COMBINED AND ADDITIVE EFFECTS OF ASSEMBLY TASKS AND CONSTRAINED BODY POSTURES

BY

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THESIS

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ABSTRACT

Despite extensive research into musculoskeletal disorders (MSDs) they continue to plague workers. Manual materials handling (MMH), in particular the concurrence of load manipulation and awkward body posture, has been identified as a key factor in the onset of MSDs. Only a few studies have looked at the interaction between *manipulation tasks* and working posture during assembly tasks and as a result their relationship has not been widely explored.

Assessing the stresses resulting from individual task factors and body posture in isolation and adding them together may be too simplified to estimate an overall risk profile, since this does not take into account that there may be a non-linear interaction in strain responses when manipulation task and body posture *interact*. Therefore, the present study investigated biophysical, physiological and psychophysical responses to combined tasks, rather than individual tasks of body posture and manipulative tasks. The objective of the research was to establish the interactive effects of constrained body postures and manipulative tasks and to identify whether a cumulative or compensatory reaction occurs during this interaction.

Nine conditions were assessed in a laboratory setting, which included combinations of three working postures (standing, sitting and stooping) and three assembly tasks (torque wrenching, precision and no task). Thirty-six subjects were required to complete all nine conditions, with each condition lasting ninety seconds. Muscle activity was recorded for seven muscles from the upper extremity, trunk and lower extremity regions and was complemented by physiological (heart rate, tidal volume, minute ventilation, oxygen consumption, energy expenditure and breathing frequency) and psychophysical (body discomfort) data. At the completion of all nine conditions subjects completed a retrospective psychophysical rating questionnaire pertaining to discomfort felt during the conditions.

Responses obtained for the different task and posture combinations revealed compensatory reactions (additive > combined) for most of the conditions assessed for the biomechanical and physiological responses. In the majority of cases for muscle activity, no significant differences were found between the combined and the additive effects ($p < 0.05$), while for the physiological responses there were mostly significant differences observed. Psychophysical responses indicated that there was a significant difference overall between the additive and combined effects.

The results of this study demonstrate that in order to identify risk areas, manipulation tasks and constrained working postures may be considered either in isolation and added together (additive) or as a combined task, since there were very few significant differences observed between these two effects. Further studies are required, however, to provide conclusive evidence.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

The rapid development in technology and the consequential introduction of automation into work environments has resulted in the need for extensive modifications to many working areas. Subsequently, in an ever-changing society, where new challenges are constantly emerging between human operators and their work, it is essential that ergonomics evolves at a corresponding rate (Moray, 2000). Ironically, despite an increase in automation and the consequent reduction in physically demanding jobs, as well as substantial research aimed at reducing work-related injuries (WRI), they continue to plague the working population (Mital and Ramakrishnan, 1999; Waters, 2005). The continued occurrence of musculoskeletal disorders (MSDs) are the principal reason researchers are concerning themselves with activities such as light manual assembly and precision tasks, complementing the work performed on manual materials handling (MMH).

In 2000, the World Health Organisation (WHO) showed that, while work is mostly beneficial in terms of social status, physical conditioning and financial gain, approximately 30% of the workforce in industrially advanced countries and, as many as 70% in industrially developing countries, may be exposed to ergonomically poor working conditions. This is compounded by the reality that most workers in developing countries have limited levels of education and labour forces constitute predominantly “cheap” labour (Asogwa, 1987; Mohan, 1987), thereby resulting in a vulnerable workforce which is more susceptible to diseases and job-related accidents.

Due to this, as well as the ongoing mismatch between task demands and worker capabilities and because of the general nature of industrial tasks, MSDs are the most frequently observed work-related injuries (Hagberg *et al.*, 1995; Bernard, 1998; Buckle and Devereux, 1999; Op de Beeck and Hermans, 2000). It is widely acknowledged that, if the strain placed on either the cardiovascular or musculoskeletal system exceeds the capacity of the system, the possible results may include discomfort, fatigue and injury (Snook, 1978; Mital *et al*., 1993; Resnick and Chaffin, 1995; Dempsey, 1998; Mital, 1999; Chung *et al*., 2001; Kumar and Scaife, 2006). Work-related musculoskeletal disorders (WMSDs) are currently the principal reason for worker absenteeism, and are the main cause of both short-term and permanent work disability, resulting in economic losses estimated to be as high as 5% of Gross Domestic Product (GDP) (South African Department of Labour, 2007). These statistics indicate that WMSDs are not abating but rather incidences of MSDs remain unchanged or are increasing annually.

