stooped posture, thereby activating the back and core muscles more (Davis *et al.*, 2002). This was relevant to the current study as the focus was on movement quality in relation to the spine. Once lifted, the box was placed on a table directly in front of the participant at a set horizontal distance of 40cm from the participants' ankles, and matched to the individual elbow height of each participant, as elbow height is considered to be an optimal working height

(Lavender *et al.*, 2003). This also allowed the lifting height to be relativized to the stature of participants. The box was then lowered to its original starting position. The starting distance of 5cm and placement distance of 40cm were standardized according to a study conducted by Lavender *et al.* (2003) and were confirmed as appropriate during explorative studies as they did not require any extensive reaching or twisting from participants.

Box lifted:

All participants continuously lifted and lowered a box measuring 40cm length x 20cm width x 20cm depth in size. The box handles were positioned 18cm above the base of the box on either side to ensure participants could easily grip the box during the lifting and lowering task.

Load lifted:

Participants were required to lift and lower a load equal to 4% of their maximal back strength, which resulted in the average load lifted being equal to 3.3kg (±1.47kg). This allowed the physical task to be relativized to the individual capabilities of each participant. The load generated by calculating 4% of each individual participant’s maximum back strength measurement recorded during their back strength test. The test required them to stand with knees fully extended and trunks flexed over the dynamometer and pull until their perceived maximal effort. Although not consistent with a realistic work environment where workers would be exposed to a certain load regardless of capabilities, this was done to minimize the impact that varying levels of fatigue between individuals may have on measured responses. This made it possible to attribute changes in movement to the addition of a cognitive task rather than muscle fatigue. A load of 4% of maximum back strength was chosen based on the results of exploratory studies, which aimed to determine a load that required a low, but meaningful, level of physical effort, but did not fatigue participants as muscle fatigue impacts muscle recruitment and movement patterns. Exploratory studies were performed on novice lifters, with no history of LBD, during which participants were required to lift loads of 4 and 8% of their maximal back strength during a self-paced lifting task. Participants repeated the lifting task 5 times, with 5 minutes rest between each cycle in order to replicate the physical conditions required for the current study. At a load of 8% of maximum strength, significant strength decrements were observed between trials and local RPE ratings reached 18 on the Borg Scale. No significant strength decrements were observed after completion of all trials at a load of 4%, and RPE ratings remained between 7 and 10 on the Borg Scale. This indicated that a load of 4% resulted in some exertion (very light to light) and minimal muscle fatigue. The load was also deemed as acceptable by participants.

Lifting style:

Participants were allowed to adopt a “free” lifting style (employing their preferred lifting technique). This was selected over a pure squat or stoop style as under realistic lifting conditions individuals have been found to adopt a combination of a squat and stoop style, and restricting lifting style may therefore not be applicable to realistic lifting conditions (Davis *et al*., 2002). A “free” lifting style also allowed for any variation in lifting style due to the addition of a cognitive task to be observed and type of style adopted by each participant during each task to be recorded for the purpose of analysing results.

Selection of dependent variables

Cognitive performance (accuracy and work output), physical performance (work output), perceptual responses (ratings of perceived physical exertion and subjective mental workload) and physical responses (spinal kinematics and muscle activity) were selected as the dependent variables for the current study. The justification for the selection of these measures is provided below.

Performance responses

Both cognitive and physical performance were measured to establish whether either the cognitive or physical task was compromised when simultaneous physical and cognitive task execution took place. It has been found that when concurrent task implementation takes place, performance decreases in that reaction time and error rate increases (Klingberg & Roland, 1997). Therefore, performance measures were used to determine whether any decline in performance occurred due to simultaneous cognitive and physical demands as this could provide insight into the effect of such dual-task conditions on worker productivity.

Cognitive performance was measured in terms of accuracy (number of correct responses completed by each participant during all conditions), as well as work output (total number of responses completed by each participant for each task during each “decision-making only” and “decision-making + physical”) experimental condition.

Since both the visual and auditory decision-making tasks were continuous it was assumed that the number of responses was directly linked to the response time of participants and provided an indication of how fast participants were able to process information. Only the decision making tasks were analysed as the memory tasks were performed according to set 45 second intervals. The accuracy of cognitive performance for each type of cognitive task was measured as follows:

- Memory tasks: Number of correct numbers recalled in each sequence presented either verbally or visually to the participants during the protocol.
- Stroop test: Number of correct colours called out by participants.
- Sound recognition: Number of correct responses called out by participants.

All measures were taken according to the participants' first response (any corrections made by participants after their first response was counted as an error).

Physical performance was measured as the total number of lifts performed throughout the 3-minute duration of each condition.

Perceptual responses

Ratings of mental workload and perceived physical exertion were measured to provide information regarding the subjective impact of the different work tasks such as perceived exertion or the task difficulty an individual experiences. This allowed for an understanding of subjective symptoms and how these related to objective findings under the same conditions.

Mental workload and local ratings of perceived exertion (specifically the lower back) were measured using the Subjective Workload Assessment Technique (SWAT) and Borg RPE scale upon completion of each 3-minute-long condition. Participants were presented with both scales upon the completion of each condition and asked to vocally rate their mental and physical effort. It must be noted that, since these are subjective measure its ability to indicate exertion/workload is dependent upon the participants' ability to accurately perceive their level of effort (Stanish and Aucoin, 2007). Accurate ratings of perceived effort could have been affected by the participants' understanding of the scale as well as motivational levels. Since the protocol involved nine consecutive test conditions monotony or boredom may have impacted task perception.

The Subjective Workload Assessment Technique

The Subjective Workload Assessment Technique (SWAT) was used to assess subjective time pressure load, mental effort load and psychological strain. Participants were asked to rate each of these on a scale of one to three with one being “low”, two “moderate” and three “high” ratings. The SWAT is a commonly used tool for measuring perceptions of mental workload (Luximon and Goonetilleke, 2001). This technique provides a subjective assessment of time load, mental effort load and psychological strain and has been found to be sensitive to changes in objective task difficulty, it highly correlates with performance and is non-intrusive (Rubio *et al*., 2004). This measure has also been specifically recommended for analysing the amount of cognitive demand and attentional resources required by a particular task (Rubio *et al*., 2004).

The Borg Scale

The Borg Rating of Perceived Exertion (RPE) Scale was used to measure feelings of local muscular effort and strain and discomfort, specific to the lower back and legs. Pain or discomfort is a common symptom of muscular strain and therefore allows muscle fatigue to be subjectively measured (Stanish and Aucoin, 2007). The scale ranges from a value of 6, representing minimal strain, to a value of 20, representing maximum strain (Borg, 1998) and is constructed on the principle that an individual’s perception of effort is based on the subjective analysis of information regarding the internal and external environment of the body (Utter *et al*., 2007). Such information includes afferent signals regarding metabolite accumulation within muscles, temperature and mechanical stress (Marcora *et al*., 2009). Furthermore, RPE has been highly correlated with mechanical markers of fatigue such as blood lactate concentration and VO_{2max} during exercise (Marcora *et al*., 2009). This has therefore been found to provide a good estimate of exertion level and reliably indicates an individual’s tolerance for exercise. However, being a subjective measure, it is limited in terms of how accurately individuals can rate their perceived exertion, as well as individual experience with the scale and mood at time of testing (Stanish and Aucoin, 2007).

Physical responses

Spinal kinematics and muscle activity were measured used to gain information regarding the movement quality and muscle activation patterns of participants due to dual-task demands. The movements and level of muscle activity involved in lifting is an important factor when considering the risk of musculoskeletal injury as increased trunk moments, velocities, accelerations, trunk muscle co-activity and muscular force are all linked to increased spinal loading (Davis and Marras, 2000). Analysing spinal kinematics and muscle activity provides a way to track the coordinated patterns and variation of dynamic trunk movements and provide an indication of the degree of muscle activation of selected muscles of the trunk and lower extremity during a lifting task (Wrigley *et al*., 2005).

Spinal kinematics and muscle activity were measured using the Lumbar Motion Monitor (iLMM^{TM}) and Biometrix Ltd Datalogger surface EMG equipment respectively.

Figure 10: Biometrix Ltd Datalogger (left) and Lumbar Motion Monitor (iLMM^{TM}) (right). (Images were adapted from: http://www.biometricsltd.com/datalog.htm and http://edge.rit.edu/edge/P10010/public/Establish%20Target%20Specificatio

Spinal kinematics

Dynamic motion characteristics of the trunk were measured using the Lumbar Motion Monitor (LMM). The LMM is an exoskeleton of the spine that is attached to participants and secured against the torso by means of a harness (David, 2005). It poses no risk to individuals and allows for data regarding instantaneous changes in trunk position, velocity and acceleration to be obtained in a 3-dimensional space (Marras *et al*., 1993) with minimal obstruction to participants' movement (Marras, 2009). The LMM is regarded as a reliable tool that can be used to provide highly accurate data on a range of variables (David, 2005). Once adjusted to the frame size of each participant, the LMM was strapped tightly onto the participant's back such that it ran parallel to the spine. The upper harness was placed between the shoulder blades and strapped over the shoulders and crossed over the chest. The straps were then adjusted to the body size of each participant. The lower harness was fitted around participants' hips whilst the participant stood upright. Once the top of the lower harness was positioned in line with lumbo-sacral joint (L5/S1) the leg and waist straps were tightened to ensure the LMM was securely fitted onto the participant. Once fitted, participants were asked to flex and extend their trunk to ensure that the LMM was in fact adjusted to the correct size.

Spinal kinematic data regarding the positions, velocities and accelerations in the frontal (lateral), sagittal and transverse (twisting) movement planes were recorded during the completion of the physical task in isolation and in combination with each cognitive task. However, given that the physical task was a lifting and lowering task involving repetitive trunk flexion and extension the primary analysis of spinal kinematic data during this investigation was delimited to the sagittal plane. This was analysed by comparing measures during each dual-task condition ("physical + cognitive") to those during the baseline measurement ("physical only") task. Specific measurements considered included:

Measurements considered included:

a) Sagittal plane

- Total range of motion: Determined by calculating the range between the maximum and minimum sagittal position reached by reached participant during each lift. This measure was selected as increases in range of motion may lead to an increased external moment about spine and therefore increase in both the external forces acting on the spine as well as the counter-balancing internal muscles forces (Ferguson *et al*., 1992). Therefore, the range of motion reached during a lifting task may provide an indication of the associated risk of injury.
- Variability in range of motion: Calculated as the coefficient of variation in total range of motion between each lift performed by each participant. This measure was selected as variance in the range of motion could indicate sudden or unfavourable movement strategies.
- Maximum trunk flexion and maximum trunk extension: Measured as the maximum and minimum sagittal position reached during each lift performed by each participant. The maximum and minimum values were used to observe the

extremes reached by each participant. These measures also provide more insight into the “total range of motion” measure as no change in the total range of motion may not necessarily mean that no change in maximum or minimum position was observed. For example, maximum position may have increased and minimum position decreased resulting no change in the total range of motion, but still increasing the external moment placed on the spine.

- Relationship between total range of motion, variability in range of motion and maximum trunk flexion and extension: Determined by use of correlations between measures to determine if an increase in total/variability in range of motion was associated with either increased trunk flexion or extension.
- Maximum velocity reached during each lift by each participant. Selected as measure of movement quality as increased velocities are associated with increased spinal loading (Davis and Marras, 2000).
- Maximum acceleration reached during each lift by each participant. As with increased velocities increased spinal loading is associated with increased and therefore this measure (Davis and Marras, 2000).

b) Frontal and transverse planes

  - Maximum and minimum positions reached during each lift performed by each participant. This was done to observe if any asymmetrical lifting strategies occurred during dual-task scenarios as an increase in asymmetrical movements may result increased spinal loading (Davis and Marras, 2000).

Muscle activity

Muscle activity was measured as the average degree of muscle activation of each selected muscle over the 3-minute duration of each test condition. Muscle activation was calculated as a percentage of the maximum voluntary exertion performed by participants for each muscle.

The muscle activity of the Erector Spinae, Rectus Abdominus, Biceps Femoris and Rectus Femoris muscles on the dominant side of participants were measured. Only the dominant side was measured due equipment limitations as too much interference and cross-talk resulted from the use of eight electrodes. Pilot studies also indicated no significant bilateral differences in muscle activity during dual-task demands. The erector spinae muscle was selected as this is the main trunk extensor (Shirado *et al*., 1995), while rectus abdominus was selected in order to observe agonist and antagonist muscle activity. The biceps femoris and rectus femoris muscles were selected to observe the interaction between the spine and the hip during trunk flexion and extension as well as any possible differences in lifting strategies between test conditions (Kankaanpa *et al*., 1998). Some strategies could be associated with greater upper leg involvement involving differences in activation of the hamstrings and quadriceps and muscles, relying less on the erector spinae muscles (Zhang and Burh, 2002).

Surface electromyography (sEMG) was selected to measure muscle activity as this technique allowed for a non-invasive and objective measure of muscle function (Oddsson and De Luca, 2001). sEMG has gained considerable popularity in assessing the muscular activation and involvement of the human body during occupational work (Yoshitake *et al*., 2001). This is a safe technique which involves placing electrodes onto the surface of the skin over the underlying muscle to measure the muscle’s electrical activity between contraction and relaxation cycles (Yoshitake *et al*., 2001). sEMG can be used for the objective quantification of the energy of muscles, muscle activation and recruitment patterns (Yoshitake *et al*., 2001; Criswell, 2011), allowing the timing, duration and degree of muscle activation to be observed from rest throughout the course of a movement (Corcos *et al*., 2002; Criswell, 2011). It must be acknowledged though that the accuracy of this technique can be negatively influenced by poor electrode placement, variations in the type of EMG equipment used, interference and cross talk, and poor cleaning and preparing of the skin before electrode attachment (Fabio, 1987; Mannion *et al*., 1997). However, despite these limitations sEMG has been shown to be a reliable and valid measure with regards to muscle activity (Minning *et al*., 2005).

Electrodes with conduction gel were placed on the participants for EMG analysis. The areas of electrode placement were shaved and cleaned with alcohol before the electrodes were placed onto the skin to minimize interference with the electrical signal. Electrodes were placed on the following muscles:

The right Erector Spinae, Rectus Abdominus, Biceps Femoris and Rectus Femoris muscles were palpated and electrodes were placed on the belly of these muscles parallel to the muscle fibers, as this provides the strongest electrical signal (Basmajian, 1967). Inter-electrode distance was 3cm and the exact positioning of electrode placement was 3cm laterally from the midline at the level of L2 for the Erector Spinae muscles, 3cm laterally from the umbilicus for Rectus Abdominus, midway between the ischial tuberosity and lateral femoral epicondyle for Biceps Femoris, and midway between the anterior iliac and the superior border of the patella for Rectus Femoris. This placement of electrodes was chosen based on a study by Silfies *et al*. (2005).

Maximal voluntary contractions (MVCs) were recorded for all selected muscles before the start of the testing protocol, and used as a reference for sEMG analysis. Although the use of MVCs has received criticism as a measurement of maximal effort, as force produced during eccentric muscle exertions may be greater than during an isometric exertion (Moynes *et al.,* 1986; Mirka, 1991; Sherman, 2003) this still remains the most common method of normalizing EMG (Halaki and Ginn, 2012). There is a debate about whether isometric contraction can be used to obtain reference EMG levels for use during dynamic tasks (Halaki and Ginn, 2012) as some research has found that the EMG levels change with muscle length (Yack *et al*., 1981; Pincivero *et* al., 2004) while other studies indicate that joint angle has little effect on maximum EMG levels (Leedham and Dowling, 1995; Kasprisin and Grabiner, 1998) or that there is no consistent pattern of change in the EMG levels with joint angle (Barr and Barbe, 2002; Mohamed *et al*., 2002). To address this potential problem, it has been recommended that maximum dynamic (usually isokinetic) contractions be used to obtain reference EMG levels in order to normalize EMG data obtained during dynamic tasks (Mirka ,1991; Sheppard, 2012). In this method, the individual performs a maximum isokinetic contraction at a speed similar to the dynamic task under investigation. However, this normalization method has been shown to have low within subject reliability (Halaki and Ginn, 2012) and, because EMG is depended on the velocity of movement for a given force level, normalization curves need to be generated for different speeds of movement (Halaki and Ginn, 2012). Furthermore, However, it must be noted from the research above that the researchers established dynamic tasks as tasks in which the participants were required to sprint (for example during activities like cricket) or exert an “all-out effort” (Mirka, 1991; Sheppard, 2012). Manual material handlers perform their tasks at self-selected pace as opposed “sprint-like” effort. Therefore, MVCs were considered to be suitable as reference/baseline readings. Each of these contractions were performed for 5 seconds and based on the protocol by Gross *et al*. (2010) as follows:

- Erector Spinae muscle: The participant was requested to lie prone on a mat on the floor with arms placed at the side. The researcher applied a downward resistance at the level of the pelvis and middle of the back, while the participant attempted to raise the neck and sternum off the mat.

- Rectus Abdominis muscle: The participant was requested to lie in the supine position on the mat on the floor, with his/her hands clasped behind the head. The researcher pressed down on the anterior aspects of the participant’s thighs in order to stabilize the lower extremities while the participant was required to perform a curl-up ensuring that the scapulae were lifted off the mat.

- Biceps Femoris muscle: The participant lay prone on a mat on the floor with knees extended as the hamstring muscles are strongest during knee extension. The researcher applied a downward pressure at the level of the pelvis and posteriorly on the thigh just above the knee, while the participant attempted to elevate the legs off the mat.

- Rectus Femoris muscle: The participant sat upright on a table with the lower legs hanging over the edge and with hands holding onto the edge of the table for support. The participant extended his/her knee while the researcher applied a resistant force.

PERMUTATION OF CONDITIONS

As this research used a repeated study design, it was necessary to permutate conditions. This was done to minimize any learning effects, fatigue and task aversion.

The permutation of conditions was based on a rule to alternate any condition containing a physical task with a condition consisting of only a cognitive task. This ensured that there were never two conditions with a physical component directly following one another. This was done to minimize physical fatigue and the risk of overexertion since the physical task was identical for all conditions and repeated 5 times during the testing protocol. The cognitive tasks theoretically drew upon different attentional resources and it was therefore deemed acceptable to have two cognitive conditions following one another. Since nine conditions were tested during this study, a complete set of permutations based on the above rule would have resulted in 2880 variations which would not have been feasible. The order in which the test conditions were permutated separately for all conditions involving all conditions containing the “physical task” (Table ii), and then for all conditions involving “cognitive only” tasks (Table iii), after which the conditions were arranged. Permutations ensured that each condition was placed in each position of the sequence once. This is demonstrated below.

Table ii: Permutations for all conditions involving the physical task

Combination	**Position in sequence**				
	1	**2**	**3**	**4**	**5**
1	Auditory memory + physical	Auditory decision making + physical	Visual memory + physical	Visual decision making + physical	Physical
2	Auditory decision making+ physical	Auditory memory + physical	Visual decision making + physical	Physical	Visual memory + physical
3	Visual memory + physical	Physical	Auditory decision making + physical	Auditory memory + physical	Visual decision making + physical
4	Visual decision making + physical	Visual memory + physical	Physical	Auditory decision making + physical	Auditory memory + physical
5	Physical	Visual decision making + physical	Auditory memory + physical	Visual memory + physical	Auditory decision making + physical

Table iii: Permutations for cognitive only conditions

Combination	**Position in sequence**			
	1	**2**	**3**	**4**
1	Auditory memory	Auditory decision making	Visual memory	Visual decision making
2	Auditory decision making	Auditory memory	Visual decision making	Visual memory
3	Visual memory	Visual decision making	Auditory decision making	Auditory memory
4	Visual decision making	Visual memory	Auditory memory	Auditory decision making

Each “cognitive only” combination was then combined with each “physical” combination, ensuring each physical and cognitive only condition appeared in each position once. Since there were five tasks containing the “physical condition” and only four “cognitive only” tasks, each combination started with a condition containing the “physical task” thus permitting alternating between the “physical” and “cognitive only” tasks. As a result, physical conditions were allocated positions 1, 3, 5, 7 and 9 and cognitive only tasks were allocated 2, 4, 6 and 8. A matrix of 20 permutations was developed as follows:

Table iv: Permutations for all conditions

Combin-ation	**Position in sequence**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	AM + P	AM	AM + P	AD	VM + P	VM	VD + P	VD	P
2	AD+ P	AM	AM + P	AD	VD + P	VM	P	VD	VM + P
3	VM + P	AM	P	AD	AD + P	VM	AM + P	VD	VD + P
4	VD + P	AM	VM + P	AD	P	VM	AD + P	VD	AM + P
5	P	AM	VD + P	AD	AM + P	VM	VM + P	VD	AM + P
6	AM + P	AD	AM + P	AM	VM + P	VD	VD + P	VM	P
7	AD+ P	AD	AM + P	AM	VD + P	VD	P	VM	VM + P
8	VM + P	AD	P	AM	AD + P	VD	AM + P	VM	VD + P
9	VD + P	AD	VM + P	AM	P	VD	AD + P	VM	AM + P
10	P	AD	VD + P	AM	AM + P	VD	VM + P	VM	AD + P
11	AM + P	VM	AD + P	VD	VM + P	AD	VD + P	AM	P
12	AD+ P	VM	AM + P	VD	VD + P	AD	P	AM	VM + P
13	VM + P	VM	P	VD	AD + P	AD	AM + P	AM	VD + P
14	VD + P	VM	VM + P	VD	P	AD	AD + P	AM	AM + P
15	P	VM	VD + P	VD	AM + P	AD	VM + P	AM	AD + P
16	AM + P	VD	AD + P	VM	VM + P	AM	VD + P	AD	P
17	AD + P	VD	AM + P	VM	VD + P	AM	P	AD	VM + P
18	VM + P	VD	P	VM	AD + P	AM	AM + P	AD	VD + P
19	VD + P	VD	VM + P	VM	P	AM	AD + P	AD	AM + P
20	P	VD	VD + P	VM	AM + P	AM	VM + P	AD	AD + P

Where:

“P” = Physical
“VM” = Visual memory
“AM” = Auditory memory
“VD” = Visual decision making
“AD” = Auditory decision making

“VM + P” = Visual memory + physical
“AM + P” = Auditory memory + physical
“VD + P” = Visual decision making + physical
“AD + P” = Auditory decision making + physical

SELECTION OF PARTICIPANTS

Twenty healthy male (n=10) and female (n=10) participants from the Rhodes University student population were recruited for this study. Participants ranged in age from 19 to 24 years. Recruitment was done via email and word of mouth. The permutation selected (Table iv) required a minimum of 20 participants to ensure that each permutation was performed at least once. Participant demographics are shown in Table v.