Manual materials handling has been cited as a major cause of these disorders and therefore a large amount of research has focused on MMH, in particular on the different interactions between load manipulation and body posture (Garg *et al*., 1978; Dempsey, 1998; Li and Haslegrave 1999; Mital, 1999; Kumar and Scaife, 2006). However, as technology has changed and international competition increased, so too has the manufacturing process, which in turn has resulted in an increase in the prevalence of light manual assembly and precision tasks in many industries (Wartenberg *et al*., 2004). Previously, these tasks received little attention in ergonomics literature, possibly due to its minor effect on the physical aspects of the workplace (Li and Haslegrave, 1999). Similarly, despite Goebel (1996) and Sporrong *et al*. (1998) demonstrating that even light manual assembly and precision tasks increase muscle activity and therefore muscle stress, there is widespread sentiment that precision tasks, provided they are dynamic in nature, do not lead to significant strains in the muscles. Therefore, with the increasing prevalence of these tasks occurring in many industries, as well as the continual presence of MSDs, it is becoming increasingly imperative that researchers focus their attention in this area in order to establish the underlying causes of these disorders.

Numerous industrial workplaces provide examples of industries where light manual assembly and precision tasks are common-place. The automotive industry is one such example. Since automobile assembly has been shown to be one of the most labour intensive industries (Chung *et al*., 2001) and requires workers to be highly skilled, several researchers have explored the relationship between automobile assembly work and musculoskeletal symptoms (Gallagher *et al*., 1988; Chung *et al*., 2001; Hussain, 2004). Results from these studies consistently indicate that there is an association between assembly work and MSDs (Hussain, 2004). Therefore, considering that motor vehicle export constitutes a large percentage of the GDP of South Africa (South African Department of Labour, 2007), it is essential to minimise the number of injuries and MSDs obtained during the assembly process, which will help to improve the efficiency of work and increase productivity (Chung *et al*., 2001).

Workers involved in automobile assembly are typically required to perform tasks which are not physically exhausting; for instance, small drilling, hammering, screwing or wrenching movements, as well as precision placing and clipping (Chung *et al*., 2001). Furthermore, these authors have shown that the execution of light manual assembly or precision tasks are often coupled with awkward working postures, of which squatting and trunk flexion, with lateral bending and twisting are the most commonly observed in the automotive industry. Figure 1 illustrates some of these interactions and demonstrates the awkward postures some workers are exposed to during assembly work in the automotive industry.

Figure 1: Examples of assembly work in the automotive industry involving the interaction between manipulative tasks and awkward working postures**.**

Interactions of posture and task

Although assembly work in general has been widely researched, few studies have dealt with the interactive effects of performing assembly tasks whilst positioned in awkward postures (Winter *et al*., 2006). At an initial glance working postures and manipulative tasks use different muscles in their execution. Hence, if these factors are performed in isolation then they could be considered independent from each other. However, often in the automotive industry there is an interaction between body posture and assembly task. These interactive effects may contribute to the occurrence of MSDs evidenced in the automotive industry. A possible explanation for this was provided by Goebel (1996) and Sporrong *et al*. (1998) who suggest that, when awkward body postures are coupled with the execution of manipulative tasks, co-contraction of antagonistic muscles is necessary to maintain the working posture as well as to stabilise the body. Furthermore, Hendriks *et al*. (2006) stated that the musculoskeletal system forms a biomechanical chain connecting adjacent sections together, whereby stresses from a given task are transferred through the body via the bone structures and compound the stresses incurred from awkward body postures. More specifically, Granata *et al*. (2005) and Hendriks *et al*. (2006) showed that during *manipulation tasks* there is a transfer of force through this chain, ultimately resulting in increased stresses on the body. Thus, due to the necessity of having to stabilise the body, as well as having to accurately perform a manipulative task, the combined effect of the two is expected to contribute to the overall risk of injury.