Table v: Mean demographic and anthropometric characteristics of the participants (Means ± standard deviation; coefficient of variation)

Back strength (kg)	**Stature (m)**	**Body mass (kg)**	**BMI**	**Number of active days per week**
79.80 ± 35.62; 44.63%	1.70 ± 0.96; 56.47%	67.25 ± 15.01; 22.32%	22.45 ± 3.14; 14.00%	3.80 ± 1.01; 26%

Inclusion criteria

Participants were required to be “novice lifters”, which meant having no history working in manual materials handling. This aspect was controlled as differences in fatigue patterns have been observed between novice and experienced lifters (Marras *et al*., 2006). Novice lifters were selected over experienced lifters as previous research has shown that experienced lifters have developed ingrained motor programs specifically for a lifting task (Marras *et al.*, 2006). With a high level of experience and developed motor programs it is likely that experienced workers can perform a lifting task automatically (Jefferys, 2008). Automation refers to the level of development where conscious attention is no longer required to produce a movement, with quality movement happening automatically (Jefferys, 2008). Evidence suggests that automation reduces mental workload and demands on attentional resources (Young and Stanton, 2002). Therefore, in a dual-task situation, automation of one task allows more resources to be allocated to the second task without comprising the performance of the first task (Glisky, 2007). Novice lifters have not developed sophisticated muscle recruitment patterns and it is therefore likely to observe greater dual task interference among inexperienced lifters. Furthermore, studies have indicated that the highest injury turnover is often observed among new workers, implying that inexperienced workers are at the greatest risk for developing injuries (Marras *et al*., 2006). Therefore, better understanding of the risks and demands imposed on inexperienced workers can lead to improved job training strategies, which in turn can lead to increased performance and decreased injury rates.

All participants were recruited from the Rhodes University student population to ensure similar education level. This was done to minimize the variability in cognitive performance between participants. Furthermore, participants had to be literate and able to speak fluent English as the visual and auditory information were presented in English and participants’ vocal responses during the cognitive tasks were expected in English.

Participants were required to be of similar age (19 to 24) years and had to have a minimum fitness level in order to minimize the risk of injury; as well as variance between participants and interference of muscular fatigue. All participants were required to be moderately trained, requiring them to exercise at least 3 days a week (Perri *et al*. 2012). Given that the physical task was a lifting task, this exercise had to include resistance training.

Exclusion criteria

Any participants with a history of low back pain, intervertebral disk, low back, shoulder, arm or hand injuries or who had surgery to the above-mentioned areas were excluded from the study, in order to minimize the risk of injury to participants as well as sample variance, since these body areas are directly involved in the execution of a lifting task. Differences in muscle fatigue and recruitment patterns, joint stability and task perception have also been observed between healthy individuals and previous patients with lower back disorder (Kankaanpaa *et al*., 1998; Silfies *et al*., 2005; Fabian *et al*., 2005). Apart from reducing risk for re-injury this also minimized the impact previous injuries may have had on the results obtained during the current study.

Any participants with deficiencies relating to attentional demand or suffered from learning difficulties such as Attention Deficit Disorder or dyslexia were also excluded from this study. Such disorders have been shown to decrease reading ability, memory, cognitive control and processing speed, which refers to the ability to efficiently and accurately respond to stimuli (King *et al*., 2012; Mahone, 2011). This was done to prevent any negative impact these disorders may have had on the performance of the cognitive tasks and therefore the results of this study.

ETHICAL CONSIDERATIONS

The study was approved by the Ethics Committee of the Human Kinetics and Ergonomics Department of Rhodes University. Prior to testing participants were informed about the aims of the study, the procedures involved and what was required of them both verbally and in writing (Appendix A1). Participants were also informed about all the risks and benefits of the study. After answering any questions they may have had to their satisfaction, the participants signed an informed consent form (Appendix A2), agreeing to voluntary participation in the study. Each participant was identified using a participant code, rather than full names to keep data anonymous and confidential. Participants were also informed that photographs may be taken during the protocol for illustrative and report purposes, but any identifying features would be obscured. This was only done with the participants' consent, which they voluntarily provided on a specific section of the consent form. Participants were reminded before and throughout the testing that they were free to terminate the testing at any point and there would be no negative consequences for them if this decision was made.

PROTOCOL

Once ethical approval was received, all testing took place in the ergonomics laboratory of the Human Kinetics and Ergonomics Department at Rhodes University. Participants reported for two sessions on two separate days. The first session was a habituation session during which the procedure was fully explained to the participants. Upon arrival, participants were briefed verbally and in writing about the purpose and the procedures of the study, as well as the risks and benefits associated with the protocol and their rights to optional withdrawal, anonymity and confidentiality. Participants were familiarised with all testing equipment, as well as the physical and cognitive tasks they would be required to perform during the protocol. Any concerns or unanswered questions were addressed. Participants then singed the informed consent form, following which, a questionnaire, containing questions about personal characteristics was completed (Appendix B). Basic demographic measurements (stature and mass) were then recorded. Finally, participants were requested to not consume any alcohol or caffeine (tea, coffee, coke. etc.) on the day of the second testing session, or perform any strenuous exercise 24 hours prior to the testing protocol.

During the second session all nine experimental conditions were performed. It was decided to not split the experimental conditions over two or more sessions to minimize day-to-day variance in responses, as well as variances that would come about through slightly different EMG electrode placement. The duration of each condition was set at three minutes. Explorative studies confirmed that three minutes was sufficient time to gain adequate information on physical responses and cognitive performance. It is important to emphasize that the design selected also aimed at preventing/minimizing the amount of physical fatigue experienced by participants. It is understood that under fatiguing conditions, the motor control system of the body will adapt, impacting movement patterns (Brereton and McGill, 1999). Therefore, in order to observe the impact of adding cognitive demanding tasks to a physical task on physical responses participants were not fatigued during the protocol. Given that three minutes is relatively short, this duration also minimized any muscular fatigue that may have been experienced by participants, and was perceived as acceptable by participants during explorative studies. Participants were given five minutes rest between conditions, as the exploratory studies, during which participants repeated the nine experimental conditions, indicated that five minutes was sufficient to prevent cumulative physical fatigue. This was tested by analysing heart rate frequency and maximal back strength responses using a back strength dynamometer after each set during explorative studies. Results showed that heart rate responses returned to resting values after 5 minutes. No significant differences in heart rate were observed between sets and no significant decrements in maximal back strength were observed after each 5-minute recovery period. The total duration of the experimental session was approximately 2 hours.

Upon arrival at the second session participants performed the maximal back strength test, during which they were required to stand with knees fully extended and trunks flexed over the dynamometer and pull until their perceived maximal effort (Beckham, 2004). Using the maximum force, the load to be lifted (4% of maximum strength) was calculated. Following this, the areas where the EMG electrodes were to be placed were then shaved and cleaned with alcohol. Electrodes were then placed on skin overlying the selected muscles (refer to “Physical Measures” for details of placement) and maximal voluntary contractions performed as reference measurements for sEMG activity. Following the completion of the muscular exertions, the Lumbar Motion Monitor was fitted to each participant, after it had been calibrated by the researcher to match the size of each participant. Finally, participants performed all nine test conditions according to the individual permutation, with a five-minute rest break between each condition. Upon completion of the protocol all equipment was removed and participants were given the opportunity to ask any further questions and voice any complaints.

STATISTICAL ANALYSES

Mean data

Analyses of mean data were performed using STATISTICA 10 (Statsoft Inc, 2010) software program. Descriptive statistics were initially carried out, followed by parametric statistics to determine significant differences of responses between experimental conditions. Selected performance, perceptual and physical responses from each dual-task scenario (physical task combined with selected cognitive task) were compared to either the physical or selected cognitive task performed in isolation (baseline measurement) for any overall differences/ general interactive effects due to concurrent physical and mental demands. This was done by comparing the average absolute values recorded during the dual-task scenarios to those at baseline using a dependent T-test. If a significant difference was found results were then further analysed firstly to assess the impact of sensory modality (verbal or auditory), and secondly to determine the impact of the stage of processing (memory or decision making) on this interaction through a two-factorial analysis of variance. For the sensory modality analysis this was done by comparing the mean percentage of responses during both visual dual-task ("memory + physical" and "decision-making + physical") to that of both auditory dual-task ("memory + physical" and "decision-making + physical") conditions, relative to their respective baseline measurements ("cognitive only" or "physical only"), while for the stage of information processing analysis this was done by comparing the mean percentage of responses during both memory dual-task ("visual + physical" and "auditory + physical") to that of both decision making dual-task ("visual + physical" and "auditory + physical") conditions, relative to their respective baseline measurements ("cognitive only" or "physical only"). The relative percentage changes were used as opposed to the absolute values for two reasons: 1) this isolated the change in performance from baseline due to the addition of the physical/ or cognitive task, and 2) given that each cognitive task was different, relative percentages allowed for the comparison between all dual-task conditions (for example the memory and decision making tasks, or the visual and auditory tasks could be combined and compared across the sensory modalities or stages of processing respectively. All statistical tests were conducted with a 95% confidence interval and significance was therefore identified at $p<0.05$.

Individual data

In addition to mean responses, individual responses were also considered in an attempt to improve the understanding of both intra and inter-human variability under the various test conditions. Typically, conclusions and recommendations during investigations regarding human performance have been based on mean response data. Although mean data is useful, it does not display variation between individuals when exposed to various conditions. The idea of the "average human" has been a defined a fundamental ergonomic fallacy (Pheasant, 1996). Since no two humans are identical human performance has been found to be influenced by a variety of factors, including but not limited to demographics, gender, personality type, cognitive abilities, work habits etc. leading to individually different responses (Borman and Schmit, 2009). These individual differences are often treated as a nuisance variable, yet understanding how different individuals interact with the varying circumstances found in today's complex work environments as well as recognizing individual differences in human capabilities and limitations is necessary to truly generate sound ergonomic guidelines (Karwowski *et al*., 2003). A purely mean based analysis may be insufficient to display significant differences in human responses under varying demands, which may not necessarily be the case when considering the responses of different individuals. Therefore, the consideration of individual responses could allow for a more comprehensive and realistic analysis of human performance as it may demonstrate how different individuals might be positive responders (exhibit improved responses), negative responders (exhibit worsened responses) or non-responders (exhibit no change in responses) under varying test condition. Individual responses were analysed by considering the individual percentage change of each participant during each dual-task ("cognitive + physical" task) condition relative to that of each respective baseline measurement ("cognitive only" or "physical only").

Correlations

A correlation analysis examining relationship between the individual percentage changes (from baseline to dual-task conditions) of all variables was performed. This was done in order to determine any direct associations between all measures or any possible trade-offs between cognitive and physical variables of interest. Research suggests that under dual-task demands individuals may compromise the performance of one task in order maintain or improve the performance of another task (Bray *et al*., 2011). All correlations were identified as significant at $p<0.05$.

CHAPTER IV:
RESULTS

This chapter displays and compares the performance, perceptual and physical (electromyographical and spinal kinematic) responses measured during each baseline and dual-task condition. The chapter specifically describes the mean and individual results of each dependent variable in terms of 1) a general interaction effect due to concurrent physical and mental/cognitive task demands, and if any significant interaction was observed, how it was impacted by 2) the sensory modality through which information is perceived, and 3) the impact of the stage of information processing which the mental/cognitive task targets. Refer to Chapter III for details of methods used for measurements and statistical analyses, and Appendix D for all statistical tables (Dependant T-tests, ANOVA's, Tukey Post-hoc and Correlations).

PERFORMANCE MEASURES

Both cognitive and physical task performance were analysed during this study. Cognitive performance was measured in terms of accuracy (number of correct responses) and work output (total number of responses), while physical performance was measured in terms of number of lifts completed during the 3-minute protocol.

Cognitive task performance (accuracy)

Table vi displays the mean absolute number of correct responses for each cognitive task performed in isolation ("cognitive only") and in combination with the physical lifting task ("cognitive + physical"). The results show that the number of correct cognitive responses decreased significantly ($p<0.01$) for each cognitive task with the addition of the physical task, compared to the cognitive task in isolation, thereby indicating an overall interference effect on cognitive performance accuracy.

Table vi: Number of correct responses performed for the cognitive task in isolation and in combination with the physical task (Means ± standard deviation; coefficient of variation)

	Cognitive only (baseline)	**Cognitive + physical**	**P-value**
Visual memory	27.45 ± 0.60; 2.20%	25.10 ± 0.79; 3.14%	<0.01 *
Auditory memory	27.10 ± 0.31; 1.14%	23.35 ± 0.75; 3.19%	<0.01 *
Visual decision-making	171.26 ± 7.88; 4.60%	113.20 ± 5.72; 5.05%	<0.01 *
Auditory decision-making	20.10 ± 1.45; 7.20%	17.10 ± 1.48; 8.67%	<0.01 *

** Indicates significance at p≤ 0.05*

The interaction presented above was further analysed to determine the impact of the 1) sensory modality (Figure 11) and 2) stage of information processing (Figure 12) on the dual-task interference, on cognitive accuracy. The results shown in Figure 11 and Figure 12 are calculated as a percentage of correct responses achieved during the "cognitive only" conditions. Displayed are the combined average responses during both visual dual-task (VM+P and VD+P) compared to both auditory dual-task (AM+P and AD+P) conditions (Figure 11), and both memory dual-task (VM+P and AM+P) compared both decision-making dual-task (VD+P and AD+P) conditions (Figure 12).

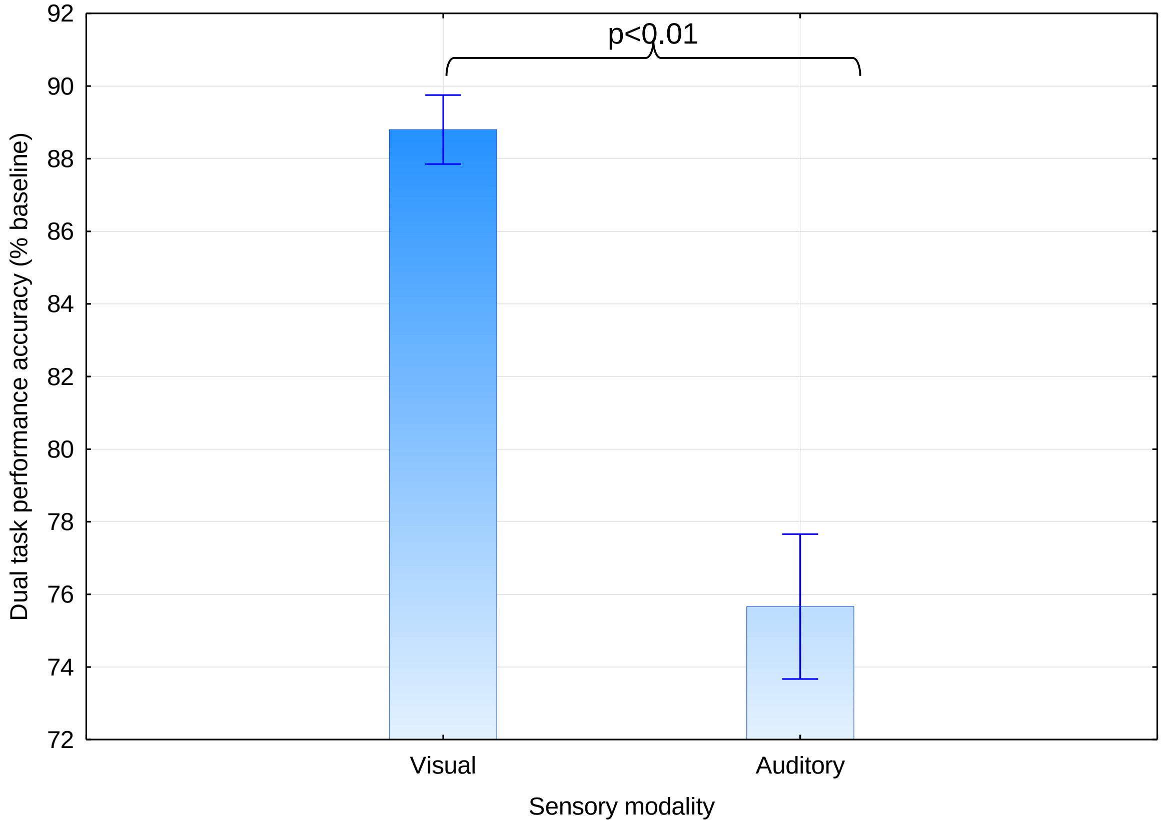


Figure 11: Percentage of correct cognitive responses for the different sensory modalities employed during dual-task conditions relative to baseline measures.

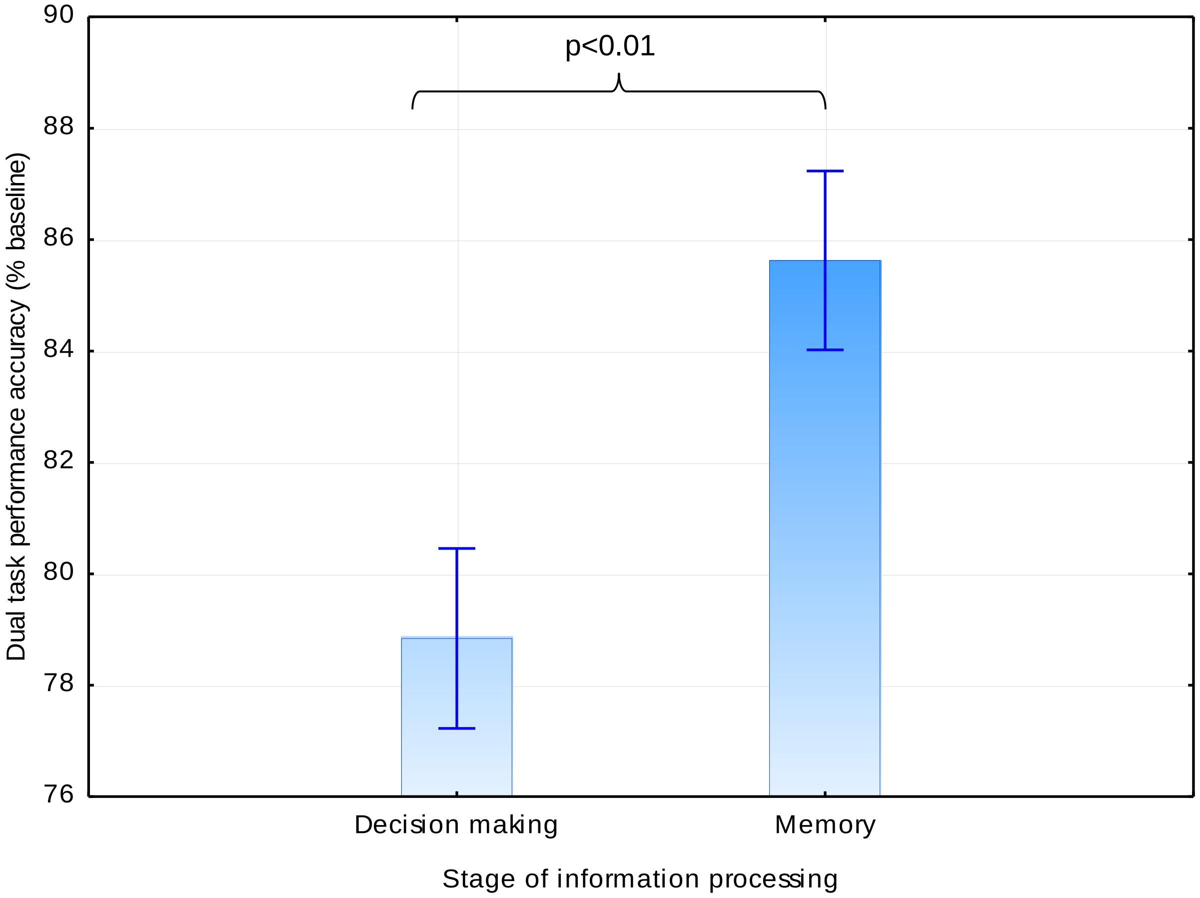
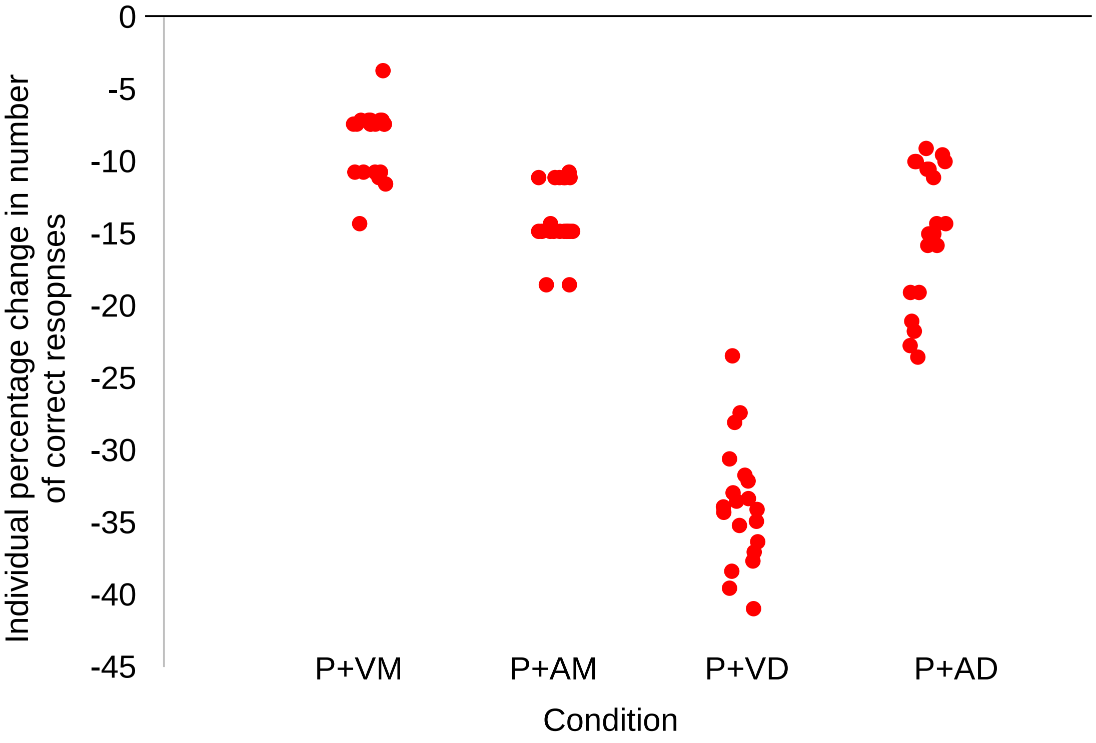


Figure 12: Performance accuracy for the different stages of information processing during dual-task conditions relative to baseline measures.