Only a limited number of studies have looked at the interactive effects that combined manipulation tasks and body posture during assembly tasks have on the musculoskeletal system. However, researchers have identified the importance of assessing task factors other than those observed during MMH. Therefore, the current research will endeavor to identify harmful interactive effects in these particular work situations by simulating postures and tasks observed during the assembly process. It is believed that the selected tasks can also be applied to other types of work and not only to automotive assembly, thus increasing the applicability of the current research.

STATEMENT OF THE PROBLEM

Despite extensive research into MSDs and intervention strategies, MSDs continue to plague the working population. Manual materials handling tasks have been cited as the major cause of these disorders. Therefore, a large part of MSD research has focused on these activities, in particular the interaction between different load factors and body posture. However, the interaction between manipulative tasks and constrained working postures during assembly tasks has not been widely explored and thus their precise relationship is presently unknown. Seemingly, a common thought is that the stresses resulting from individual task factors can be summed up to provide an overall risk profile. However, the current study hypothesises that there is a non-linear relationship to strain and thus, risk, when two or more task factors interact.

The objective of the current research was to identify whether significant interaction effects exist between the posture adopted by workers and the manipulative task they are performing. This will add to the understanding of the biomechanical, physiological and psychophysical effects that such complex or combined tasks have on individuals, and whether the interaction of those factors contribute to the risk of injury.

RESEARCH HYPOTHESES

This study aims to identify whether an interaction between an individual's working posture (tested for stooping and sitting) and the manipulative task being performed (tested for a torque wrenching and a precision task) exists, and whether any exaggerated effects, such as increased effort or strain, are observed due to this interaction. It is expected that the interaction of awkward body posture and manipulative task will elicit similar physiological, biomechanical and psychophysical responses to those observed for task and posture measured separately.

STATISTICAL HYPOTHESES

Where: A is the effect of body posture only

B is the effect of the activity only

C is the effect of the combined body posture and activity

Hypothesis 1: The null hypothesis states that the biophysical responses obtained from the effect of body posture only plus the effect of the activity only will not be significantly different to those obtained from the effect of the interaction between body posture and activity.

H_o: $\mu_{biophys(A+B)} = \mu_{biophys(C)}$

$H_{a:}$ $\mu_{biophys(A+B)} \neq \mu_{biophys(C)}$

Where biophys = biophysical responses (e.g. muscular activity)

Hypothesis 2: The null hypothesis states that the physiological responses obtained from the effect of body posture only plus the effect of the activity only will not be significantly different to those obtained from the effect of the interaction between body posture and activity.

H_o: $\mu_{phys(A+B)} = \mu_{phys(C)}$

$H_{a:}$ $\mu_{phys(A+B)} \neq \mu_{phys(C)}$

Where phys = physiological responses (e.g. heart rate; breathing frequency; minute ventilation; oxygen consumption; tidal volume; energy expenditure)

Hypothesis 3: The null hypothesis states that the psychophysical responses obtained from the effect of body posture only plus the effect of the activity only will not be significantly different to those obtained from the effect of the interaction between body posture and activity.

H_o: $\mu_{psychophys(A+B)} = \mu_{psychophys(C)}$

$H_{a:}$ $\mu_{psychophys(A+B)} \neq \mu_{psychophys(C)}$

Where psychophys = psychophysical responses (e.g. perceived body discomfort)

DELIMITATIONS

This study examined the physiological, biomechanical and psychophysical responses observed during a combined manipulative task and constrained body posture. It was delimited to the responses of 18 female and 18 male subjects aged between 20 and 28 years and falling within a stature range of 1600mm and 1850mm, to reduce the variability between trunk flexion angles. The testing procedures were confined to a laboratory setting and therefore environmental factors, such as lighting and temperature, were controlled. The tasks assessed during this research were limited to the examples of a precision and a torque wrenching task and the postures were limited to stooping and sitting. Furthermore, the study was based on tasks observed in the automotive industry, which may have an impact on the applicability to other industries.