Figure 11 shows that the visual tasks had a significantly greater impact on dual-task performance than the auditory tasks ($p<0.01$). During the dual-task conditions using the visual modality cognitive performance accuracy decreased to 75.55 ± 2.02% (CV=2.67%) relative to the “cognitive only” (baseline) tasks (a 24.45% reduction in performance) and during the auditory dual-task conditions to 88.63 ± 1.00% (CV=1.13%) (a 11.28% reduction in performance). The decision-making tasks in Figure 12 were significantly more affected by dual-task performance than the memory tasks ($p<0.01$), with accuracy decreasing to 78.78 ± 1.01% (CV=1.28%) of the baseline measures during the decision-making dual-task conditions (a 21.22% reduction in performance) but only to 85.62 ± 2.00% (CV=2.36%) during the dual tasks involving memory (a 14.38% reduction).

Analysis of individual data is shown in Figure 13, which depicts the percentage change, from each “cognitive only” task, in correct number of responses during each dual-task test condition for each individual participant. All 20 participants demonstrated a decrease in cognitive performance accuracy for all cognitive tasks when that cognitive task was combined with the physical lifting task. It is also worth noting that the addition of a physical task appeared to have the largest impact on the “visual decision-making” task.



P+VM = “physical+ visual memory”
P+AM = “physical+ auditory memory”
P+AD = “physical+ auditory decision-making”
P+AD = “physical+ auditory decision-making”

Figure 13: Individual percentage change in correct cognitive responses during dual-task conditions relative to baseline measures

Cognitive task performance (work output)

The mean number of responses completed for the visual and auditory decision-making tasks performed in isolation (“cognitive only”) and in combination with the physical lifting task (“cognitive + physical”) are shown in Table vii. Since both tasks were continuous it was assumed that the number of responses was directly linked to the response time of participants and therefore higher the number of responses the faster/greater the work output. Only the decision making tasks were analysed as the memory tasks were performed according to set 45 second intervals and thus externally paced.

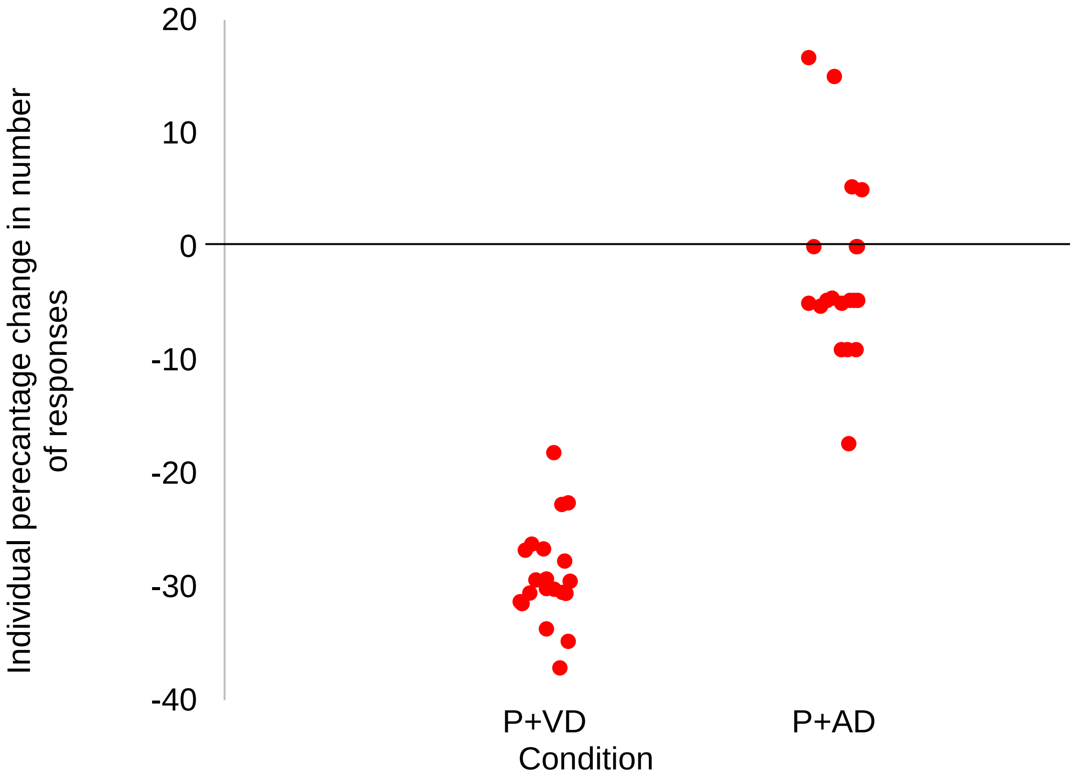
Table vii: Number of responses performed for the decision-making task in isolation and in combination with the physical task (Means ± standard deviation; coefficient of variation)

	Cognitive task only	**Cognitive + Physical Task**	**P-value**
Visual decision-making	173.11 ± 8.09; 4.63%	122.61 ± 5.75; 4.69%	<0.01 *
Auditory decision-making	20.63 ± 1.27; 6.14%	20.10 ± 1.07; 5.33%	0.98

** Indicates significance at $p \leq 0.05$*

The addition of the physical task resulted in a significant decrease in the number of responses work output recorded during the “visual decision-making” task, thereby indicating a significant decrease in working pace. Dual task performance did not significantly impact the work output of the “auditory decision-making” tasks.

The analysis of individual results are displayed in Figure 14 as the individual percentage change, in work output (number of responses) during each dual-task test condition relative to each “cognitive only” condition. All 20 participants demonstrated a decrease in work output during the “visual decision-making” task when performed concurrently with the physical lifting task. However, a range of responses (i.e. change in work output) were observed when the “auditory decision-making” task was combined with the physical task, where 14 participants demonstrated a decrement in performance, two showed no change and four increased their work output. It is also clearly illustrated that the overall decrement in performance was considerably greater for the dual task condition involving visual decision-making (ranging between 18.18 and 37.17%) than that involving “auditory decision-making (ranging between 4.45 and 17.39%).



P+VD = "physical+ visual decision-making"
P+AD = "physical+ auditory decision-making"

Figure 14: Individual percentage change in number of cognitive responses during dual-task conditions relative to baseline measures

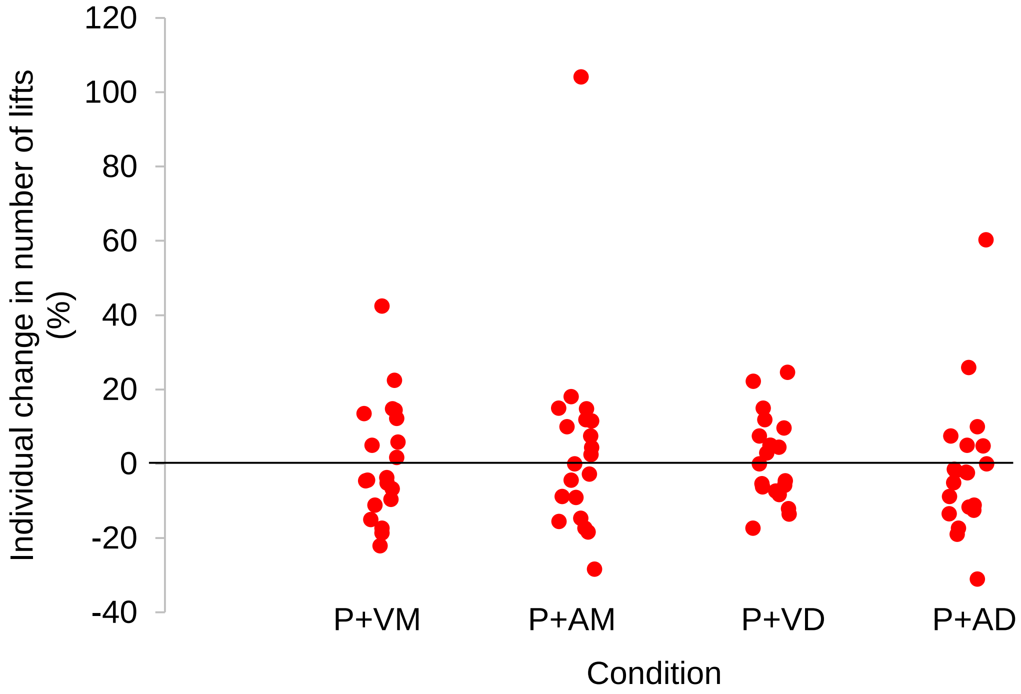
Physical performance

Table viii: Number of lifts performed for the physical task in isolation and in combination with the cognitive tasks (Means ± standard deviation; coefficient of variation)

Condition	**Number of lifts**	**P-value**
Physical only	55.80 ± 16.47; 29.51%	-
Physical + visual memory	56.35 ± 20.57; 36.51%	0.10
Physical + auditory memory	58.40 ± 26.99; 46.21%	0.85
Physical + visual decision-making	56.25 ± 17.46; 31.03%	0.10
Physical + auditory decision-making	54.55 ± 19.72; 36.15%	0.10

Compared to the "physical only" condition the average number of lifts completed increased slightly during the "physical+ visual memory", "physical+ auditory memory" and "physical+ visual decision-making" dual-task conditions increased, but decreased for the "physical+ auditory decision-making" condition. However, these changes were not statistically significant. Since no overall significant differences were found between baseline and dual-task conditions, results were not further analysed to determine the effects of sensory modality and stage of information processing.

Figure 15 shows the individual percentage change in the number of lifts, observed when switching from the "physical only" condition to each "physical + cognitive" condition. It is clearly illustrated that there were both positive responders (increased number of lifts) and negative responders (decreased number of lifts) due to the addition of each cognitive task. Approximately half of the participants exhibited an increase and half a decrement in physical performance during each "physical + cognitive" condition, irrespective of the modality utilized or the stage of processing.



P+VM = "physical+ visual memory" *P+AM = "physical+ auditory memory"*
P+VD = "physical+ visual decision-making" *P+AD = "physical+ auditory decision-making"*

Figure 15: Individual percentage change in number of lifts during dual-task conditions relative to baseline measures (positive values indicate an increase in performance; negative values indicate a decrease in performance)

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PERCEPTUAL MEASURES

Ratings of cognitive demand

Table ix to Table xi display the mean ratings of perceived level of a) time pressure, b) mental effort and c) psychological stress during each test condition. It should be noted that only descriptive statistics were used during the analysis of time pressure ratings as all 20 participants rated time pressure as “low” for during each “cognitive only” condition. Since there was no variability in ratings a dependent T-test could not be performed.

a) Time pressure

Table ix: Ratings of perceived time pressure during the cognitive tasks performed in isolation and in combination with the physical task (Means ± standard deviation; coefficient of variation)

	Cognitive task only (baseline)	**Combined Cognitive + Physical Task**
Visual memory	1.00	1.40 ± 0.50; 35.90%
Auditory memory	1.00	1.40 ± 0.50; 35.90%
Visual decision-making	1.00	1.80 ± 0.62; 34.20%
Auditory decision-making	1.00	1.45 ± 0.69; 47.33%

b) Mental effort

Table x: Ratings of perceived mental effort during the cognitive tasks performed in isolation and in combination with the physical task (Means ± standard deviation; coefficient of variation)

	Cognitive task only (baseline)	**Combined Cognitive + Physical Task**	**p-value**
Visual memory	1.35 ± 0.49; 36.25%	2.10 ± 0.45; 21.30%	<0.01 *
Auditory memory	1.40 ± 0.50; 35.90%	2.30 ± 0.47; 20.44%	<0.01 *
Visual decision-making	1.75 ± 0.44; 25.39%	2.50 ± 0.61; 24.28%	<0.01 *
Auditory decision-making	1.05 ± 0.22; 21.26%	1.50 ± 0.51; 34.20%	0.02 *

** Indicates significance at p≤ 0.05*

c) Psychological stress

Table xi: Ratings of perceived psychological stress during the cognitive tasks performed in isolation and in combination with the physical task (Means ± standard deviation; coefficient of variation)

	Cognitive task only (baseline)	**Combined Cognitive + Physical Task**	**p-value**
Visual memory	1.05 ± 0.22; 21.26%	2.05 ± 0.39; 19.22%	<0.01 *
Auditory memory	1.30 ± 0.47; 36.17%	2.05 ± 0.60; 29.50%	<0.01 *
Visual decision-making	1.45 ± 0.51; 35.20%	2.60 ± 0.50; 19.33%	<0.01 *
Auditory decision-making	1.05 ± 0.22; 21.26%	1.40 ± 0.50; 35.80%	0.03 *

** Indicates significance at p≤ 0.05*

The findings displayed in Table ix to Table xi indicate increases in the perceived of time pressure, and statistically significant increases in perceived mental exertion and psychological stress experienced by participants when each cognitive task was combined with the physical task lift. This suggests that participants perceived an increase in cognitive workload with the addition of physical demands. Given that significant differences were observed, results were further analysed to determine the separate impacts of sensory modality and stage of processing on relative percentage changes in task perception.

Each individual's percentage change in ratings of cognitive demand, observed during the dual task conditions, relative to those during the "cognitive only" conditions are displayed in Table xii. The grouping of responses appeared to vary between each dual task condition, but it is worth noting that no participants exhibited a positive response, in other words, a decrease in cognitive demand ratings during any of the dual-task conditions, showing that participants either exhibited no change or a negative response (an increase in perceived cognitive demand during the dual task conditions).

Table xii: Summary table of individual responses in perceived cognitive demand displaying total number of participants who displayed an increase (+), decrease (-) or no change (=) in muscle activity of selected measures during dual-task conditions

	Physical+ visual memory			**Physical+ auditory memory**			**Physical+ visual decision making**			**Physical+ auditory decision making**		
	+	**-**	**=**	**+**	**-**	**=**	**+**	**-**	**=**	**+**	**-**	**=**
Time pressure	8	0	12	12	0	8	6	0	14	13	0	7
Mental effort	15	0	5	18	0	2	15	0	5	9	0	11
Psychological stress	18	0	2	14	0	6	20	0	0	7	0	13

Impact of sensory modality on cognitive demand

Table xiii displays the combined mean percentages (relative to baseline/“cognitive only” conditions) of the ratings of perceived cognitive demand during both visual dual-task (VM+P and VD+P) and both auditory dual-task (AM+P and AD+P) conditions.

Table xiii: Average percentage in perceived cognitive workload ratings for visual and auditory tasks relative to baseline measurements (Means ± standard deviation; coefficient of variation)

	Visual	**Auditory**	**p-value**
Time pressure	140.16 ± 25.56; 15.42	162.06 ± 40.61; 15.42	0.82
Mental effort	171.28 ± 17.17; 10.02%	145.72 ± 21.72; 14.91%	0.04 *
Psychological stress	183.42 ± 22.73; 13.39%	142.39 ± 22.73; 24.31%	0.02 *

** Indicates significance at p≤ 0.05 between the sensory modalities*

Visual tasks resulted in significantly greater perceptions of cognitive demand during dual-task performance than the auditory tasks, both for perceived mental effort and psychological stress, but no significant difference in ratings of time pressure was observed between the visual and auditory dual-task conditions.

Impact of stage of information processing on cognitive demand

Similar to sensory modality, Table xiv displays the combined mean percentages (relative to baseline/“cognitive only” results) of the ratings of perceived cognitive demand during both memory dual-task (VM+P and AM+P”) and both decision-making dual-task (VD+P and AD+P) conditions.

Table xiv: Mean perceived cognitive workload ratings for memory and decision making tasks relative to baseline measurements (Means ± standard deviation; coefficient of variation

	Memory	**Decision making**	**p-value**
Time pressure	142.41 ± 35.08; 24.63	159.92 ± 29.97; 18.74	0.69
Mental effort	157.55 ± 20.78; 13.19%	159.89 ± 24.98; 15.62%	0.83
Psychological stress	196.20 ± 21.92; 11.17%	129.27 ± 28.61; 22.13%	<0.01 *

** Indicates significance at p≤ 0.05*

Perceived psychological stress was significantly greater during dual-task performance involving the memory tasks, than the decision making tasks. No significant difference in ratings of time pressure or mental effort were observed between the memory and decision making dual-task conditions.

Ratings of perceived physical exertion

Table xv: Ratings of perceived exertion (RPE) during the physical task in isolation and in combination with the cognitive tasks (Means ± standard deviation; coefficient of variation)

Condition	**RPE**	**P-value**
Physical only	6.70 ± 1.08; 16.13%	-
Physical + visual memory	7.00 ± 1.17; 16.71%	0.90
Physical + auditory memory	7.70 ± 2.20; 28.61%	0.03 *
Physical + visual decision-making	7.80 ± 2.04; 28.61%	0.01 *
Physical + auditory decision-making	6.95 ± 1.19; 17.14%	0.95

** Indicates significance at p≤ 0.05 relative to the "Physical only" condition*

Local RPE increased from the physical task in isolation during all dual-task conditions. However, these increases were only significant with the addition of the auditory memory and visual decision making tasks, and not the visual memory or auditory decision making tasks.

Percentage change in RPE recorded for all participants when switching from the "physical only" condition to each dual task condition, are shown in Figure 16. Once again results varied between individuals, but the grouping of responses appeared to be similar between each dual task condition. Very few (one to two participants) exhibited a decrease to the various conditions, while about half (10 to 13 participants) showed no change and the remaining 6 to 8 participants exhibited an increase in RPE with the addition of each cognitive task. The "P+AM" and "P+VD" conditions showed more extreme changes in RPE ratings ranging between -22.22% and 116.67% and -11.11% and 85.17% respectively, compared to those of the "P+VM" and "P+AD" conditions which ranged between -22.22% and 33.33% and -11.11% and 33.33% respectively.

P+VM = "physical+ visual memory"
P+AM = "physical+ auditory memory"
P+VD = "physical+ visual decision-making"
P+AD = "physical+ auditory decision-making"

Figure 16: Individual percentage change in ratings of perceived exertion during dual-task conditions relative to baseline measures

PHYSICAL MEASURES (MOVEMENT QUALITY)

Spinal kinematic and electromyography results were measured as an indication of movement quality during this study.

Spinal kinematics

This section depicts the results for spinal kinematics data (positions/displacements, velocities and acceleration) within the sagittal plane only. Given that the physical task was a lifting and lowering task involving repetitive trunk flexion and extension the primary analysis of spinal kinematic data during this investigation was focused on sagittal plane measurements. Selected measurements included range of motion, variability in range of motion, maximum and minimum positions, velocity and acceleration.