LIMITATIONS

Due to the numerous interactions and responses occurring during an investigation, it is virtually impossible to control all factors which could affect the results, especially when conscious and unconscious behavioural effects on physiological, biomechanical and psychophysical parameters cannot be excluded. Effort was made to ensure that interfering factors were rigorously controlled; however, the following limitations still remained:

Subjects were not randomly selected, but were student volunteers from different departments at Rhodes University, thereby limiting the applicability of the results, particularly if considering elderly persons.

Electromyography electrodes are subject to crosstalk from nearby muscle activity. Therefore, effort was made to ensure crosstalk was minimised but, despite this, there is a small chance that this may have occurred. This influence varies depending on the muscle studied, but we found this to be about the same for all the subjects as standardised electrode settings were used.

It was not possible to have a testing duration that exceeded two minutes as the muscles would become fatigued; as a consequence of this, steady-state was not reached for all of the physiological responses.

Although subjects were familiarised prior to testing in each of the conditions, the environment in which they were tested was not familiar to them. Furthermore, the equipment used required markers and electrodes to be placed on the skin throughout the testing. These factors augmented the lack of familiarity and may have influenced the subjects' responses.

Clear and detailed instructions on the use of the rating scales for perceptual purposes were given to each subject; however, the researcher had no means of ensuring that the subjects had a clear understanding and could use the scale properly. Since this scale is a "self report" chart, the validity needs to be assessed in this light.

Although a written and verbal request was made to subjects to maintain normal eating, drinking and exercising habits (see Appendix B1), the researcher could not be certain that this was adhered to, besides asking the individual on arrival for testing. As a result, this could have affected the physiological responses obtained.

No extrinsic rewards were offered, although verbal encouragement was given. This may have provided some subjects with increased motivation, thereby encouraging them to perform better, while for others this may not have had an impact.

Another possible source of error was the development of fatigue during the tasks; however, this was evaluated by looking at the trends of the muscle activity and according to this, no fatigue was setting in.

CHAPTER II

REVIEW OF RELATED LITERATURE

INTRODUCTION

The association between awkward working postures and the development of musculoskeletal disorders (MSDs) during manual materials handling (MMH) tasks has been widely researched in previous literature (Mital and Ayoub, 1989; Snook and Ciriello, 1991; Hidalgo *et al*., 1995; Delleman *et al*., 2004). The notion that MMH tasks are the main cause of these disorders has been the driving force behind these studies. However, despite numerous attempts at reducing these disorders, MSDs continue to plague industrial workplaces. For this reason, increasing numbers of authors are directing their focus towards light, manipulative tasks found in industry, in particular assembly tasks, and their influences on the human operator and MSDs (Chung *et al*., 2001). Therefore, the effects of manipulative tasks on the human operator are yet to be explored in depth. What is known and accepted however, is that even with all the studies performed on MMH tasks, the prevalence and severity of MSDs is still present (Waters, 2005; Colombini and Occhipinti, 2006), thereby suggesting a more complex problem.

ERGONOMICS IN INDUSTRIALLY DEVELOPING COUNTRIES

Over several decades, ergonomics has gained credibility in almost all industrial areas including mining, automobile assembly, forestry, product manufacturing and military. This is due to the recognition that human labour is a vital component in each of these areas and the consequences of neglecting ergonomic principles are detrimental to all parties involved in the interaction. In industrially developing countries (IDCs), especially, there is a lack of consideration of these principles and thus the resultant incompatibility between tasks and workers leads to absenteeism, production losses and errors, poor worker morale and an increase in worker compensation (Helali and Shahnavaz, 2003).

Recently, with increases in the complexity of requirements in the working environment, and in conjunction with increased pressure for efficiency, operators are having to cope with more complex tasks. At the same time they are obliged to have a more precise knowledge of these tasks and their effects on the musculoskeletal system in order to identify whether occupational risks are present in their work environment.

Wyndham (1975) noted that since there is a shortage of available resources and capital for automated machinery, most industries in IDCs rely more on manual labour, thereby resulting in stresses on the musculoskeletal system which manifest themselves as MSDs. Kemmlert *et al.* (1993) and Leboeuf-Yde *et al.* (1996) reported that even in countries where ergonomic approaches have been widely implemented in industry, MSDs still occur. More recently, however, Graf *et al*. (1995), Murphy *et al*. (1996) and Scott (1999) argue that in many IDCs heavy physical work is slowly being replaced with light manual assembly tasks, yet MSDs are still prevalent in these workplaces. Furthermore, in IDCs, workers are often required to perform work in awkward body postures due to the arrangement of the workplace, as well as the nature of the work which they are required to carry out. These awkward postures, coupled with light assembly tasks may result in a greater prevalence of MSDs occurring in workers in IDCs.

MUSCULOSKELETAL DISORDERS

According to Dempsey (1998), different task demands place physical stresses on operators and draw upon their biomechanical, physiological and psychological capacities. Already, Taylor (1911) demonstrated the positive effect that keeping task demands within physical capabilities has on productivity. In developing countries a balance is seldom found as worker capacity is often exceeded by the demands of the task. This places stresses on the body that are manifested as strains on the musculoskeletal and cardiovascular systems. Although the human body is capable of performing in a wide variety of environments and circumstances, there are occasions when awkward tasks or environmental demands exceed the capacity of the musculoskeletal system, thereby resulting in discomfort, fatigue and injury (Snook, 1978; Ayoub *et al*., 1983; Mital *et al*., 1993; Resnick and Chaffin, 1995; Dempsey, 1998; Mital, 1999; Gallagher, 2005).

In the industrialised world, the incidence of MSDs has reached epidemic proportions. Work-related musculoskeletal disorders (WMSDs) occur frequently in industrial workplaces and are a cause for concern for managers and workforces alike (Hagberg *et al*., 1995; Bernard, 1998; Buckle and Devereux, 1999; Op de Beeck and Hermans, 2000; Buckle and Devereux, 2002; Bosch *et al*., 2007). Hussain (2004) stated that annually in the UK, approximately 1.2 million adults are affected by MSDs caused or aggravated by work, while in the United States alone these disorders affect a quarter of all workers (US Bureau of Labour Statistics, 2004). Similarly, it has been reported that 65% of all non-fatal occupational disease cases reported in the United States in 2002 were associated with WMSDs in the manufacturing sector, with motor vehicles and car body industries recording the highest rate of WMSDs in 2002 (692 injuries for every 10000 workers; US Bureau of Labour Statistics, 2004). Numerous authors have shown that a higher degree of muscle activation is experienced when fatigue sets in and this has subsequently been linked to a greater prevalence of MSDs (Op de Beeck and Hermans, 2000; Buckle and Devereux, 2002; Bosch *et al*., 2007).

Despite the difficulty of making international comparisons, reports show that there is a substantial and regular increase in MSDs worldwide (Waters, 2005). This is an opinion which is echoed by Colombini and Occhipinti (2006), who assert that WMSDs continue to plague industrial work forces. The US Bureau of Labour Statistics (2004) suggested that in 2001, over half a million cases of musculoskeletal disorders were reported in the United States alone. It is further estimated that 5.4 million working days are lost annually due to work-related neck and upper limb MSDs, costing industries over $100 billion in compensation (Paoli, 1997). Therefore, after receiving minimal attention throughout the first half of the 20^{th} century, WMSDs have become one of the main focuses in the area of occupational injury prevention (Colombini and Occhipinti, 2006).

Manual materials handling is a major cause of these injuries. However, recent research into assembly tasks found evidence to suggest that even small forces placed on the worker may have negative and detrimental effects on the musculoskeletal and cardiovascular systems (Chung *et al*., 2001; Escorpizo and Moore, 2007). This is illustrated in figures from the United States Bureau of Labour Statistics (2004) which reported 17,800 cases of MSDs associated with manipulative tasks such as grasping, placing and moving objects for the year 2003 alone. Many of these injuries are caused by static postures, sometimes with forceful exertions or repetitive movements (Delleman *et al*., 2004). There is no comprehensive database in South Africa which provides figures for the South African context, thereby making comparisons with international values difficult.