Only the average minimum and maximum positions within the frontal and transverse planes were examined to determine if any asymmetrical lifting patterns occurred during dual-task scenarios. No significant differences between the “physical only” and each dual-task condition were observed and results can be found in Appendix F.

Sagittal plane

Initially results were analysed by considering the mean responses during the first and last ten lifts during the “physical + cognitive” conditions compared to the “physical” only condition. This was done in order to determine if any initial differences in movement were apparent, or, if any differences over time occurred once participants had become more accustomed (delayed response) to each dual-task scenario. No significant differences in any measurements were observed between the “physical only” and any of the dual task conditions during the first or final ten lifts, nor between the first and final ten lifts of each condition. Full results can be found in Appendix F.

After determining that there was no initial or delayed change in spinal kinematic responses due to the introduction of the various cognitive tasks the mean responses during the full three-minute duration of each dual-task condition were compared to those during the “physical only” condition. These results are displayed in Table xvi. Once again no significant differences were observed between any of the “physical + cognitive” and “physical only” condition.

Table xvi: Spinal kinematic measurements observed in the sagittal plane between baseline measurement and dual-task scenarios (Means ± standard deviation; coefficient of variation%).

	Physical only	**Physical+ visual memory**	**Physical+ auditory memory**	**Physical+ visual decision making**	**Physical+ auditory decision making**
Range of motion (°)	35.52± 8.34; 23.47%	32.89± 10.22; 31.07%	34.16± 8.65; 25.33%	35.02± 7.74; 22.10%	34.50± 9.07; 26.30%
Variability in range of motion (%)	10.30± 3.59; 34.86%	9.37± 3.57; 38.12%	9.56± 3.18; 33.32%	9.56± 3.13; 32.77%	9.23± 3.29; 35.61%
Maximum position/ flexion (°)	31.56± 7.19; 22.79%	29.18± 8.33; 28.55%	29.30± 7.72; 26.35%	30.44± 6.40; 21.03%	30.19± 7.77; 25.74%
Minimum position/ extension (°)	-3.96± 4.82; -121.76%	-3.71± 5.47; -147.41%	-4.86± 5.14; -105.84%	-4.58± 4.95; -108.15%	-4.30± 4.17; -96.97%
Maximum velocity ($m.s^{-1}$)	35.44± 25.54; 72.08%	45.23± 33.44; 73.94%	38.28± 26.99; 70.51%	40.69± 25.99; 63.87%	34.86± 22.98; 65.93%
Maximum acceleration ($m.s^{-2}$)	286.59± 97.55; 34.04%	289.75± 142.42; 49.15%	303.28± 135.22; 44.59%	286.11± 84.36; 29.49%	273.30± 95.20; 34.83%

Table xvii displays each individual's relative change between the "physical only" and a dual task condition for each sagittal plane measurement. As with the performance and perceptual measures responders and non-responders are clearly evident during dual task performance for all spinal kinematic measurements during both the first and final ten lifts. This highlights that although significant differences in spinal kinematics were not observed between the "physical only" and "physical + cognitive" conditions via the analysis of the mean data, an interaction between physical and cognitive demands was observed on an individual basis. The number of responders and non-responders for each spinal kinematic variable when transitioning to dual-task conditions can be found in Appendix F.

Table xvii: Summary table of individual spinal kinematic responses within the sagittal plane - displaying total number of participants who displayed an increase (+), decrease (-) or no change (=) in selected measurements during dual-task conditions

	Physical+ visual memory			**Physical+ auditory memory**			**Physical+ visual decision making**			**Physical+ auditory decision making**		
	+	**-**	**=**	**+**	**-**	**=**	**+**	**-**	**=**	**+**	**-**	**=**
Range of motion (°)	6	14	0	10	10	0	10	10	0	11	9	0
Variability in range of motion (%)	6	14	0	10	10	0	10	10	0	6	14	0
Maximum position/ flexion (°)	9	11	0	8	12	0	9	11	0	8	12	0
Minimum position/ extension (°)	10	10	0	10	10	0	13	7	0	7	12	1
Maximum velocity ($m.s^{-1}$)	14	6	0	15	5	0	11	9	0	12	8	0
Maximum acceleration ($m.s^{-2}$)	13	7	0	11	9	0	8	12	0	11	9	0

Electromyographical responses

Due to equipment failure data from one participant was excluded for the Erector Spinae and Rectus Abdominus muscles, while two and three were excluded for the Biceps Femoris and Rectus Femoris muscles respectively. This was done as the electrode used on these muscles for these particular participants failed during testing and results were not recorded.

The mean electromyographical responses of the selected muscles during the “physical only” (baseline) and each dual-task condition, as displayed in Table xviii. However, as with the spinal kinematic measures, large variability for electromyographical responses was evident between participants.

Table xviii: Muscle activation of selected muscles, comparing mean EMG of the physical task in isolation with that of each dual task condition (Means ± standard deviation; coefficient of variation; p-value in brackets)

Condition	**Muscle activation (%MVC)**			
	Erector Spinae	**Rectus Abdominus**	**Biceps Femoris**	**Rectus Femoris**
Physical only	53.72 ± 28.46; 52.98%	7.26 ± 4.90; 67.40%	13.83 ± 7.96; 57.51%	11.66 ± 9.49; 81.34%
Physical + visual memory	53.84 ± 27.38; 50.86% (p=0.93)	8.29 ± 8.67; 104.52% (p=0.37)	15.28 ± 9.70; 63.45% (p=0.17)	11.64 ± 12.42; 106.69% (p=0.10)
Physical + auditory memory	54.35 ± 26.73; 49.18% (p=0.10)	8.02 ± 7.72; 96.31% (p=0.67)	14.41 ± 7.86; 54.58% (p=0.89)	11.86 ± 13.98; 117.85% (p=1.00)
Physical + visual decision-making	54.44 ± 26.88; 49.38% (p=0.10)	7.85 ± 6.12; 77.88% (p=0.83)	14.25 ± 8.77; 61.56% (p=0.97)	9.90 ± 8.12; 81.99% (p=0.75)
Physical + auditory decision-making	52.82 ± 28.26; 53.51% (p=0.21)	7.60 ± 6.22; 81.92% (p=0.98)	14.62 ± 9.27; 63.37% (p=0.73)	11.72 ± 12.73; 108.55% (p=1.00)

Table xix displays the individual percentage changes in selected muscle activity when switching from the “physical only” to each “physical + cognitive” condition. Once again, positive and negative responders, as well as non-responders to the addition of all cognitive tasks are clearly illustrated with individual participants showing an increase, decrease or no change in muscle activity for all muscles during all “physical + cognitive” conditions.

Table xix: Summary table of individual electromyographical responses displaying total number of participants who displayed an increase (+), decrease (-) or no change (=) in muscle activity of selected muscles during dual-task conditions

	Physical+ visual memory			**Physical+ auditory memory**			**Physical+ visual decision making**			**Physical+ auditory decision making**		
	+	**-**	**=**	**+**	**-**	**=**	**+**	**-**	**=**	**+**	**-**	**=**
Erector Spinae	6	12	1	8	10	1	6	11	2	7	9	3
Rectus Abdominus	9	9	1	13	6	0	16	2	1	10	8	1
Biceps Femoris	12	5	1	12	6	0	10	8	0	11	6	1
Rectus Femoris	7	10	0	5	12	0	6	11	0	7	10	0

CORRELATIONS BETWEEN VARIABLES

A Product-Moment correlation was processed using Statistica. Changes in performance, perceptual and physical responses were correlated with one another. This was conducted to determine if any significant relationships existed between these measures, in order to assist in the understanding of the observed responses. Only significant relationships are described in this section. For full correlation results matrix refer to Appendix E.

Significant and noteworthy correlations observed included:

- Sagittal range of motion positively correlated with maximum trunk flexion (all dual-task conditions)
- Variability in sagittal range of motion positively correlated with maximum flexion (all dual-task conditions) and RPE (P+VM).
- Maximum sagittal velocity positively correlated with cognitive performance (P+AM), RPE (P+AM), sagittal range of motion (P+AM and P+AD), variability in sagittal range of motion (P+AM and P+AD), maximum flexion (P+AM), and Erector Spinae activity (P+VM and P+AM).
- Maximum sagittal acceleration positively correlated with maximum flexion (P+VM) and psychological stress (P+VM).
- Cognitive performance positively correlated with range of motion (P+AM) and variability in sagittal range of motion (P+AM), maximum trunk extension (P+VM) and maximum sagittal velocity (P+AM).
- Erector Spinae Muscle activity positively correlated with Rectus Abdominus Muscle activity (P+AM" and P+AD).
- Erector Spinae Muscle activity positively correlated with Biceps Femoris Muscle activity (P+AM and P+AD) conditions.
- Biceps Femoris Muscle activity positively correlated with physical performance (P+AM).

CHAPTER V:
DISCUSSION

This chapter integrates the performance, perceptual and physical responses obtained during the physical and each cognitive task performed in isolation, as well as the physical task performed concurrently with each cognitive task, to establish whether, or not, they support the hypotheses of this study. It was hypothesised that, compared to the physical and cognitive tasks performed in isolation, participants would elicit unfavourable differences in task performance, spinal kinematics, muscle recruitment patterns, and perceptual responses when performing the physical and cognitive tasks concurrently. It was further hypothesised that the stage of information processing (memory or decision making) and the modality through which information is perceived (visual or auditory) would impact these responses. All hypotheses were generated based on the theory of shared and limited attentional resources, as well as the impact of increased stress and perceived workload during dual-task execution.

GENERAL DUAL-TASK INTERACTION

Results observed during the current study provide evidence in support of a general dual-task interaction between concurrent physical and cognitive demands, which impacts performance, perceptual and physical responses, either on a group or an individual level. The results therefore provide support to the theory of shared brain-based energy resource (Bray *et al*., 2011) and that the anterior cingulate cortex (the area of the brain in which motor control and cognition converge) may be part of the attentional control network (Turken and Swick, 1999). Results further support the neurocognitive model presented by (Diedrick and Audiffen, 2011), which argues that cognitive functions will be downregulated to a lower priority during physical activity to ensure optimal motor control. The most convincing findings in this regard were that of cognitive performance accuracy and visual decision-making work output. A statistically significant decrease in the mean number of correct cognitive responses was observed for each cognitive task when executed concurrently with the physical task. Similarly, the addition of the physical task appeared to negatively impact the work output of cognitive performance during the visual decision-making task, as shown by a statistically significant reduction in the mean number of total responses. These results were further strengthened upon analysis of the individual data which showed that, due to the addition of the physical task, all participants demonstrated a reduction in the number of responses (cognitive output) during all cognitive tasks, as well as the total number of responses (indicating a greater work output) during visual decision-making. Conversely, results of the mean analysis showed that the addition of the physical task did not have a statistically significant impact on the work output of auditory decision-making. However, it should be noted that 70% of participants showed a decrease, 10% no change and 20% an increase in auditory decision-making work output. Given these individual observations, although no statistical significant difference was observed, these findings still provide further support of an interaction between concurrent physical and cognitive demands. It is possible that this greater decrement during the visual-decision making task may have resulted from the movement of the participant’s head and continuous adjustment of their line of vision required to manipulate and place the box. This may have been more distracting than the ‘noise’ from the auditory task. Based on the theory of limited attentional capacity in humans, these results were expected. Attention is defined as the underlying commodity that enables information processing and task execution (Smith and Buchholz, 1991). However, being limited, if humans are exposed to numerous sources of cognitive demand, such as in dual-task situations, attentional resources must be distributed between the multiple demands (Wickens, 2008). It is therefore likely that the performance of one or both tasks will be compromised (Hommel, 1998; Schumacher et al., 2001; Johnston and McCann, 2003; Wickens, 2008, Hiraga et al., 2009). These results suggest that the simultaneous performance of a cognitive and physical task increased the attentional demands placed on participants, resulting in a decrease in cognitive task performance. This supports the theory of a limited brain-based energy resource and that attention may have been controlled by the anterior cingulate cortex in order to regulate the cognitive and physical tasks. Furthermore, these results are in agreement with the research regarding the anterior cingulate cortex (Klingber and Roland, 1997; Bray et al., 2011). It is believed that the anterior cingulate cortex is an area of the brain in which motor control, cognition and emotion converge and it thus governs the performance of tasks that require cognitive, physical and emotional effort (Turken and Swick, 1999; Critchley et al., 2003; Marcora et al., 2009). It has been suggested that self-regulating performance of one task may lead to diminished effortful performance of another task, provided that both tasks require some degree of emotional, cognitive or physical regulation (Bray et al., 2011). This argument is reinforced when taking into consideration the physical performance responses of the participants, as no significant differences were found in the mean number of lifts (physical performance) with the addition of each cognitive task. Given that cognitive performance decreased while physical performance did not, these results imply that participants may have directed more attention towards the physical task, leaving less attentional resources available for the execution of the simultaneously performed cognitive tasks, hence the degradation in cognitive, but not physical task performance. This increased attention towards the physical task over the cognitive tasks may be attributed to the possible threat of pain. Several studies have found that humans may exhibit hypervigilance when exposed to situations that may be appraised as "dangerous" (Vlaeyen and Lintion, 2000; Allappattu and Bishop, 2011; Van Damme et al., 2010). In this context hypervigilance can best be defined as the readiness to select information regarding possible signals of threat of pain over any other information from the environment (Van Damme et al., 2010). What this essentially means is that humans will direct more attention towards avoiding any potential risk of pain at the expense of other tasks (Vlaeyen and Lintion, 2000; Allappattu and Bishop, 2011). Given that the physical task in this study was a repetitive lifting and lowering protocol, the known potential risks associated with lifting as well as any general physical discomfort associated with the physical demands, may have caused participants to place greater importance on the physical task at the expense of the cognitive task.

Since humans differ in their abilities, to fully understand the extent of this interaction it is necessary to cross-examine the individual responses. Physical performance measures showed a range of individual responses to the addition of each cognitive task. Approximately 50% of participants exhibited an increase and 50% a decrease in physical performance during each "physical + cognitive" condition. All participants demonstrated a decrement in cognitive performance accuracy and visual decision-making work output, and the majority of participants showed a decrement in auditory decision-making work output. It can therefore be argued that approximately 50% of the participants increased physical performance at the expense of cognitive performance, while the other 50% of participants appeared to downregulate the performance of both tasks. Irrespective of these individual differences all participants demonstrated a decrement in performance of one or both tasks under dual-task conditions, providing strong evidence for an interaction between concurrent physical and cognitive demands.

Further evidence of interacting cognitive and physical demands is provided by the perceptual responses of participants. Mean RPE increased from baseline (physical task performed in isolation) during all dual task (“physical + cognitive”) conditions. This increased perception of exertion was however only statistically significant due to the addition of the auditory memory task and the visual decision-making task, of which the greatest decrement resulted from the visual decision-making task. No significant changes occurred due to the addition of the visual memory or auditory decision making task. This outcome could be as a result of the short duration of the experimental protocol (three minutes) of each test condition. While mean RPE increased marginally during the dual-task conditions for visual memory and auditory decision-making, three minutes may not have been sufficient to induce a significant change for all conditions. In support of this it is worth noting that the individual results showed that during the “P+AM” and “P+VD” conditions participants showed more extreme changes in RPE ratings ranging between -22.22 and 116.67% and -11.11 and 85.17% respectively, compared to those during the “P+VM” and “P+AD” conditions which ranged between -22.22 and 33.33% and -11.11 and 33.33% respectively. This suggests that although changes were exhibited during these conditions they were not yet extreme enough to be statistically significant. There is however the possibility that, if performed over a longer duration, these changes might have been more extreme. As with RPE, perception of cognitive work-load also appeared to increase during dual-task conditions. Since baseline measures showed no variance, statistical analysis could not be performed for perceived time pressure, but results do indicate that this measure increased during the dual task conditions. Mental effort and psychological stress both increased significantly from baseline (cognitive tasks performed in isolation) due to the addition of the physical lifting task during all dual task conditions. These results suggest that simultaneous physical and mental demands lead to increased perception of both physical and cognitive effort required to complete both tasks simultaneously, compared to executing either the physical or cognitive task in isolation. This again supports the theory of a shared brain-based energy resource, which regulates physical and cognitive tasks governing the performance of such tasks (Bray *et al*., 2011) and that cognitive effortful tasks may lead to increased perception of physical exertion and vice versa. It can therefore be proposed that concurrent physical and cognitively demanding tasks deplete the same pool of central nervous system energy referred to by Bray *et al*. (2011). This essentially means that, if performed over a long period of time or an entire work shift, execution of concurrent physical and cognitive demands may result in faster rates to physical and cognitive fatigue (Bray *et al*., 2011), negatively impacting worker performance/productivity, risk of errors and injury. Furthermore, when considering these perceptual results in conjunction with the performance measures during the dual-task conditions, it worth noting that an increased perception of both physical and cognitive exertion/demand was associated with decrements in cognitive, but not necessarily physical performance. It therefore appears that participants may have down-regulated cognitive performance, in order to enhance physical performance. This result is similar to that of Hagger *et al*. (2010) who found that resource depletion in one domain (e.g. cognitive, physical or emotional) lead to deteriorated performance of tasks in the same or another domain. This further supports the idea that participants directed more attention towards the optimal performance of the physical task than the cognitive tasks during dual-task conditions. Increased attention towards the physical task over the cognitive tasks may be attributed to the possible threat of pain. Several studies have found that humans may exhibit hypervigilance when exposed to situations that may be appraised as "dangerous" (Vlaeyen and Lintion, 2000; Allappattu and Bishop, 2011; Van Damme *et al*., 2010). In this context hypervigilance can best be defined as the readiness to select information regarding possible signals of threat of pain over any other information from the environment (Van Damme *et al*., 2010). What this essentially means is that humans will direct more attention toward minimizing any potential risk of pain at the expense of other tasks, as a protective mechanism (Vlaeyen and Lintion, 2000; Allappattu and Bishop, 2011). Given that the physical task was a repetitive lifting and lowering protocol and the potential risks associated with lifting are known, it is possible that as the perception of physical effort increased participants focused more on performing the lifting task correctly at the expense of the cognitive task. Participants may have done this out of fear of possible injury, physical pain or discomfort. In order to investigate this concept further it would be advised to observe changes in both perceptions of effort and cognitive and physical performance over time. This was beyond the scope of the current study, but provides an avenue for future research.

Examination of individual responses revealed that (dependent on the condition) between 30 and 40% of participants exhibited no change in either RPE or perceived cognitive demand, while between 50 and 65% exhibited an increase. Once again this may imply individually-specific responses to concurrent physical and cognitive demands as the task perception of a notable amount of participants did not appear to be affected by the introduction of a secondary task. This lack of change may be attributed to cognitive distraction caused by the secondary task (Brereton and McGill, 1999) or the ability of individuals to accurately rate their perceived level of effort (Stanish and Aucoin, 2007). Accurate ratings of perception could have been affected by the participants' understanding of the scale as well as motivational levels (Stanish and Aucoin, 2007).

Further evidence of an individual specific interaction between cognitive and physical demands is provided by the physical (movement quality) responses of participants. While no statistically significant differences in mean spinal kinematics or muscle activity were observed between the "physical only" and any of the dual task conditions, a large variability between individual responses was noted, and the lack of statistical significance may be attributed to this large variance. Several notable findings can however be highlighted from the investigation of individual physical responses and the correlation analysis between selected variables of interest. As with the selected performance and perceptual measures individual kinematic results (Table xvii) provided evidence of both positive and negative responders to all dual-task conditions, which could explain the lack of statistical significance between the mean responses. Furthermore, both increased sagittal range of motion and increased variability in sagittal range of motion was found to be associated with increased trunk flexion during all dual-task conditions, suggesting that the increase in range of motion observed in certain individuals was most likely caused by an increase in trunk flexion. This is of importance as increased trunk flexion is linked to an increase in the compressive, and anterior-posterior and lateral shearing forces exerted onto the spine, particularly at the L5/S1 joint (Davis and Marras, 2000). Additionally, sagittal range of motion and variability in sagittal range of motion were positively correlated with maximum sagittal velocity during the "P+AM" and "P+AD" conditions, and maximum sagittal acceleration during the "P+VM" condition suggesting an even greater risk of injury during under dual-task demands due to increased trunk dynamics and ultimately increased muscle co-activation and spinal loading (Davis *et al*., 2002). This is supported by the positive correlation between maximum sagittal velocity and Erector Spinae Muscle activity during the “P+AM” condition. Increased cognitive performance was also associated with increased range of motion and variability in range of motion during the “P+AM” condition, increased sagittal velocity during the “P+AM” condition and trunk extension during the “P+VM” condition. This suggests the possibility that those participants who increased cognitive performance under dual-task conditions may have done so at an expense of movement quality, placing them at a greater risk of injury. Although no statistically significant differences were observed between the “physical only” and “physical+cognitive” tasks, these individual results still have practical relevance. The increases in range of motion, variability in movement, velocity and accelerations imply an individual-specific interaction between concurrent mental and physical demands that may negatively impact the movement quality of workers. Additional evidence for increased trunk range of motion and rapid movements under dual-task demands was provided by the electromyographical results. Between 30 and 40% of participants demonstrated increased Erector Spinae activity and up to 90% increased Rectus Abdominus activity during dual-task conditions. Increased Erector Spinae activity was also significantly and positively correlated with increased Rectus Abdominus activity during the “P+AM” and “P+AD” conditions. This increase in muscle co-activity could be attributed to either increased trunk range of motion within the sagittal plane, as these muscles are largely responsible for both initiating and controlling trunk flexion and extension (Clarkson, 2000), or increased trunk dynamics, which would require an increase in muscle activation for increased postural support (Marras *et al*., 1993; Davis and Marras, 2000). These findings provide evidence of more extreme and rapid movements of the spine together within increased variance in movement patterns for certain individuals, when placed under concurrent physical and mental demands, which essentially places individuals an increased risk of low back injury.