Kumar (2001) stated that although work is an essential part of society and the nature of work is mostly predetermined, there is little that can be done to change the incidence of injury occurring in the workplace. Kumar (2001) further stated that these injuries are, however, preventable and controllable with an understanding of the cause of occupational accidents. Thus, if worker capabilities are fully understood and the workplace is effectively designed, then a more pertinent intervention can occur, resulting in better control of injuries which have significant cost-saving results.

Gender and WMSDs

Traditionally, males have made up the majority of the workforce in industry; however the demographics of the industrial labour force are changing as the number of female operators being employed in the workplace is increasing. In 2005, women accounted for 45% of all workers in the United States (US Bureau of Labour Statistics, 2004) and in South Africa the rate of female participation in the labour force rose from 47.4% in 2004 to 51.1% in 2006 (Statistics South Africa, 2007). This is of concern to the ergonomist since, according to Sharp *et al*. (1993), females have 53% of the whole body strength of males, yet they are required to produce at the same intensity as males, while being at an obvious disadvantage. Therefore, a weaker person will work at a higher relative force level than an individual who is bigger and stronger, thus resulting in muscle strain and fatigue (Mital and Sanghavi, 1986). This results in an increase in the prevalence of MSDs among women operators (Knapik, 1997). In 2000/01, men and women were equally likely to endure MSDs, however in 2004 it was noted that women now accounted for two-thirds of all reported work-related injuries (US Bureau of Labour Statistics, 2004).

MSDs of the upper extremity

Studies show that upper-limb WMSDs (UL-WMSDs) have become a major problem in recent times, with increasing incidence and prevalence (Visser *et al*., 2004). Furthermore, UL-WMSDs have been identified as the most common form of WMSDs in the United States, Europe and in other parts of the industrialised world (Visser *et al*., 2004). In one year alone in the United States, the total compensable cost for upper-limb WMSDs was estimated to be $563 million (Webster and Snook, 1994), and in 2004, Eurostat indicated that in Europe, UL-WMSDs account for 45% of all occupational diseases.

Previously it was thought that UL-WMSDs were caused by high forces acting on the upper extremities. However, the National Research Council and Institute of Medicine (2001) and Andersen *et al*. (2003) reported that they also occurred in the absence of high force exertion and in the presence of precision movements. Therefore the risk factors for UL-WMSDs have recently been recognised to include not only repetitiveness (Kilbom, 1992; Ekberg *et al*., 1995; Piligian *et al*., 2000; Bosch *et al*., 2007), elevated arms (Bjelle *et al*., 1981; Kilbom and Persson, 1987), and unnatural or static loads (Monad, 1985; Aarås, 1987; Kilbom and Persson, 1987; Shahnavaz, 1987; Bosch *et al*., 2007), but precision demands as well (Ekberg *et al*., 1995; Buckle and Devereux, 2002; Visser *et al*., 2004). Precision demands in particular require that the muscles of the upper limb stabilise this body region, thereby causing stress to the muscles and other surrounding soft tissues.

During assembly work upper extremity stresses are plentiful (Sporrong *et al*., 1998). Schüldt *et al*. (1986) demonstrated that sustained tension in the neck and shoulder muscles has been considered a possible predisposing factor in the development of MSDs. More specifically, the use of hand tools has been associated with increased incidence rates of UL-WMSDs by introducing static loading on the musculature through repetitive gripping, supporting the weight of the tool, exposure to vibration and deviated hand postures (Armstrong *et al*., 1982; Grant *et al*., 1994; Mital, 1999). Kruizinga *et al*. (1998), Sporrong *et al*. (1998) and Escorpizo and Moore (2007) describe how, as increased hand activity is required, the shoulder muscles require further stabilising contractions which increases the risk of MSDs. Very little research has been performed on the effect of high precision demands on the shoulder muscles (Sporrong *et al*., 1998). However one such study by Milerad and Ericson (1994) found that precision tasks had a significant influence on these muscles and that the stresses increased with greater precision requirements.