Between ten and 55 and 65% of participants showed an increase in Biceps Femoris activity, and between 60 and 70% 17 participants a decrease in Rectus Femoris activity during the various dual-task conditions compared to the “physical only” task. This again implies an individual specific response to concurrent physical and cognitive demands. The observation that Biceps Femoris activity increased while Rectus Femoris activation decreased also supports the argument for increased trunk flexion during dual-task conditions as this provides evidence of a hip-spine interaction during flexion and extension. Research has found a simultaneous rhythm between the lumbar and pelvis movements during both forward and backward trunk movements and therefore simultaneous actions of trunk flexion and hip flexion (Clarkson, 2000; Tafazzol *et al*., 2014). This is supported by positive and significant correlations between Biceps Femoris and Erector Spinae activity during the “P+VM” and “P+AD” conditions. When lifting an object, individuals tend to adopt either a stooped or a squatting posture. A stooped posture involves greater reliance on flexion and extension of the trunk and therefore greater activation of the paraspinal, abdominal and hip extensor muscles, while a squatting posture involves greater reliance on knee flexion and extension while keeping the spine straight (Davis *et al*., 2002). During a squatting posture the knee and pelvis are less stable and therefore increased squatting is associated with the increased activation of the quadriceps muscle group in order to maintain adequate support and stability (Gallagher, 1997). This observed trend in muscle activity supports the likelihood that participants may have engaged more in a stooped lifting posture during the dual task conditions, as opposed to a squatting posture. However, given the lack of statistical significance, no convincing conclusions can be drawn from this finding, but it may be worth investigating this relationship further in future studies. A further finding is that increased Biceps Femoris activity during the “P+VM” conditions was associated with increased physical performance. It could be proposed from this finding that the participants who increased physical performance under dual-task demands may have done so at the expense of movement quality, placing themselves at a greater risk of injury. However, given that this was correlation was only statistically significant for one dual-task condition this interaction requires further investigation.

In summary, the findings from this study imply that a general interaction between concurrent physical and cognitive demands does exist. This interaction appears to be individual specific with dependency on the capabilities and limitations of different individuals. Such differences could include level of cognitive ability, training volume, physical strength or ability to cope with stress. It appears that such dual-task conditions may be either detrimental or advantageous to task performance, perception of task demands and movement quality of workers. Such findings support the idea that individual responses, capabilities and limitations should be considered when providing recommendations regarding task design. While the interaction between specific individual differences and dual-task performance was not investigated during this study this is an area for future research.

IMPACT OF SENSORY MODALITY

Further analyses of results support the hypothesis that dual-task interaction between concurrent physical and cognitive demands is affected by the sensory modality through which information is perceived. This impact was however only apparent for the cognitive performance and perceptual measures of cognitive demand, while the sensory modality did not appear to impact physical performance, RPE or physical responses on a mean or individual level, suggesting once again that cognitive performance may have been down regulated in attempt to maintain physical performance regardless of the type of cognitive task in the dual-task scenario. The current study did however find that the physical task interfered more with the visual than the auditory tasks. This was initially shown by a significantly greater impact on cognitive performance accuracy during dual-task execution. Furthermore, the addition of the physical task resulted in a significant decrease in the work output of visual decision-making, but did not significantly impact that of auditory decision-making. This result may be explained by the Multiple Resource Theory developed by Wickens (1985), which explains that visual and auditory processing target different resource pools characterized by different capacity limits. Since lifting and lowering a box from one position to another requires the use of visual information processing resources, and particularly the continuous adjustment of the visual field, it is likely that participants found it more difficult to perform the visually than the auditory orientated cognitive tasks while simultaneously lifting the box, as both tasks were competing for the same mental resources (Guillery *et al*., 2013), thereby placing a higher demand on the visual processing resource pool, than the auditory resource pool. Examination of individual responses strengthens this argument as, with the addition of the physical task all participants demonstrated a decrement in work output during visual decision-making, ranging between 18.18% and 37.17%, while only 70% of participants showed a decrement in the work output for auditory decision-making which ranged between 4.45% and 17.39%. This indicates that the physical task had a larger effect on the performance of the visual decision-making task, again implying a larger motor-cognitive interaction between the physical and visual cognitive tasks compared to the physical and auditory cognitive tasks. In addition to the cognitive performance measures, it was also found that the addition of the physical task had a significantly greater impact on the perceived level of cognitive demand of the visual tasks, compared to the auditory task during dual-task execution, as increases in both perceived mental effort and psychological stress were greater during the visual dual-task conditions, which in itself could explain the larger performance decrements during these tasks as increased stress has been linked to decreased cognitive function (Stawski *et al*., 2006). Apart from separate visual and auditory resource pools this increased dual-task interaction during visually orientated tasks may be attributed to a phenomenon known as auditory dominance (Robinson and Sloutsky, 2004) or preference in learning style (Felder and Spurlin, 2005; Gilankjani and Ahmadi, 2011). Research surrounding the ability to process simultaneous verbal and auditory information suggests an auditory dominant effect where visual processing appears to be hindered (Eimer and van Velzen, 2006; Robinson and Sloutsky, 2004). However, the exact mechanisms causing auditory dominance are still unclear and the majority of this limited research has been completed on children (Robinson and Sloutsky, 2004), thereby opening an area for future research. This interaction may also have been influenced by preferences in learning style, which can be defined as the style and manner in which individuals perceive and process information (Gilankjani, and Ahmadi 2011). Felder and Spurlin (2005) explain that individuals have different strengths and preferences in learning styles and visual and auditory styles are clearly distinguished by Gilankjani and Ahmadi (2011). It is therefore possible that individual preferences and abilities to process visual and auditory stimuli impacted the results of the current study. Despite the above evidence it should not be disregarded that the increased interference during the visual dual-tasks may have resulted from the continuous adjustment of participants' line of vision during the lifting task as opposed to a resource conflict. This study does however indicate a stronger dual-task interaction during visual tasks, but research into the impact of sensory modality on motor-cognitive interaction is limited and this interaction and the mechanisms behind it should be explored in future studies.

IMPACT OF STAGE OF PROCESSING

Results from the current study provide conflicting evidence about the impact of the stage of processing on the dual-task interaction between physical and cognitive demands. Findings regarding cognitive accuracy indicate that decision-making tasks were significantly more affected by the addition of the physical task than the memory tasks. As with the impact of sensory modality there is little research surrounding the different stages of information processing and motor-cognitive interactions, but one possible explanation for the increased task interference observed during the "decision-making dual task" could be due to the response selection phase during the execution of the physical task. Schmidt and Wrisberg (2008) identified three cognitive processes which govern action control, namely signal identification, action selection and action execution. In order to execute an action, the correct motor response must be selected to produce the required muscular contraction. Therefore, action execution is always preceded by action selection. However, in certain environments multiple movements may be continuously required and one action may create a signal for the next required action selection (Verbruggen *et al.*, 2014). Repetitive lifting and lowering would be an example of this. Each individual lift and lower results in a change in the position of the box and the desired action. Each time the box is lifted a new decision/response selection is required to lower the box; as is the case to lift the box again, once lowered. This therefore implies that the response selection stage required for motor control may draw on the same decision-making resource pool required for cognitive processing during purely mentally demanding decision-making tasks, which differs from the resource pool required for memory tasks (Wickens, 1985). Although perceptual resources, which according to the Multiple Resource Theory are the same as those required for memory (Wickens, 1985), are also continuously required to perceive the change in position of the box, the results suggest that the lifting task placed a higher attentional demand on decision-making attentional resources, than perceptual resources.

Conversely, perceptual measures imply that the physical task had a greater impact on the memory tasks as increased perceived level of psychological stress during the memory tasks was significantly greater than that perceived during the decision making tasks during dual-task execution. Since the stage of processing did not appear to significantly impact perceived time pressure or mental effort during dual-task conditions, it cannot be suggested that the stage of processing has any effect on overall perception of cognitive task demands. It is more likely that participants simply found the memory tasks more stressful, possibly due to greater test anxiety or less self-confidence in the correct performance of the memory tasks. This could be due to individual cognitive preference, which is defined as an individual’s strategy of processing information that characterizes a personal way of perceiving, remembering and problem solving (Caeser, 2010), or cognitive abilities (Choi and Sardar, 2011). This is however just speculation and previous research surrounding this is not apparent in the literature. Further research investigating induced stress levels from various cognitive tasks and the possible mechanisms behind varying levels of induced stress is needed to provide more insight. As with the sensory modality results, stage of information processing did not appear to impact physical performance, RPE or physical responses, which was apparent through analysis of individual data as participant responses between all dual task conditions for these measures appeared to be similar. Similar to sensory modality, the stage of information processing appeared to only impact cognitive performance and perception, and not physical performance, RPE or physical responses, again supporting the argument of downregulation of the cognitive tasks in order to maintain physical performance in each dual task conditions, regardless of the nature of the cognitive task.

CHAPTER VI:
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

BACKGROUND AND PURPOSE OF RESEARCH

In a modern day work environment many tasks require some degree of dual tasking, that is, engaging in more than one activity concurrently, and many jobs require the simultaneous performance of cognitive jobs alongside physical activity. Previous research has indicated a possible relationship between concurrent physical and cognitive demands and task performance, safety and efficiency. However, this research is both limited and contradictory.

The aim of this study was to identify whether an interaction exists between a physical and a cognitive task performed concurrently, taking into consideration the possible effects on both quality and quantity of physical and cognitive task performance as well as perceptual responses. More specifically, the study focused on the effect of different types of cognitive tasks, namely visual and auditory memory and decision-making tasks, on the performance of a lifting activity. Specific measures of interest included: cognitive task performance (accuracy and work output), physical task performance (work output), perceived physical and cognitive demand, spinal kinematics (changes in sagittal plane minimum and maximum trunk position, velocities and accelerations during movements of the spine) and degree of muscle activation of selected muscles.

SUMMARY OF PROCEDURES

All testing took place in the ergonomics laboratory of the Human Kinetics and Ergonomics Department at Rhodes University. Independent variables included the 9 different test conditions. Five of these were baseline measures made up of four different types of cognitive tasks performed in isolation (a visual memory task, an auditory memory task, a visual decision-making task and an auditory decision-making task) and one physical task (lifting task) in isolation. The remaining four conditions were dual-task tests requiring the performance of the different cognitive tasks in combination with the physical task. Dependent variables measured were the performance (accuracy and work output), perceptual (Ratings of Perceived Exertion and the Subjective Workload Analysis Technique) and physical (muscle activity and spinal kinematics) responses of participants.

Participants reported for two sessions on two separate days. The first session was a habituation session during which the testing procedure was fully explained to the participants. Participants were briefed verbally and in writing (Appendix A) about the purpose, procedures, risks and benefits associated with the protocol and their rights to optional withdrawal, anonymity and confidentiality. Participants were familiarised with all testing equipment as well as the lifting and cognitive tasks they were required to perform during the protocol, and any concerns or unanswered questions were addressed. Participants were asked to sign the informed consent form, following which, a questionnaire, containing questions about personal characteristics was filled out and basic demographic measurements recorded (Appendix B. Finally, participants were reminded of the pre-testing instructions (Appendix A).

The second session involved all nine experimental conditions which were administered in a random sequence. Upon arrival at the second session participants performed the maximal voluntary back strength test, after which and electrodes were placed onto participants. Maximal voluntary exertions for the selected muscles were then performed as reference measurements for EMG activity, after which the Lumbar Motion Monitor was fitted to each participant and calibrated. Participants then performed all nine test conditions, with a ten-minute rest break between each condition.

SUMMARY OF RESULTS

Mean results were analysed using a dependent T-test to observe for any general interaction, and a Two-way ANOVA for the impact of sensory modality and stage of processing. Individual responses were also considered to gain better understanding of both intra and inter-human variability under the various test conditions. A correlation analysis examining relationship between the individual percentage changes (from baseline to dual-task conditions) of all variables was performed

Performance measures

i) Cognitive performance

The accuracy of cognitive responses decreased significantly during each cognitive task, when switching from the “cognitive only” to dual task condition. There was a significantly greater decrement in performance during the visual tasks, compared to the auditory tasks, and a significantly greater decrement in performance during the decision making tasks compared to the memory tasks. Average work output of cognitive performance decreased significantly during the “visual decision-making” task when performed concurrently with the lifting task, but not during the “auditory decision making” task. Individual results showed all 20 participants demonstrated a decrease in cognitive performance accuracy for all cognitive tasks, and work output of the “visual decision-making” task when that cognitive task was combined with the physical lifting task. However, when the “auditory decision-making” task was performed concurrently with the physical lifting task 14 participants demonstrated a decrement, two showed no showed change and four increased their work output.

ii) Physical performance

No significant differences in the mean number of lifts were observed between the “physical only” and any of the dual task conditions. Individual results showed that approximately half of the participants exhibited an increase and half a decrement in physical performance during each dual task condition.

Perceptual responses

a) Time pressure

Mean perceived time pressure increased during each cognitive task, with the addition of the physical task.

b) Mental effort

Mean perceived mental effort increased significantly during all dual-task conditions compared to performing each cognitive task in isolation. Stage of processing did not significantly impact this interaction, but visual tasks resulted in significantly greater increment in perceived mental effort during dual-task conditions, compared to the auditory tasks.

c) Psychological stress

Mean perceived psychological stress increased significantly during all dual-task conditions compared to performing each cognitive task in isolation. Visual tasks resulted in significantly greater increments in psychological stress than the auditory tasks during dual-task conditions, as did the memory tasks compared to the decision-making tasks.

No participants exhibited a decrease in any of the cognitive demand ratings, while approximately half showed no change and half exhibited an increase in perceived time pressure, mental effort and psychological stress during the dual task conditions.

d) Ratings of perceived exertion

Mean RPE increased for all dual-task conditions compared to performing the physical task in isolation. Increases due to the addition of the auditory memory and visual decision making were significant, while those due to the visual memory and auditory decision making were not. Results varied between individuals; one to two participants) exhibited a decrease, about half (ten to 13 participants) showed no change and the remaining 6 to 8 participants an increase in RPE with the addition of each cognitive task.

Physical measures

a) Spinal kinematics

No statistically significant differences in spinal kinematic measures were observed between the “physical only” and dual task conditions. A large variety of responses between individuals was observed for 1) total ranges of motion 2) variability in range of motion 3) maximum and minimum position 4) maximum velocities and 5) maximum accelerations across test conditions within the sagittal plane.

b) Electromyographical responses

No statistically significant differences in mean muscle activation were found between the “physical only” task and the “physical + cognitive” tasks for any of the muscles recorded. Similar to the spinal kinematic results a large variety of responses between individuals was observed.

Correlation analysis

Significant and positive relationships between physical performance, sagittal range of motion variability in range of motion, velocity and acceleration were found. Significant and positive correlations were also observed between total range of motion and maximum flexion during both the first and final ten lifts.

RESPONSES TO HYPOTHESES

Hypothesis 1:

The null hypothesis stated that participants would elicit no differences in selected performance, physical, and perceptual responses, during the isolated execution of a physical task (repetitive lifting and lowering protocol) or a selected cognitive task (visual memory, auditory memory, visual decision making and auditory decision making task), and the simultaneous execution of the physical and selected cognitive task. This hypothesis was rejected for cognitive task performance and cognitive perceptual measures, but accepted for physical task performance, perceived physical exertion and physical/movement quality measures.

Hypothesis 2:

This null hypothesis stated any dual task interaction would be affected by the sensory modality through which information was perceived. The null hypothesis was rejected accepted for cognitive performance and perceptual measures (mental effort and psychological stress), but accepted for physical performance, physical perceptual and physical response measures.

Hypothesis 3:

This hypothesis stated that any dual task interaction would be affected by the stage of information processing. The null hypothesis was rejected for cognitive performance and perceptual measures (psychological stress), but accepted for physical performance, physical perceptual and physical response measures.

DELIMITATIONS

The aim of this study was to identify any interactions between a physical and cognitive task performed concurrently, taking into consideration the possible effects this dual task interaction may have on performance, perceptual and physical responses. More specifically, this study focused on the effects of different types of cognitive tasks on the performance of a lifting task.

The study consisted of nine different test conditions, including a physical lifting task and four different information-processing tasks performed in isolation and the physical lifting task combined with each information-processing task. The information-processing tasks selected were delimited to a visual decision making task, auditory decision making task, visual memory task and auditory memory task. Each condition was performed for three minutes and interaction effects during fatigue development were not considered.

The dependent variables were restricted to physical and cognitive performance, measured as the number of lifts (physical) and correct responses (cognitive), spinal kinematics, electromyographical responses of the right Erector Spinae, Rectus Abdominus, Biceps Femoris, and Rectus Femoris muscles, and ratings of perceived physical exertion on the BORG scale and time pressure, mental effort and psychological stress using SWAT.

The sample used for this study was delimited to 20 participants from Rhodes University. Equal number of males (n=10) and females (n=10) were used in the investigation. Participants ranged in age between 18 and 25 years and were physically active and healthy.

Data collection took place in a controlled laboratory setting to control potentially confounding environmental factors such as lighting and temperature. This also ensured that the protocol remained consistent among participants. The study involved a mixed repeated measures design and task learning effects are often experienced when participants are exposed to numerous trials of a given task. In an attempt to reduce order and learning effects test conditions were permutated for each participant, ensuring the order in which the tasks were performed was randomised.

LIMITATIONS AND RECOMMENDATIONS

The sample size was considered a limitation. If this study was to be conducted again, it would be beneficial to increase the sample size as this may allow for greater statistical significant differences to be observed. It should also be noted that all participants used in this experimental study were students of Rhodes University, aged between 19 and 24 years old. All participants were considered healthy, with no history low back injury or any attention deficit disorders. All participants were also fluent in English with the same level of education. Therefore, the results of this research cannot necessarily be generalised to all populations such as elderly groups, previously injured or uneducated workers, or those of different cultural and educational backgrounds. It may be worthwhile considering how dual-task demands impact groups of workers of different ages with varying social, educational and physical demographics to make the research more applicable to the general workforce, particularly in the context of an industrially developing country such as South Africa.

Another limitation of this study was that all participants used during this study were novice lifters. Apart from the fact that this may have contributed to the large variance in physical responses between participants and test conditions, it also limits the practicality of the research unless dealing with new workers in industry. Given that efficient motor pathways and autonomy are developed with practice of movement it would be worth considering how the introduction of cognitively demanding tasks impacts the movement patterns of experienced lifters.

Since the study focused on the allocation of attentional resources the impact that simultaneous physical and mental demands may have on worker fatigue was not investigated. To control for this the duration of each test condition was only three minutes in order to minimize the impact that fatigue may have on performance, perceptual and physical responses. This short duration may not have been sufficient enough however to induce statistically significant differences in physical responses and may have contributed to the lack of differences between the baseline and dual-task conditions. In a realistic MMH environment it is likely that workers would perform tasks repetitively for an entire work shift of up to eight hours and therefore would reach some level of fatigue. It would thus be worth considering that, if performed over a longer period of time, dual-task performance decrements would have been even greater or whether workers would adapt and develop coping strategies. Future research should investigate how concurrent physical and mental demands impact not only attentional resource allocation but also the fatigability of workers and how this may further influence worker performance and risk injury.

The focus of this research was on the interactive effects of different types of mentally demanding tasks and one specific lifting task. The complexity of the mental tasks was therefore controlled, but since different levels of complexity can significantly impact attentional resource depletion, it would also be important to investigate how more simple or complex cognitive tasks impact the dual-task interaction between concurrent physical and mental demands. Mehta and Parasuraman (2014) observed decreased motor output during concurrent physical and cognitive demands, which they attributed to mental fatigue. While the results for the current study differ from this, it may be worth considering different task complexities and their impact on mental fatigue and subsequent impact on physical performance. Similarly, this research only used a lifting task to produce a physical workload. The effect of dual-task interference during simultaneous physical loads and cognitive information processes may depend on the nature or level of physical activity. Thus, future research should consider other types of physical tasks that are applicable to real work environments other than lifting, such as running, pushing, pulling or assembly tasks as these would be applicable to professions such as the military, firefighters or factory workers. Future research could therefore investigate other types of physical tasks (e.g. static vs dynamic or fine manipulative tasks involving smaller muscles) as well as tasks involving other regions of the body (apart from the lower back) to determine whether similar trends emerge, and provide further information on movement quality and risk MSDs in general. Furthermore, other levels of physical tasks should be investigated as a more demanding physical task may result in a larger interference effect.

Although participants were requested to refrain from physical activity and alcohol/ caffeine consumption prior to testing adherence to this request was not considered and this may have impacted results. Furthermore, other nutritional intake or any medication participants may have been taking was also not controlled for and this may have affected the level of alertness of participants. Future studies should consider such factors.

The time of day that participants were tested was not standardized. This could have influenced the results as some participants may have perceived themselves and being more tired at certain times of the day than others. Given the human circadian rhythm it may also be worthwhile considering how time of day impacts dual-task interaction it future studies.

Individual factors such as personality, cognitive capabilities and genetics were not controlled during the current study. It may also be worth considering the impact of that age may have on dual-task interference as both physical and cognitive capabilities decline with age. This would be applicable to an older workforce.

SIGNIFICANCE OF FINDINGS

The findings from this study suggest an interactive effect between concurrent physical and mental task demands, which indicates cognitive-motor interference associated with cognitive performance decrements, increased perception of physical and cognitive task demands and psychological stress; as well as possible decrements in movements quality and muscle recruitment patterns. Results from the current study provide evidence of a common attentional resource pool from which concurrent mental and physical demands compete for available resources. Additionally, the study indicates the possibility of downregulation of cognitive task performance in order to maintain or improve that of the physical task under cognitive-physical dual-task conditions. Furthermore, findings from this study suggest that, apart from psychological stress measures which increased more during dual-task conditions involving memory tasks, visual and decision-making tasks result in greater dual-task interference compared to that of auditory and memory tasks respectively. This was shown by greater decrements in cognitive task performance and perception during dual-task conditions. Conversely, no impact of sensory modality and stage of processing was indicated for physical performance, RPE or physical responses. Analyses of individual data imply a clear decrement in cognitive performance, but the impact of this interaction on physical performance, task perception and physical responses is individually specific and may depend on the unique characteristics and abilities of different individuals. Therefore, this interactive effect may be detrimental, beneficial, or have no impact on worker performance/productivity, movement quality, on the job error and injury rates and overall worker well-being.

APPENDICES

APPENDIX A: LETTERS OF INFORMATION

Appendix A1: Letter of information to participant

Dear Participant

Thank you for volunteering to participate in the study tilted, “An investigation into the interaction effects of simultaneous physical and cognitive task execution on performance, perceptual and physical responses”.

Background and purpose of research

In a modern day work environment many tasks require some degree of dual tasking, that is, engaging in more than one activity concurrently, and many jobs require the simultaneous performance of cognitive jobs alongside physical activity. Previous research has indicated a possible relationship between concurrent physical and cognitive demands and task performance, safety and efficiency. However this research is both limited and inconsistent.

The aim of this study is to identify the interaction, if any, between a physical and a cognitive task performed concurrently, taking into consideration the possible effects on both physical and cognitive task performance. More specifically, the study focuses on the effect of different types of cognitive tasks, namely visual and auditory memory and decision-making tasks, on the performance of a lifting task. Specific measures of interest include: spinal kinematics, muscle activation, task performance and task perception.

Protocol

In participating in this project you will be required to attend two sessions. During the first session, which is anticipated to last approximately 30 minutes, you will be habituated to the testing procedure, which will be fully explained to you. Upon arrival, you will be briefed verbally about the purpose and the procedures of the study, as well as the risks and benefits associated with the protocol and your rights to optional withdrawal, anonymity and confidentiality. You will be familiarised with all testing equipment as well as the lifting and cognitive tasks you will be required to perform during the protocol, and any concerns or unanswered questions will be addressed. You will be asked to sign the informed consent form, following which, you will be requested to fill out a questionnaire, containing questions about personal characteristics and injury and job history, and basic demographic measurements recorded (stature and mass). During the second session maximum back strength will be measured. The second session will also involve performing all experimental conditions and will last about 2 hours. The experimental protocol consists of nine experimental conditions which will be randomized and which will last 3 minutes each. The following conditions will be tested:

1. A physical lifting task performed in isolation
2. A visual memory task performed in isolation
3. An auditory memory task performed in isolation
4. A visual decision-making task performed in isolation
5. An auditory decision-making task performed in isolation
6. A visual memory task performed in combination with a lifting task
7. A visual decision-making task performed in combination with a lifting task
8. An auditory memory task performed in combination with a lifting task and
9. An auditory decision-making task performed in combination with a lifting task

The decision making tasks will include the Stroop test (visual task), and a sound identification task (auditory task), and the memory tasks will include a 7 digit memory task (visual and auditory). Between tasks you will be given a 10-minute rest break.

Throughout the protocol the following measurements will be recorded: Spinal kinematics and muscle activity will be measured using the Lumbar Motion Monitor and the Biometrix Datalogger surface EMG equipment respectively. The lumbar motion monitor is an exoskeleton of the spine that measures and records instantaneous changes in trunk position, velocity and acceleration and will be secured against your torso by means of a harness. This poses no physical risk to you. The use of EMG equipment will involve the placement of surface electrodes on the skin over the muscles involved. This will involve cleaning and shaving a small area on the skin over the muscle, but this will be done with extreme caution and a new razor will be used for each participant. This will also be done privately. Since surface EMG activity will be monitored, you will be required to perform a reference task before beginning the lifting task. This will involve performing a maximal contraction of all the muscles which will be measured.

Cognitive performance will also be measured throughout the protocol by considering the number of errors made during the cognitive tasks. You will also be asked for your ratings of perceived physical exertion, i.e. how hard you perceive your muscles to be working based on the BORG RPE scale, as well as perceived mental effort based on the SWAT index at regular intervals. Both will be presented and explained to you in detail during the first session.

Risks and benefits

As the protocol requires a manual lifting task to be performed, you will be exposed to some degree of physical and emotional risk when participating in this study. These risks have however been minimized and the risk of injury is highly unlikely.

You will be required to perform a maximal back strength test as well as maximal voluntary exertions of the muscles being tested, which hold the risk of muscle strain or intervertebral disc (IVD) injury. This risk will however be minimized as you have indicated that you have no history of back injuries and you fulfil a certain fitness requirement. You will also be guided through warm-up exercises and shown the correct technique for performing these maximal exertions.

During the lifting task muscle strain of the erector spinal muscles is another risk which may occur due to the physical nature of the task. The load lifted will however be relativized to your personal strength capabilities and will be 4% of your maximum back strength, which will be determined during a maximal back strength test before the commencement of the testing protocol. 4% has been perceived as a highly acceptable load during explorative studies and indicated very low risk of fatigue and therefore possible injury. The duration of the activity will also be limited to 3 minutes to minimize/prevent fatigue, therefore further reducing the risk.

You may also feel some muscle discomfort (delayed onset of muscle soreness) about two days after the experiment, which is due to the unaccustomed nature of the lifting task. This discomfort is however transient and will disappear after a few days.

There is also a risk of cuts and infection, as excess hair has to be removed via shaving before placement of the electrodes. This is however unlikely as a new disposable razor will be used and the skin will be cleaned with alcohol beforehand. Antiseptic cream and plasters will be available in the case of a cut.

You may also feel slightly embarrassed exposing bare skin for the areas where electrodes will be placed. Preparation will however be done in private and nobody else, bar the researcher and another research assistant of the same sex as you will be present.

It is very important that any pain or discomfort experienced during the protocol is reported immediately to the researcher so that any potential injuries can be avoided. Should you feel any discomfort or uneasiness about continuing with the protocol you may withdraw at any point without any negative consequences.

Personal benefits to you will be educational in nature. You will learn more about the nature of kinesiology research and specifically about dual-task performance involving both cognitive and physical parameters. The outcomes of this research could contribute to a better understanding of movement characteristics and assist in the development of intervention strategies for injury prevention and increase task performance and worker well-being.

Privacy and Anonymity

All data collected will remain anonymous by using a coding system instead of your name. The results presented in the report will be summative, i.e. all participants' data together, so no individual participant's results can be singled out. Photographs may be taken for illustrative purposes, but any identifying features will be obscured and no photographs will be taken without your prior consent.

Feedback

The summative results of the project will be made available to you upon completion of the study.

Pre-testing instructions

- Do not consume and alcohol or caffeine (tea, coffee, coke. etc.) before the testing session.
- Do not perform any strenuous exercise 24 hours prior to the testing protocol.

If you have any further questions please to not hesitate to ask.

Yours Sincerely

Natalie Ross	Miriam Mattison (supervisor)
G09r1541@campus.ru.ac.za	m.mattison@ru.ac.za
071 611 3992	

Appendix A2: Participant informed consent form

I ……………………………….. , voluntary consent to participate in the study titled “An investigation into the interaction effects of simultaneous physical and cognitive task execution on performance, perceptual and physical responses”.

I have been fully informed of the experimental requirements as well all the risks and benefits involved in participating in this study and I understand that I should immediately report any signs of distress, discomfort, pain, dizziness, nausea or any other unusual feelings or responses that may be experienced during the study to the researcher. This is important to avoid injury.

By voluntarily consenting to participate in this research I accept joint responsibility together with the Human Kinetics and Ergonomics Department, in that should any injury be sustained due to the protocol, the department will cover any 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 or due to non-compliance with the researcher’s instructions.

I am aware that photographs may be taken during this research and may be used for illustrative purposes, but these photographs will not expose my identity. I realise that whilst my anonymity will be preserved throughout the study, my results may be published as part of the combined group’s results for scientific or statistical purposes.

I am aware that I may withdraw from this study at any point without any negative consequences.

I have read and understood the above information, as well as the information provided in the letter accompanying this form.

Signed at the Department of Human Kinetics and Ergonomics, Rhodes University, on ……/……../2014.

I DO / DO NOT (circle appropriate) consent to having photographs taken provided that identifying features will be obscured.

PARTICIPANT…………………………(NAME)……………………………………(SIGN)

WITNESS………………………………(NAME)……………………………………(SIGN)

REARCHER…………………………(NAME)…………………………………(SIGN)

WITNESS………………………………(NAME)……………………………………(SIGN)

APPENDIX B: PARTICIPANT QUESTIONNAIRE

Participant code	
Age	
Gender	
Stature (cm)	
Mass (kg)	
Maximum back strength	
Knee height (cm)	
Elbow height (cm)	
Have you ever suffered from a lower back injury including IVD injury, muscular injury, non-specific low back pain or other (please specify)	
How often do exercise a week?	
Have you ever worked in a manual materials handling environment or any other job requiring repetitive lifting? If yes, please provide details e.g. Job requirements, hours worked.	
Do you suffer from ADD, ADHD or dyslexia?	

APPENDIX C: SUMMARY DATA TABLES OF SPINAL KINEMATIC MEASUREMENTS

Sagittal plane: first and final ten lifts

Table xx: Spinal kinematic measurements observed in the sagittal plane between dual-task scenarios and baseline measurement during first and final ten lifts (Means ± standard deviation; coefficient of variation%).

	Physical only		**Physical+ visual memory**		**Physical+ auditory memory**		**Physical+ visual decision making**		**Physical+ auditory decision making**	
	First ten lifts	**Final ten lifts**	**First ten lifts**	**Final ten lifts**	**First ten lifts**	**Final ten lifts**	**First ten lifts**	**Final ten lifts**	**First ten lifts**	**Final ten lifts**
Range of motion (°)	26.20± 8.86; 33.83%	23.98± 10.67; 44.51%	23.68± 9.26; 39.09%	21.52± 10.60; 49.26%	23.56± 10.54; 44.74%	22.21± 12.10; 54.45%	25.45± 9.13; 35.86%	22.70± 10.48; 46.17%	23.79± 9.88; 41.52%	22.06± 10.95; 49.66%
Variability in range of motion (%)	13.60± 11.96; 87.95%	18.18± 15.15; 83.71%	20.22± 16.52; 81.65%	19.73± 19.16; 97.13%	15.79± 11.46; 72.58%	16.06± 14.58; 90.78%	14.34± 8.29; 57.80%	22.22± 29.88; 134.45%	26.77± 18.42; 68.81%	19.81± 13.30; 67.13%
Maximum position/ flexion (°)	25.89± 7.25; 27.99%	25.59± 8.12; 32.00%	25.60± 6.51; 25.42%	25.25± 4.20; 16.63%	25.75± 6.54; 25.39%	23.76± 8.16; 34.35%	25.74± 6.50; 25.26%	24.34± 9.12; 37.46%	25.81± 6.59; 25.54%	23.54± 8.15; 35.00%
Minimum position/ extension (°)	0.03± 4.88; 15673.65%	-0.55± 1.42; 258.98%	-0.09± 5.52; 5840.88%	-0.22± 1.71; 788.52%	-0.46± 5.31; 1162.67%	-0.68 ± 6.75; 985.11%	0.93± 5.03; 543.69%	0.84± 5.25; 622.44%	-0.26± 5.19; 2011.20%	-0.35 ± 1.55; 445.15%
Maximum velocity ($m.s^{-1}$)	44.87± 16.28; 36.28%	44.07± 18.97; 43.03%	43.02± 15.97; 37.12%	39.74± 19.66; 49.48%	43.95± 13.75; 31.29%	42.34± 18.22; 43.03%	43.52± 12.89; 29.61%	41.98± 17.26; 41.12%	42.25± 13.32; 31.53%	40.23± 14.68; 36.49%
Maximum acceleration ($m.s^{-2}$)	194.74± 74.18; 38.09%	194.21± 95.30; 49.07%	191.64± 91.27; 47.62%	175.61± 110.06; 62.67%	196.55± 89.28; 45.42%	192.30± 106.23; 55.24%	185.12± 60.08; 32.46%	179.28± 83.55; 46.60%	180.51± 60.29; 33.40%	177.44± 66.22; 37.32%

Frontal plane

Table xxi: Spinal kinematic measurements observed in the frontal plane between dual-task scenarios and baseline measurement during first and final ten lifts (Means ± standard deviation; coefficient of variation%).

	Physical only		**Physical+ visual memory**		**Physical+ auditory memory**		**Physical+ visual decision making**		**Physical+ auditory decision making**	
	First ten lifts	**Final ten lifts**	**First ten lifts**	**Final ten lifts**	**First ten lifts**	**Final ten lifts**	**First ten lifts**	**Final ten lifts**	**First ten lifts**	**Final ten lifts**
Maximum position (°)	3.28± 2.13; 64.83%	3.27± 2.58; 78.89%	3.01± 2.17; 72.13%	3.63± 3.74; 103.19%	3.63± 2.28; 62.81%	3.33± 2.39; 71.77%	3.46± 2.24; 64.75%	4.17± 3.66; 87.83%	3.07± 2.28; 74.47%	3.09± 2.68; 86.84%
Minimum position (°)	0.84± 1.94; 230.49%	0.84± 2.04; 243.75%	0.63± 2.14; 337.51%	0.95± 2.23; 235.49%	1.11± 2.27; 204.88%	1.17± 2.13; 183.09%	0.83± 1.99; 238.10%	1.14± 2.34; 204.78%	0.52± 2.48; 480.21%	0.63± 2.42; 382.60%

Table xxii: Spinal kinematic measurements observed in the frontal plane between dual-task scenarios and baseline measurement (Means ± standard deviation; coefficient of variation%).

	Physical only	**Physical+ visual memory**	**Physical+ auditory memory**	**Physical+ visual decision making**	**Physical+ auditory decision making**
Maximum position (°)	3.10± 2.10; 67.64%	6.67± 10.80; 162.02%	3.32± 2.29; 68.95%	5.23± 8.96; 171.3%1	3.88± 2.59; 66.68%
Minimum position (°)	-2.32± 1.65; -71.17%	-2.15± 2.31; -107.50%	-2.38± 1.85: -77.84%	-2.90± 2.39; -82.32%	-2.26± 1.54; -67.97%

Transverse plane

Table xxiii: Spinal kinematic measurements observed in the transverse plane between dual-task scenarios and baseline measurement during first and final ten lifts (Means ± standard deviation; coefficient of variation%)

	Physical only		**Physical+ visual memory**		**Physical+ auditory memory**		**Physical+ visual decision making**		**Physical+ auditory decision making**	
	First ten lifts	**Final ten lifts**	**First ten lifts**	**Final ten lifts**	**First ten lifts**	**Final ten lifts**	**First ten lifts**	**Final ten lifts**	**First ten lifts**	**Final ten lifts**
Maximum position/ flexion (°)	25.89± 7.25; 27.99%	25.59± 8.12; 32.00%	25.60± 6.51; 25.42%	2.25± 4.20; 186.88%	25.75± 6.54; 25.39%	23.76± 8.16; 34.35%	25.74± 6.50; 25.26%	24.34± 9.12; 37.46%	25.81± 6.59; 25.54%	23.54± 8.15; 35.00%
Minimum position/ extension (°)	0.03± 4.88; 15673.65%	-0.55± 1.42; 256.16%	-0.09± 5.52; 5840.88%	-0.22± 1.71; 788.52%	-0.46± 5.31; 1162.67%	-0.68± 6.75; 985.11%	0.93± 5.03; 543.69%	0.84± 5.25; 622.44%	-0.26± 5.19; 2011.20%	-0.35± 1.55; 445.15%

Table xxiv: Spinal kinematic measurements observed in the transverse plane between dual-task scenarios and baseline measurement (Means ± standard deviation; coefficient of variation%)

	Physical only	**Physical+ visual memory**	**Physical+ auditory memory**	**Physical+ visual decision making**	**Physical+ auditory decision making**
Maximum position (°)	4.99± 2.63; 52.73%	6.15± 4.81; 78.23%	5.17± 2.35; 45.41%	5.68± 3.98; 70.14%	5.04± 2.66; 52.74%
Minimum position (°)	-0.41± 2.50; -613.04%	-0.77± 2.59; -337.88%	-0.58± 3.26; -561.74%	-0.52± 2.58; -492.41%	-1.48± 3.75; -252.89%

APPENDIX D: STATISTICAL TABLES

Table xxv: Post-Hoc Tukey test for difference in cognitive accuracy

Cell No.	LSD test; variable DV_1 (Cognitive accuracy performance) Probabilities for Post Hoc Tests Error: Within MSE = 12,831, df = 133,00								
	R1	VM 27,450	VM+P 25,100	AM 27,100	AM+P 23,350	VD 171,20	VD+P 113,20	AD 20,100	AD+P 17,100
1	VM		0,039949	0,757815	0,000418	0,00	0,00	0,000000	0,000000
2	VM+P	0,039949		0,079751	0,124738	0,00	0,00	0,000021	0,000000
3	AM	0,757815	0,079751		0,001199	0,00	0,00	0,000000	0,000000
4	AM+P	0,000418	0,124738	0,001199		0,00	0,00	0,004789	0,000000
5	VD	0,000000	0,000000	0,000000	0,000000		0,00	0,000000	0,000000
6	VD+P	0,000000	0,000000	0,000000	0,000000	0,00		0,000000	0,000000
7	AD	0,000000	0,000021	0,000000	0,004789	0,00	0,00		0,009064
8	AD+P	0,000000	0,000000	0,000000	0,000000	0,00	0,00	0,009064	

Table xxvi: Two-way ANOVA for impact of sensory modality and stage of information processing on cognitive accuracy

Effect	Repeated Measures Analysis of Variance with Effect Sizes and Powers (Cognitive performance correct responses - Copy) Sigma-restricted parameterization Effective hypothesis decomposition				
	SS	Degr. of Freedom	MS	F	p
Modality	3451,8	1	3451,8	216,75	0,000000
Error	302,6	19	15,9		
Stage	921,2	1	921,2	53,33	0,000001
Error	328,2	19	17,3		

Table xxvii: Post-Hoc Tukey test for difference in cognitive work output

Cell No.	Tukey HSD test; variable DV_1 (Cognitive work output) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 24,325, df = 57,000				
	R1	VD 172,95	VD+P 122,60	AD 20,650	AD+P 20,100
1	VD		0,000158	0,000158	0,000158
2	VD+P	0,000158		0,000158	0,000158
3	AD	0,000158	0,000158		0,984874
4	AD+P	0,000158	0,000158	0,984874	

Table xxviii: Post-Hoc Tukey test for difference in physical performance

Cell No.	Tukey HSD test; variable DV_1 (Number of lifts- physical performance) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 67,420, df = 76,000					
	R1	P 55,800	VM+P 56,350	AM+P 58,400	VD+P 56,250	AD+P 54,550
1	P		0,999594	0,854035	0,999817	0,988899
2	VM+P	0,999594		0,932968	1,000000	0,957428
3	AM+P	0,854035	0,932968		0,921203	0,576804
4	VD+P	0,999817	1,000000	0,921203		0,965290
5	AD+P	0,988899	0,957428	0,576804	0,965290	

Table xxix: Two-way ANOVA for impact of sensory modality and stage of information processing on perceived time pressure

Effect	Repeated Measures Analysis of Variance (Time pressure) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 85,03198				
	SS	Degr. of Freedom	MS	F	p
Intercept	210058,4	1	210058,4	29,05195	0,000034
Error	137378,3	19	7230,4		
Modality	10193,3	1	10193,3	3,36468	0,082319
Error	57560,5	19	3029,5		
Stage	6108,0	1	6108,0	3,71420	0,069039
Error	31245,7	19	1644,5		

Table xxx: Post-Hoc Tukey test for difference in ratings of perceived mental effort