MSDs of the lower back

Low back pain (LBP) has affected work forces for decades and occurs at an alarming frequency (Ayoub, 1992). According to Bernard *et al*. (1999), the lifetime prevalence of LBP is estimated at approximately 75%, while more recently numerous authors such as Cunningham *et al*. (2006) and Ghaffari *et al*. (2006) have shown this figure to be between 50% and 85%. Back injuries are the largest single category of MSDs and are one of the most common and most costly MSDs suffered in the workplace (Ayoub, 1992; Marras, 2000; Song *et al*., 2004). This is highlighted by Marras (2000) who showed that back injuries and disabling low back pain incidents are responsible for up to 25.5% of all worker compensation claims. Furthermore, approximately 70 million Americans (and increasing by 7 million per year) suffer from back injuries (Caillet, 1994). Ayoub (1992) believes that in the United Kingdom, 19% of all reported accidents affect the spine and trunk.

Research by Pope and Novotny (1993) showed that, although the precise cause of LBP is not known in 80 to 90% of cases, mechanical loading and work posture are speculated to be important risk factors (Omino and Hayashi, 1992). Other risk factors identified by Norman *et al*. (1998) and Neumann *et al*. (2001) include awkward postures, heavy physical work and forceful movements, as well as sustained static postures of the trunk. Marras *et al*. (1993) and Granata *et al*. (2005) propose that there is an increased risk of LBP for workers who perform periods of static or cyclic trunk flexion. Few studies, if any, have looked at precision tasks or light manual assembly tasks in relation to LBP, as historically, these do not cause significant stresses on the musculoskeletal system.

According to de Souza and Coury (2005), epidemiological and biomechanical studies have shown a relationship between low back injuries and deviation away from the neutral standing position. This is substantiated by results from at least two studies (Keyserling *et al.*, 1992; Bernard, 1998) where evidence of a relationship between non-neutral postures and LBP were found. Furthermore, Splittstoesser *et al*. (2007) state that stooped, restricted, kneeling and other awkward working postures have frequently been associated with the onset of LBP, while Vingård *et al*. (2000) and Gallagher (2005) agree that flexion of the trunk increases the prevalence of low back disorders. However, it is not only the dynamic postures that increase LBP, but also sustained static postures of the trunk, such as prolonged sitting or forward bending (Marras *et al.*, 1993; Chung *et al*., 2001).

AUTOMOTIVE INDUSTRY

The automotive industry provides an example of an industry where MSDs prevail and where, not only heavy manual labour is prevalent, but also light assembly tasks. Womack *et al*. (1990) and Hägg (2003) describe the automotive industry as “the industry of industries” as it is one of the largest and most influential industries worldwide (Chung *et al*., 2001). Furthermore, it plays an important role in the economy of developing countries. This is highlighted by the South African Department of Labour (2007) who indicate that the automotive industry is a key player in the South African economy, accounting for 7% of South Africa’s total exports, as well as 7% of the total gross domestic product (GDP). In South Africa, the automobile manufacturing industry is a prominent sector around Johannesburg, Mpumalanga and the Eastern and Western Cape, providing employment to 91,000 South Africans, with approximately 32 500 of those employed in the assembly sector (South African Department of Labour, 2007).

The development of automotive plants has been rapid, however, often these new plants have neglected basic ergonomic requirements and have been developed without the human operator in mind. As a consequence, in the automotive assembly industry, many ergonomic risk factors are observed, including repetitive work, awkward postures and hand-intensive work, resulting in the prevalence of MSDs in the industry (Punnett *et al*., 1991; Park *et al.,* 1994; Fransson-Hall *et al.,* 1995; Engström *et al.,* 1999; Chung *et al.,* 2001).

Automotive Assembly

Among the modern manufacturing companies, automobile assembly is one of the major industries that employs light manual assembly tasks. As a result, numerous studies have explored the relationship between MSD symptoms and automobile assembly work, and have consistently shown an association between the two (Waluyo *et al*., 1996; Hägg *et al*., 1997; Engström *et al*., 1999; Chung *et al*., 2001; Hussain, 2004). Gallagher *et al*. (1988) insist that this is due to workers having to adopt awkward postures during the assembly process and therefore stresses are placed on the musculoskeletal system. Whereas many authors have reported on the biomechanical and postural stresses, very few studies have been conducted on the physiological stresses in automobile assembly,

During the automotive assembly process, the most prevalent tasks have been identified by Chung *et al*. (2001) as carrying parts from storage to the assembly line and performing drilling, screwing and small motor tasks to assemble them. Furthermore, Chung *et al*. (2001) acknowledge that the most commonly observed awkward working postures during screw driving tasks in the automobile assembly line are squatting and forward flexion with lateral bending and twisting in the trunk. These postures with long duration and high repetition are believed to have harmful effects on workers (Chung *et al*., 2001). In accordance with this, Brauchler and Landau (2001) recognized that kneeling, standing stooped, standing upright, normal sitting and stooped sitting are the five most prevalent postures adopted during car manufacturing.