Cell No.	Tukey HSD test; variable DV_1 (Mental effort) Approximate Probabilities for Post Hoc Tests Error: Within MSE = ,23482, df = 133,00								
	R1	VM 1,3500	VM+P 2,1000	AM 1,3000	AM+P 2,1000	VD 1,6000	VD+P 2,4000	AD 1,0500	AD+P 1,5500
1	VM		0,000056	0,999981	0,000056	0,731245	0,000032	0,510831	0,897274
2	VM+P	0,000056		0,000036	1,000000	0,024466	0,510831	0,000032	0,007986
3	AM	0,999981	0,000036		0,000036	0,510831	0,000032	0,731245	0,731245
4	AM+P	0,000056	1,000000	0,000036		0,024466	0,510831	0,000032	0,007986
5	VD	0,731245	0,024466	0,510831	0,024466		0,000036	0,007986	0,999981
6	VD+P	0,000032	0,510831	0,000032	0,510831	0,000036		0,000032	0,000033
7	AD	0,510831	0,000032	0,731245	0,000032	0,007986	0,000032		0,024466
8	AD+P	0,897274	0,007986	0,731245	0,007986	0,999981	0,000033	0,024466	

Table xxxi: Two-way ANOVA for impact of sensory modality and stage of information processing on perceived mental effort

	Repeated Measures Analysis of Variance with Effect Sizes and Powers (Mental effort) Sigma-restricted parameterization Effective hypothesis decomposition				
Effect	SS	Degr. of Freedom	MS	F	p
Error	41375	19	2178		
Modality	12500	1	12500	10,5556	0,004224
Error	22500	19	1184		
Stage	125	1	125	0,0476	0,829586
Error	49875	19	2625		

Table xxxii: Post-Hoc Tukey test for difference in ratings of perceived psychological stress

	Tukey HSD test; variable DV_1 (Stress) Approximate Probabilities for Post Hoc Tests Error: Within MSE = ,15855, df = 133,00								
Cell No.	R1	VM 1,1000	VM+P 2,0500	AM 1,3000	AM+P 2,0500	VD 1,4500	VD+P 2,6000	AD 1,0000	AD+P 1,4000
1	VM		0,000032	0,757553	0,000032	0,100065	0,000032	0,993464	0,249811
2	VM+P	0,000032		0,000032	1,000000	0,000079	0,000354	0,000032	0,000038
3	AM	0,757553	0,000032		0,000032	0,934682	0,000032	0,249811	0,993464
4	AM+P	0,000032	1,000000	0,000032		0,000079	0,000354	0,000032	0,000038
5	VD	0,100065	0,000079	0,934682	0,000079		0,000032	0,008442	0,999929
6	VD+P	0,000032	0,000354	0,000032	0,000354	0,000032		0,000032	0,000032
7	AD	0,993464	0,000032	0,249811	0,000032	0,008442	0,000032		0,032161
8	AD+P	0,249811	0,000038	0,993464	0,000038	0,999929	0,000032	0,032161	

Table xxxiii: Two-way ANOVA for impact of sensory modality and stage of information processing on perceived psychological stress

	Repeated Measures Analysis of Variance with Effect Sizes and Powers (Stress) Sigma-restricted parameterization Effective hypothesis decomposition				
Effect	SS	Degr. of Freedom	MS	F	p
Error	40751	19	2145		
Modality	18001	1	18001	6,739	0,017734
Error	50749	19	2671		
Stage	78127	1	78127	52,778	0,000001
Error	28126	19	1480		

Table xxxiv: Post-Hoc Tukey test for difference in ratings of perceived exertion (RPE)

Cell No.	Tukey HSD test; variable DV_1 (RPE) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 1,1532, df = 76,000					
	R1	P 6,7000	VM+P 7,0000	AM+P 7,7000	VD+P 7,8000	AD+P 6,9500
1	P		0,902215	0,033882	0,014968	0,947389
2	VM+P	0,902215		0,247704	0,139092	0,999904
3	AM+P	0,033882	0,247704		0,998406	0,187785
4	VD+P	0,014968	0,139092	0,998406		0,100759
5	AD+P	0,947389	0,999904	0,187785	0,100759	

Table xxxv: Post-Hoc Tukey test for difference in range of motion during first and final ten lifts (sagittal plane)

Cell No.	Tukey HSD test; variable DV_1 (Total ROM) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 37,907, df = 171,00										
	R1	P1 25,496	PVM1 23,926	PAM1 25,118	PVD1 25,741	PAD1 24,438	P2 26,157	PVM2 21,645	PAM2 24,765	PVD2 25,654	PAD2 23,609
1	P1		0,998511	1,000000	1,000000	0,999942	0,999999	0,614668	0,999998	1,000000	0,993910
2	PVM1	0,998511		0,999842	0,995451	1,000000	0,979914	0,976621	0,999992	0,996872	1,000000
3	PAM1	1,000000	0,999842		0,999999	0,999999	0,999950	0,745816	1,000000	1,000000	0,998914
4	PVD1	1,000000	0,995451	0,999999		0,999668	1,000000	0,524746	0,999971	1,000000	0,985315
5	PAD1	0,999942	1,000000	0,999999	0,999668		0,996983	0,916667	1,000000	0,999813	0,999993
6	P2	0,999999	0,979914	0,999950	1,000000	0,996983		0,377486	0,999431	1,000000	0,952006
7	PVM2	0,614668	0,976621	0,745816	0,524746	0,916667	0,377486		0,847481	0,556894	0,991835
8	PAM2	0,999998	0,999992	1,000000	0,999971	1,000000	0,999431	0,847481		0,999987	0,999878
9	PVD2	1,000000	0,996872	1,000000	1,000000	0,999813	1,000000	0,556894	0,999987		0,989080
10	PAD2	0,993910	1,000000	0,998914	0,985315	0,999993	0,952006	0,991835	0,999878	0,989080	

Table xxxvi: Post-Hoc Tukey test for difference in range of motion (sagittal plane)

Cell No.	Tukey HSD test; variable DV_1 (SAG ROM) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 15,606, df = 76,000					
	R1	P 35,524	P+VM 32,891	P+AM 34,161	P+VD 35,017	P+AD 34,496
1	P		0,227278	0,810456	0,994210	0,922706
2	P+VM	0,227278		0,846845	0,438838	0,701095
3	P+AM	0,810456	0,846845		0,959150	0,998904
4	P+VD	0,994210	0,438838	0,959150		0,993596
5	P+AD	0,922706	0,701095	0,998904	0,993596	

Table xxxvii: Post-Hoc Tukey test for difference in variance in range of motion during first and final ten lifts (sagittal plane)

Cell No.	Tukey HSD test; variable DV_1 (Variance in ROM) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 997,59, df = 171,00										
	R1	P1 19,766	PVM1 44,684	PAM1 17,822	PVD1 17,822	PAD1 22,318	P2 11,475	PVM2 35,019	PAM2 12,234	PVD2 20,674	PAD2 17,624
1	P1		0,270975	1,000000	1,000000	1,000000	0,998132	0,881579	0,999127	1,000000	1,000000
2	PVM1	0,270975		0,177735	0,177735	0,429493	0,030212	0,993983	0,038480	0,323187	0,169676
3	PAM1	1,000000	0,177735		1,000000	0,999988	0,999784	0,783324	0,999926	1,000000	1,000000
4	PVD1	1,000000	0,177735	1,000000		0,999988	0,999784	0,783324	0,999926	1,000000	1,000000
5	PAD1	1,000000	0,429493	0,999983	0,999988		0,986180	0,959948	0,991785	1,000000	0,999983
6	P2	0,998132	0,030212	0,999784	0,999784	0,986180		0,351951	1,000000	0,995845	0,999834
7	PVM2	0,881579	0,993983	0,783324	0,783324	0,959948	0,351951		0,401242	0,915985	0,771570
8	PAM2	0,999127	0,038480	0,999926	0,999926	0,991785	1,000000	0,401242		0,997854	0,999945
9	PVD2	1,000000	0,323187	1,000000	1,000000	1,000000	0,995845	0,915985	0,997854		1,000000
10	PAD2	1,000000	0,169676	1,000000	1,000000	0,999983	0,999834	0,771570	0,999945	1,000000	

Table xxxviii: Post-Hoc Tukey test for difference in variance in range of motion (sagittal plane)

Cell No.	Tukey HSD test; variable DV_1 (SAG VAR) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 1,3130, df = 76,000				
	P 10,163	P+VM 9,3968	P+AM 9,5554	P+VD 9,5606	P+AD 9,3361
1		0,224464	0,453982	0,462842	0,161933
2	0,224464		0,992288	0,991268	0,999840
3	0,453982	0,992288		1,000000	0,973907
4	0,462842	0,991268	1,000000		0,971566
5	0,161933	0,999840	0,973907	0,971566	

Table xxxix: Post-Hoc Tukey test for difference in maximum sagittal position during first and final ten lifts

Cell No.	Tukey HSD test; variable DV_1 (Sagittal maximum position) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 17,404, df = 171,00										
	R1	P1 25,891	PVM1 25,601	PAM1 25,755	PVD1 25,738	PAD1 25,813	P2 25,588	PVM2 22,075	PAM2 23,756	PVD2 24,339	PAD2 23,544
1	P1		1,000000	1,000000	1,000000	1,000000	1,000000	0,107553	0,839811	0,975997	0,748592
2	PVM1	1,000000		1,000000	1,000000	1,000000	1,000000	0,184808	0,928239	0,994487	0,867591
3	PAM1	1,000000	1,000000		1,000000	1,000000	1,000000	0,139962	0,886788	0,987277	0,809306
4	PVD1	1,000000	1,000000	1,000000		1,000000	1,000000	0,144338	0,891820	0,988292	0,816104
5	PAD1	1,000000	1,000000	1,000000	1,000000		1,000000	0,125148	0,867659	0,983073	0,784023
6	P2	1,000000	1,000000	1,000000	1,000000	1,000000		0,188966	0,931152	0,994892	0,871918
7	PVM1	0,107553	0,184808	0,139962	0,144338	0,125148	0,188966		0,959372	0,786581	0,983530
8	PAM2	0,839811	0,928239	0,886788	0,891820	0,867659	0,931152	0,959372		0,999990	1,000000
9	PVD2	0,975997	0,994487	0,987277	0,988292	0,983073	0,994892	0,786581	0,999990		0,999860
10	PAD2	0,748592	0,867591	0,809306	0,816104	0,784023	0,871918	0,983530	1,000000	0,999860	

Table xl: Post-Hoc Tukey test for difference in maximum sagittal position

Cell No.	Tukey HSD test; variable DV_1 (SAG MAX P) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 12,868, df = 76,000					
	R1	P 31,565	P+VM 29,181	P+AM 29,301	P+VD 30,442	P+AD 30,194
1	P		0,230177	0,278230	0,859316	0,746967
2	P+VM	0,230177		0,999974	0,799751	0,898367
3	P+AM	0,278230	0,999974		0,851975	0,933501
4	P+VD	0,859316	0,799751	0,851975		0,999543
5	P+AD	0,746967	0,898367	0,933501	0,999543	

Table xli: Post-Hoc Tukey test for difference in minimum sagittal position during first and final ten lifts

Cell No.	Tukey HSD test; variable DV_1 (SP Min) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 14,897, df = 171,00										
	R1	P1 ,03116	PVM1 -,0944	PAM1 -,4567	PVD1 ,92552	PAD1 -,2580	P2 -,5539	PVM2 -,2166	PAM2 -,6847	PVD2 -,8437	PAD2 -,3483
1	P1		1,000000	0,999996	0,999306	1,000000	0,999980	1,000000	0,999889	0,999420	1,000000
2	PVM1	1,000000		1,000000	0,998031	1,000000	0,999998	1,000000	0,999979	0,999838	1,000000
3	PAM1	0,999996	1,000000		0,981451	1,000000	1,000000	1,000000	1,000000	0,999999	1,000000
4	PVD1	0,999306	0,998031	0,981451		0,993893	0,970672	0,995316	0,949515	0,911453	0,989559
5	PAD1	1,000000	1,000000	1,000000	0,993893		1,000000	1,000000	0,999999	0,999980	1,000000
6	P2	0,999980	0,999998	1,000000	0,970672	1,000000		1,000000	1,000000	1,000000	1,000000
7	PVM2	1,000000	1,000000	1,000000	0,995316	1,000000	1,000000		0,999997	0,999964	1,000000
8	PAM2	0,999889	0,999979	1,000000	0,949515	0,999999	1,000000	0,999997		1,000000	1,000000
9	PVD2	0,999420	0,999838	0,999999	0,911453	0,999980	1,000000	0,999964	1,000000		0,999995
10	PAD2	1,000000	1,000000	1,000000	0,989559	1,000000	1,000000	1,000000	1,000000	0,999995	

Table xlii: Post-Hoc Tukey test for difference in minimum sagittal position

Cell No.	Tukey HSD test; variable DV_1 (SAG MIN P) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 4,8915, df = 76,000				
	P -3,960	P+VM -3,710	P+AM -4,860	P+VD -4,575	P+AD -4,301
1		0,996501	0,700102	0,903709	0,988289
2	0,996501		0,474403	0,730050	0,915401
3	0,700102	0,474403		0,994142	0,930311
4	0,903709	0,730050	0,994142		0,995007
5	0,988289	0,915401	0,930311	0,995007	

Table xliii: Post-Hoc Tukey test for difference in maximum sagittal velocity during first and final ten lifts

	Tukey HSD test; variable DV_1 (Sagittal velocity) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 95,306, df = 171,00										
Cell No.	R1	P1 44,869	PVM1 43,024	PAM1 43,953	PVD1 43,521	PAD1 42,248	P2 44,074	PVM2 39,736	PAM2 42,335	PVD2 41,977	PAD2 40,231
1	P1		0,999870	1,000000	0,999991	0,997778	1,000000	0,816577	0,998293	0,995288	0,891810
2	PVM1	0,999870		1,000000	1,000000	1,000000	0,999999	0,987935	1,000000	0,999999	0,996377
3	PAM1	1,000000	1,000000		1,000000	0,999933	1,000000	0,937516	0,999957	0,999771	0,971701
4	PVD1	0,999991	1,000000	1,000000		0,999995	1,000000	0,968389	0,999997	0,999971	0,987886
5	PAD1	0,997778	1,000000	0,999933	0,999995		0,999881	0,998399	1,000000	1,000000	0,999728
6	P2	1,000000	0,999999	1,000000	1,000000	0,999881		0,926007	0,999921	0,999626	0,965080
7	PVM2	0,816577	0,987935	0,937516	0,968389	0,998399	0,926007		0,997911	0,999356	1,000000
8	PAM2	0,998293	1,000000	0,999957	0,999997	1,000000	0,999921	0,997911		1,000000	0,999615
9	PVD2	0,995288	0,999999	0,999771	0,999971	1,000000	0,999626	0,999356	1,000000		0,999918
10	PAD2	0,891810	0,996377	0,971701	0,987886	0,999728	0,965080	1,000000	0,999615	0,999918	

Table xliv: Post-Hoc Tukey test for difference in maximum sagittal velocity

	Tukey HSD test; variable DV_1 (SAG V) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 232,17, df = 76,000					
Cell No.	R1	P 35,438	P+VM 45,230	P+AM 38,276	P+VD 40,693	P+AD 34,858
1	P		0,261009	0,976426	0,811001	0,999957
2	P+VM	0,261009		0,602089	0,879751	0,209311
3	P+AM	0,976426	0,602089		0,987038	0,953865
4	P+VD	0,811001	0,879751	0,987038		0,745212
5	P+AD	0,999957	0,209311	0,953865	0,745212	

Table xlv: Post-Hoc Tukey test for difference in maximum sagittal acceleration during first and final ten lifts

Cell No.	Tukey HSD test; variable DV_1 (Sagittal acceleration) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 2778,3, df = 171,00										
	R1	P1 194,74	PVM1 191,64	PAM1 196,55	PVD1 185,12	PAD1 180,51	P2 194,21	PVM2 175,61	PAM2 192,30	PVD2 179,28	PAD2 177,44
1	P1		1,000000	1,000000	0,999903	0,997674	1,000000	0,979702	1,000000	0,995626	0,989959
2	PVM1	1,000000		1,000000	0,999997	0,999674	1,000000	0,994260	1,000000	0,999238	0,997710
3	PAM1	1,000000	1,000000		0,999593	0,994213	1,000000	0,962954	1,000000	0,990086	0,979786
4	PVD1	0,999903	0,999997	0,999593		1,000000	0,999940	0,999913	0,999992	0,999999	0,999986
5	PAD1	0,997674	0,999674	0,994213	1,000000		0,998264	1,000000	0,999479	1,000000	1,000000
6	P2	1,000000	1,000000	1,000000	0,999940	0,998264		0,983236	1,000000	0,996633	0,991965
7	PVM2	0,979702	0,994260	0,962954	0,999913	1,000000	0,983236		0,992285	1,000000	1,000000
8	PAM2	1,000000	1,000000	1,000000	0,999992	0,999479	1,000000	0,992285		0,998847	0,996758
9	PVD2	0,995626	0,999238	0,990086	0,999999	1,000000	0,996633	1,000000	0,998847		1,000000
10	PAD2	0,989959	0,997710	0,979786	0,999986	1,000000	0,991965	1,000000	0,996758	1,000000	

Table xlvi: Post-Hoc Tukey test for difference in maximum sagittal acceleration

Cell No.	Tukey HSD test; variable DV_1 (SAG A) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 3538,3, df = 76,000				
	P 286,59	P+VM 289,75	P+AM 303,28	P+VD 286,11	P+AD 273,30
1		0,999838	0,900813	1,000000	0,954412
2	0,999838		0,951497	0,999716	0,905359
3	0,900813	0,951497		0,891182	0,505861
4	1,000000	0,999716	0,891182		0,959998
5	0,954412	0,905359	0,505861	0,959998	

Table xlvii: Post-Hoc Tukey test for differences in frontal plane

Cell No.	Tukey HSD test; variable DV_1 (Frontal) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 26,795, df = 266,00															
	R1	P 3,1000	P+VM 6,6675	P+AM 3,3180	P+VD 5,2300	P+AD 3,8810	P -2,322	P+VM -2,149	P+AM -2,378	P+VD -2,901	P+AD -2,262	P 5,4215	P+VM 8,8160	P+AM 5,6965	P+VD 8,1305	P+VD 6,1435
1	P max		0,679888	1,000000	0,993862	1,000000	0,063933	0,087452	0,057450	0,019882	0,071277	0,985888	0,036097	0,961941	0,126569	0,873247
2	P+VM max	0,679888		0,770435	0,999923	0,932928	0,000030	0,000033	0,000029	0,000027	0,000030	0,999987	0,993310	0,999999	0,999905	1,000000
3	P+AM max	1,000000	0,770435		0,997993	1,000000	0,042065	0,058767	0,037544	0,012245	0,047233	0,994587	0,055364	0,982343	0,177972	0,925451
4	P+VD max	0,993862	0,999923	0,997993		0,999965	0,000403	0,000648	0,000345	0,000090	0,000474	1,000000	0,671731	1,000000	0,909509	1,000000
5	P+AD max	1,000000	0,932928	1,000000	0,999965		0,012699	0,018666	0,011150	0,003168	0,014505	0,999824	0,147483	0,998856	0,372266	0,988933
6	P min	0,063933	0,000030	0,042065	0,000403	0,012699		1,000000	1,000000	1,000000	1,000000	0,000240	0,000026	0,000117	0,000026	0,000047
7	P+VM min	0,087452	0,000033	0,058767	0,000648	0,018666	1,000000		1,000000	1,000000	1,000000	0,000384	0,000026	0,000183	0,000026	0,000064
8	P+AM min	0,057450	0,000029	0,037544	0,000345	0,011150	1,000000	1,000000		1,000000	1,000000	0,000206	0,000026	0,000102	0,000026	0,000044
9	P+VD min	0,019882	0,000027	0,012245	0,000090	0,003168	1,000000	1,000000	1,000000		1,000000	0,000060	0,000026	0,000040	0,000026	0,000029
10	P+AD min	0,071277	0,000030	0,047233	0,000474	0,014505	1,000000	1,000000	1,000000	1,000000		0,000281	0,000026	0,000136	0,000026	0,000052
11	P rom	0,985888	0,999987	0,994587	1,000000	0,999824	0,000240	0,000384	0,000206	0,000060	0,000281		0,752726	1,000000	0,946199	1,000000
12	P+VM rom	0,036097	0,993310	0,055364	0,671731	0,147483	0,000026	0,000026	0,000026	0,000026	0,000026	0,752726		0,850825	1,000000	0,951747
13	P+AM rom	0,961941	0,999999	0,982343	1,000000	0,998856	0,000117	0,000183	0,000102	0,000040	0,000136	1,000000	0,850825		0,978249	1,000000
14	P+VD rom	0,126569	0,999905	0,177972	0,909509	0,372266	0,000026	0,000026	0,000026	0,000026	0,000026	0,946199	1,000000	0,978249		0,996985
15	P+AD rom	0,873247	1,000000	0,925451	1,000000	0,988933	0,000047	0,000064	0,000044	0,000029	0,000052	1,000000	0,951747	1,000000	0,996985	

Table xlviii: Post-Hoc Tukey test for differences in transverse plane

Cell No.	Tukey HSD test; variable DV_1 (Transverse) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 8,8546, df = 266,00															
	R1	P 4,9910	P+VM 6,1530	P+AM 5,1705	P+VD 5,6805	P+AD 5,0400	P -,4070	P+VM -,7655	P+AM -,5800	P+VD -,5240	P+AD -1,484	P 5,3980	P+VM 6,9185	P+AM 5,7505	P+VD 6,2045	P+AD 6,5235
1	P max		0,996396	1,000000	0,999992	1,000000	0,000027	0,000026	0,000027	0,000027	0,000026	1,000000	0,769078	0,999973	0,994391	0,952707
2	P+VM max	0,996396		0,999417	1,000000	0,997706	0,000026	0,000026	0,000026	0,000026	0,000026	0,999974	0,999970	1,000000	1,000000	1,000000
3	P+AM max	1,000000	0,999417		1,000000	1,000000	0,000027	0,000026	0,000026	0,000026	0,000026	1,000000	0,874017	0,999999	0,998967	0,983968
4	P+VD max	0,999992	1,000000	1,000000		0,999997	0,000026	0,000026	0,000026	0,000026	0,000026	1,000000	0,993152	1,000000	1,000000	0,999902
5	P+AD max	1,000000	0,997706	1,000000	0,999997		0,000027	0,000026	0,000026	0,000027	0,000026	1,000000	0,801040	0,999988	0,996315	0,963849
6	P min	0,000027	0,000026	0,000027	0,000026	0,000027		1,000000	1,000000	1,000000	0,998396	0,000026	0,000026	0,000026	0,000026	0,000026
7	P+VM min	0,000026	0,000026	0,000026	0,000026	0,000026	1,000000		1,000000	1,000000	0,999986	0,000026	0,000026	0,000026	0,000026	0,000026
8	P+AM min	0,000027	0,000026	0,000026	0,000026	0,000026	1,000000	1,000000		1,000000	0,999778	0,000026	0,000026	0,000026	0,000026	0,000026
9	P+VD min	0,000027	0,000026	0,000026	0,000026	0,000027	1,000000	1,000000	1,000000		0,999554	0,000026	0,000026	0,000026	0,000026	0,000026
10	P+AD min	0,000026	0,000026	0,000026	0,000026	0,000026	0,998396	0,999986	0,999778	0,999554		0,000026	0,000026	0,000026	0,000026	0,000026
11	P rom	1,000000	0,999974	1,000000	1,000000	1,000000	0,000026	0,000026	0,000026	0,000026	0,000026		0,955642	1,000000	0,999943	0,997418
12	P+VM rom	0,769078	0,999970	0,874017	0,993152	0,801040	0,000026	0,000026	0,000026	0,000026	0,000026	0,955642		0,996199	0,999987	1,000000
13	P+am rom	0,999973	1,000000	0,999999	1,000000	0,999988	0,000026	0,000026	0,000026	0,000026	0,000026	1,000000	0,996199		1,000000	0,999966
14	P+VD rom	0,994391	1,000000	0,998967	1,000000	0,996315	0,000026	0,000026	0,000026	0,000026	0,000026	0,999943	0,999987	1,000000		1,000000
15	P+AD rom	0,952707	1,000000	0,983968	0,999902	0,963849	0,000026	0,000026	0,000026	0,000026	0,000026	0,997418	1,000000	0,999966	1,000000	

Table xlix: Post-Hoc Tukey test for difference in Erector Spinae muscle activity

Cell No.	Tukey HSD test; variable DV_1 (Erector Spinae) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 8,0301, df = 72,000					
	R1	P 53,716	PVM 52,989	PAM 53,658	PVD 53,984	PAD 51,732
1	P		0,932780	0,999997	0,998456	0,207619
2	PVM	0,932780		0,949606	0,815270	0,649801
3	PAM	0,999997	0,949606		0,996601	0,233500
4	PVD	0,998456	0,815270	0,996601		0,114023
5	PAD	0,207619	0,649801	0,233500	0,114023	

Table I: Post-Hoc Tukey test for difference in Rectus Abdominus muscle activity

Cell No.	Tukey HSD test; variable DV_1 (Rectus Abdominus) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 3,0323, df = 72,000					
	R1	P 7,2642	PVM 8,2905	PAM 8,0184	PVD 7,8532	PAD 7,5989
1	P		0,372280	0,670575	0,834784	0,975854
2	PVM	0,372280		0,988866	0,937312	0,737490
3	PAM	0,670575	0,988866		0,998444	0,945767
4	PVD	0,834784	0,937312	0,998444		0,991428
5	PAD	0,975854	0,737490	0,945767	0,991428	

Table Ii: Post-Hoc Tukey test for difference in Biceps Femoris muscle activity

Cell No.	Tukey HSD test; variable DV_1 (Biceps Femoris) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 3,6788, df = 68,000					
	R1	P 13,834	PVM 15,281	PAM 14,405	PVD 14,251	PAD 14,624
1	P		0,170226	0,898809	0,965957	0,731255
2	PVM	0,170226		0,649100	0,495729	0,842034
3	PAM	0,898809	0,649100		0,999296	0,997039
4	PVD	0,965957	0,495729	0,999296		0,977090
5	PAD	0,731255	0,842034	0,997039	0,977090	

Table Iii: Post-Hoc Tukey test for difference in Rectus Femoris muscle activity

Cell No.	Tukey HSD test; variable DV_1 (Rectus Femoris) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 17,373, df = 60,000					
	R1	P 11,858	PVM 12,028	PAM 11,864	PVD 10,097	PAD 11,836
1	P		0,999963	1,000000	0,754148	1,000000
2	PVM	0,999963		0,999968	0,685854	0,999940
3	PAM	1,000000	0,999968		0,751975	1,000000
4	PVD	0,754148	0,685854	0,751975		0,762531
5	PAD	1,000000	0,999940	1,000000	0,762531	

APPENDIX E: CORRELATION ANALYSIS

Table liii: Correlation Matrix showing relationships between all variables during the "P+VM" condition

Variable	Correlations (All varaibles for correlations VM) Marked correlations are significant at p < ,05000															
	ES	RA	BF	RF	AV ROM1	CV1	Max P	Min P	Max V	Max A	Cog perf	RPE	Phys perf	TP	ME	Str
ES	1,000000	0,103943	0,647439	-0,002699	-0,105835	-0,368672	-0,181493	0,038518	0,656877	-0,091718	0,040714	-0,043265	-0,103847	-0,068169	0,168517	-0,088929
RA	0,103943	1,000000	0,284810	0,547633	-0,122836	-0,001950	-0,120168	-0,080853	-0,045745	0,121024	-0,146736	0,179779	-0,081569	0,310258	0,296112	-0,024094
BF	0,647439	0,284810	1,000000	-0,180784	0,017707	0,048005	0,049618	-0,172848	0,656469	-0,200495	-0,208591	0,170869	-0,638436	0,014033	0,154569	0,068107
RF	-0,002699	0,547633	-0,180784	1,000000	-0,037741	-0,186284	-0,080435	0,038840	-0,259661	0,050659	0,008834	0,193491	0,271820	0,124114	0,036615	0,149818
AV ROM1	-0,105835	-0,122836	0,017707	-0,037741	1,000000	0,504813	0,908655	0,116747	0,098835	0,539946	-0,206774	0,208073	0,019984	-0,136039	0,196475	0,651667
CV1	-0,368672	-0,001950	0,048005	-0,186284	0,504813	1,000000	0,658370	0,228503	-0,304858	0,292723	-0,028580	0,447467	-0,366568	0,205571	0,073614	0,300312
Max P	-0,181493	-0,120168	0,049618	-0,080435	0,908655	0,658370	1,000000	-0,047117	0,024898	0,496695	-0,228218	0,440051	-0,129392	0,017776	0,224942	0,626996
Min P	0,038518	-0,080853	-0,172848	0,038840	0,116747	0,228503	-0,047117	1,000000	-0,361528	0,173311	0,494194	-0,142781	0,227894	-0,386379	-0,318164	-0,015548
Max V	0,656877	-0,045745	0,656469	-0,259661	0,098835	-0,304858	0,024898	-0,361528	1,000000	-0,095395	-0,300880	-0,055550	-0,282065	0,062366	0,081382	0,028066

Max A	-0,091718	0,121024	-0,200495	0,050659	0,539946	0,292723	0,496695	0,173311	-0,095395	1,000000	0,019012	0,048081	0,310263	0,045776	0,204443	0,255735
Cog perf	0,040714	-0,146736	-0,208591	0,008834	-0,206774	-0,028580	-0,228218	0,494194	-0,300880	0,019012	1,000000	-0,189297	0,267617	-0,357119	-0,141075	-0,189480
RPE	-0,043265	0,179779	0,170869	0,193491	0,208073	0,447467	0,440051	-0,142781	-0,055550	0,048081	-0,189297	1,000000	-0,244630	0,203560	0,242395	0,431194
Phys perf	-0,103847	-0,081569	-0,638436	0,271820	0,019984	-0,366568	-0,129392	0,227894	-0,282065	0,310263	0,267617	-0,244630	1,000000	0,054679	-0,149482	0,062515
TP	-0,068169	0,310258	0,014033	0,124114	-0,136039	0,205571	0,017776	-0,386379	0,062366	0,045776	-0,357119	0,203560	0,054679	1,000000	0,263251	-0,000000
ME	0,168517	0,296112	0,154569	0,036615	0,196475	0,073614	0,224942	-0,318164	0,081382	0,204443	-0,141075	0,242395	-0,149482	0,263251	1,000000	0,262161
Str	-0,088929	-0,024094	0,068107	0,149818	0,651667	0,300312	0,626996	-0,015548	0,028066	0,255735	-0,189480	0,431194	0,062515	-0,000000	0,262161	1,000000

Table liv: Correlation Matrix showing relationships between all variables during the “P+AM” condition

Variable	Correlations (All varaibles for correlations new AM) Marked correlations are significant at p < ,05000															
	ES	RA	BF	RF	AV ROM1	CV1	Max P	Min P	Max V	Max A	Cog perf	RPE	Phys perf	TP	ME	Str
ES	1,000000	0,450190	0,321606	-0,069323	0,165226	0,104916	0,253417	0,036590	0,564705	0,069693	-0,260005	0,287894	0,049272	-0,146166	0,199784	0,181273
RA	0,450190	1,000000	-0,049945	0,164439	0,035851	0,062913	0,262656	0,306037	0,200367	-0,044609	-0,073858	0,108063	-0,115446	-0,247024	0,143068	-0,088969
BF	0,321606	-0,049945	1,000000	-0,149019	0,058050	-0,033395	0,029926	0,184561	0,442201	-0,464796	-0,136055	0,611907	-0,159801	-0,300096	0,060742	-0,130216
RF	-0,069323	0,164439	-0,149019	1,000000	-0,207629	-0,060775	-0,077298	-0,314545	-0,056140	-0,076198	0,290221	-0,147983	-0,170783	0,365389	-0,173864	0,177438
AV ROM1	0,165226	0,035851	0,058050	-0,207629	1,000000	0,892444	0,852945	0,110508	0,622074	0,209167	0,461277	0,108320	-0,147202	-0,148069	0,004678	0,194403

CV1	0,104916	0,062913	-0,033395	-0,060775	0,892444	1,000000	0,724867	0,032788	0,499970	0,093185	0,444436	-0,086514	-0,354038	-0,069509	0,006552	0,176202
Max P	0,253417	0,262656	0,029926	-0,077298	0,852945	0,724867	1,000000	0,137583	0,519781	0,298787	0,430949	0,057212	-0,073883	-0,129759	0,029534	0,196053
Min P	0,036590	0,306037	0,184561	-0,314545	0,110508	0,032788	0,137583	1,000000	0,147671	-0,028900	-0,011641	0,166947	0,165728	-0,234876	-0,143622	-0,693197
Max V	0,564705	0,200367	0,442201	-0,056140	0,622074	0,499970	0,519781	0,147671	1,000000	-0,105276	0,227721	0,551438	-0,058663	-0,314971	0,032989	0,200005
Max A	0,069693	-0,044609	-0,464796	-0,076198	0,209167	0,093185	0,298787	-0,028900	-0,105276	1,000000	-0,012987	-0,081528	0,307852	0,356652	0,272342	0,370927
Cog perf	-0,260005	-0,073858	-0,136055	0,290221	0,461277	0,444436	0,430949	-0,011641	0,227721	-0,012987	1,000000	-0,180279	-0,089816	-0,155748	-0,299210	0,234742
RPE	0,287894	0,108063	0,611907	-0,147983	0,108320	-0,086514	0,057212	0,166947	0,551438	-0,081528	-0,180279	1,000000	-0,028336	-0,251602	0,052410	0,029410

Phys perf	0,049272	-0,115446	-0,159801	-0,170783	-0,147202	-0,354038	-0,073883	0,165728	-0,058663	0,307852	-0,089816	-0,028336	1,000000	-0,293868	-0,244486	-0,192982
TP	-0,146166	-0,247024	-0,300096	0,365389	-0,148069	-0,069509	-0,129759	-0,234876	-0,314971	0,356652	-0,155748	-0,251602	-0,293868	1,000000	0,000000	0,115342
ME	0,199784	0,143068	0,060742	-0,173864	0,004678	0,006552	0,029534	-0,143622	0,032989	0,272342	-0,299210	0,052410	-0,244486	0,000000	1,000000	0,456267
Str	0,181273	-0,088969	-0,130216	0,177438	0,194403	0,176202	0,196053	-0,693197	0,200005	0,370927	0,234742	0,029410	-0,192982	0,115342	0,456267	1,000000

Table lv: Correlation Matrix showing relationships between all variables during the “P+VD” condition

Variable	Correlations (All varaibles for correlations new VD) Marked correlations are significant at p < ,05000															
	ES	RA	BF	RF	AV ROM1	CV1	Max P	Min P	Max V	Max A	Cog perf	RPE	Phys perf	TP	ME	Str
ES	1,000000	0,347912	-0,116317	-0,096816	-0,421643	-0,231966	-0,299338	-0,022140	-0,137818	-0,020500	-0,181874	0,026847	0,186404	-0,243251	-0,461214	-0,104560
RA	0,347912	1,000000	-0,077870	-0,109687	-0,441086	-0,197373	-0,180183	-0,006995	-0,103868	0,163160	0,099312	0,035113	0,402566	-0,271606	-0,278650	-0,220721
BF	-0,116317	-0,077870	1,000000	-0,165003	0,091613	-0,131732	0,213641	-0,046022	0,211399	-0,008168	-0,132974	0,379067	0,483774	-0,255488	-0,136600	-0,028956
RF	-0,096816	-0,109687	-0,165003	1,000000	-0,214740	-0,062508	-0,373779	0,195996	-0,039249	-0,039263	0,074378	-0,106844	0,026735	0,344209	0,229459	0,082083
AV ROM1	-0,421643	-0,441086	0,091613	-0,214740	1,000000	0,401036	0,861847	0,116380	-0,038061	0,284073	-0,234452	0,049695	-0,133923	-0,043651	0,351461	-0,476919

CV1	-0,231966	-0,197373	-0,131732	-0,062508	0,401036	1,000000	0,528146	0,026300	-0,280542	0,186055	-0,108583	-0,025019	-0,324590	0,190319	0,304713	-0,107332
Max P	-0,299338	-0,180183	0,213641	-0,373779	0,861847	0,528146	1,000000	-0,073412	-0,040146	0,224688	-0,156103	0,136112	-0,118548	-0,272773	0,235443	-0,458148
Min P	-0,022140	-0,006995	-0,046022	0,195996	0,116380	0,026300	-0,073412	1,000000	-0,387676	0,075375	-0,320441	-0,017040	-0,059338	-0,043230	0,074156	0,091196
Max V	-0,137818	-0,103868	0,211399	-0,039249	-0,038061	-0,280542	-0,040146	-0,387676	1,000000	-0,208753	-0,124311	-0,120609	0,072037	0,074690	-0,328619	-0,048239
Max A	-0,020500	0,163160	-0,008168	-0,039263	0,284073	0,186055	0,224688	0,075375	-0,208753	1,000000	-0,004103	-0,158178	0,437336	0,077434	0,224699	-0,154556
Cog perf	-0,181874	0,099312	-0,132974	0,074378	-0,234452	-0,108583	-0,156103	-0,320441	-0,124311	-0,004103	1,000000	0,028458	0,105843	0,079423	0,231743	0,074985
RPE	0,026847	0,035113	0,379067	-0,106844	0,049695	-0,025019	0,136112	-0,017040	-0,120609	-0,158178	0,028458	1,000000	-0,019691	-0,395048	0,215324	-0,240602

Phys perf	0,186404	0,402566	0,483774	0,026735	-0,133923	-0,324590	-0,118548	-0,059338	0,072037	0,437336	0,105843	-0,019691	1,000000	0,143209	-0,207570	-0,273484
TP	-0,243251	-0,271606	-0,255488	0,344209	-0,043651	0,190319	-0,272773	-0,043230	0,074690	0,077434	0,079423	-0,395048	0,143209	1,000000	0,099658	0,115095
ME	-0,461214	-0,278650	-0,136600	0,229459	0,351461	0,304713	0,235443	0,074156	-0,328619	0,224699	0,231743	0,215324	-0,207570	0,099658	1,000000	-0,158533
Str	-0,104560	-0,220721	-0,028956	0,082083	-0,476919	-0,107332	-0,458148	0,091196	-0,048239	-0,154556	0,074985	-0,240602	-0,273484	0,115095	-0,158533	1,000000

Table lvi: Correlation Matrix showing relationships between all variables during the “P+AD” condition

Variable	Correlations (All varaibles for correlations new AD) Marked correlations are significant at p < ,05000															
	ES	RA	BF	RF	AV ROM1	CV1	Max P	Min P	Max V	Max A	Cog perf	RPE	Phys perf	TP	ME	Str
ES	1,000000	0,487663	-0,562883	0,024229	-0,173042	-0,174037	-0,229185	-0,202721	-0,030736	0,338988	0,244263	-0,094621	0,300256	-0,228476	0,093449	0,314183
RA	0,487663	1,000000	-0,726384	0,173935	-0,167713	-0,016854	-0,041315	-0,514638	-0,155559	-0,035827	0,156629	-0,124628	-0,149324	-0,135320	-0,338758	0,210920
BF	-0,562883	-0,726384	1,000000	0,162149	0,345441	0,280288	0,248731	0,403384	0,333278	0,149247	-0,178107	0,266457	-0,099756	0,232235	0,237643	-0,108074
RF	0,024229	0,173935	0,162149	1,000000	-0,119259	-0,242535	-0,221077	0,124780	0,103236	-0,019215	-0,044324	0,044342	-0,460574	0,015024	0,390278	0,250449
AV ROM1	-0,173042	-0,167713	0,345441	-0,119259	1,000000	0,704674	0,777022	0,409779	0,731391	-0,051450	-0,231890	0,305731	0,091233	-0,150334	-0,047084	-0,214866
CV1	-0,174037	-0,016854	0,280288	-0,242535	0,704674	1,000000	0,708293	0,113715	0,570841	0,045336	-0,391087	0,303828	-0,294681	0,152904	-0,333286	-0,472863
Max P	-0,229185	-0,041315	0,248731	-0,221077	0,777022	0,708293	1,000000	0,207708	0,340397	0,086231	-0,197100	0,125707	0,196608	-0,065756	-0,402651	-0,246149
Min P	-0,202721	-0,514638	0,403384	0,124780	0,409779	0,113715	0,207708	1,000000	0,154967	-0,112933	-0,203170	0,189846	0,010869	-0,208471	-0,037432	-0,183488
Max V	-0,030736	-0,155559	0,333278	0,103236	0,731391	0,570841	0,340397	0,154967	1,000000	-0,048732	-0,487126	0,302086	-0,204281	-0,079970	0,238129	-0,213426
Max A	0,338988	-0,035827	0,149247	-0,019215	-0,051450	0,045336	0,086231	-0,112933	-0,048732	1,000000	-0,100441	0,404927	0,302025	-0,112440	0,130940	0,032111

Cog perf	0,244263	0,156629	-0,178107	-0,044324	-0,231890	-0,391087	-0,197100	-0,203170	-0,487126	-0,100441	1,000000	-0,076146	0,316942	0,050308	0,064159	0,296416
RPE	-0,094621	-0,124628	0,266457	0,044342	0,305731	0,303828	0,125707	0,189846	0,302086	0,404927	-0,076146	1,000000	-0,231506	0,000000	0,000000	-0,545855
Phys perf	0,300256	-0,149324	-0,099756	-0,460574	0,091233	-0,294681	0,196608	0,010869	-0,204281	0,302025	0,316942	-0,231506	1,000000	-0,259584	0,034227	0,285483
TP	-0,228476	-0,135320	0,232235	0,015024	-0,150334	0,152904	-0,065756	-0,208471	-0,079970	-0,112440	0,050308	0,000000	-0,259584	1,000000	0,107571	-0,093594
ME	0,093449	-0,338758	0,237643	0,390278	-0,047084	-0,333286	-0,402651	-0,037432	0,238129	0,130940	0,064159	0,000000	0,034227	0,107571	1,000000	0,273827
Str	0,314183	0,210920	-0,108074	0,250449	-0,214866	-0,472863	-0,246149	-0,183488	-0,213426	0,032111	0,296416	-0,545855	0,285483	-0,093594	0,273827	1,000000

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