In a recent study by Winter *et al*. (2006), an ergonomic evaluation of different workstations in the automotive assembly industry was performed. Results showed that, although most of the work is performed close to the body and involves a substantial amount of standing and awkward body postures, only relatively low levels of forces are required. Yet MSDs still occur with alarming frequency in this sector of the automotive industry, suggesting a more complex problem than simply manual handling of objects.

Precision Tasks

Graf *et al*. (1995) stated that due to the increase in automation in many workplaces, a significant change in work activities in the developed countries has occurred. Similarly, Kroemer and Grandjean (1997) and Heuer (1999) acknowledged that, as technology has changed, so too have both the manufacturing process and the nature of precision assembly. These authors suggested that recently, manual assembly tasks in industry have changed from heavy work, towards increased demands of skill and precision, resulting in major changes in physical demands on the human body. Chung *et al*. (2001) observed that, nowadays, numerous jobs in industry rely less on physical labour and more on light manual tasks. The reduction in heavy work has, however, not shown a concomitant decline in MSDs and therefore these researchers have proposed that even light manual work brings with it its own array of problems (Graf *et al*., 1995; Kroemer and Grandjean, 1997; Heuer, 1999). Li and Haslegrave (1999) pointed out that most ergonomic guidelines focus on the physical layout of a work environment and neglect task characteristics such as precision demands. To the author's awareness, manual precision as a factor contributing to postural demands has not been studied before thereby limiting the ability to make comparisons to prior studies.

Assembly operators who perform precision tasks are highly skilled workers and are required to perform complex tasks in order to assemble a wide range of finished products from manufactured parts (Dictionary of Occupational Titles, 2007). Unlike some assemblers who perform simple, repetitive tasks, precision assemblers carry out tasks requiring high demands of accurate and precise movements. Precision assemblers also use a variety of tools and precision measuring instruments (Dictionary of Occupational Titles, 2007), especially in the automotive manufacturing industry, where numerous tasks require precise, accurate movements in order to fulfill a task (Chung *et al*., 2001). Awkward working postures are frequently observed in industries where precision assembly is required, with many of these workers having to sit or stoop for long periods of time (Dictionary of Occupational Titles, 2007).

Work tasks requiring the use of hand-held tools are common place in today's industrial sector (Shyhalla, 2007). These tasks are generally repetitive and are performed at high speed and require high levels of precision. Straker and Mekhora (2000) identified high muscle activity levels as a risk factor for MSDs. Aarås and Westgaard (1987) and Bosch *et al*. (2007) however, contradict this and show that even tasks which place low levels of strain on the musculoskeletal system can cause MSDs. Previous research confirmed this, with Laursen *et al*. (1998) and Sporrong *et al*. (1998) showing that increased muscle tension occurs with greater demands for speed and precision. Additionally, these authors provide examples of low intensity work, such as light manual assembly tasks, which result in increased risks of neck and shoulder muscle disorders. An explanation for this was proposed by Shyhalla (2007) who demonstrated that the accumulation of biomechanical stress during low intensity tasks could lead to the development of MSDs. According to observations by Li and Haslegrave (1999), high precision demands do not only directly cause MSDs, but rather poor working postures owing to these precision demands can result in injuries as well.

Torque Wrenching

Torque wrenching is considered a light assembly task, since very little force is required to perform these movements. This is illustrated by Chung *et al*. (2001) who state that torque wrenching tasks hardly involved the handling of heavy objects and forceful movements. Torque wrenching, along with screw-driving, is a common task performed in the automotive assembly industry and often workers performing torque wrenching movements are required to adopt awkward working postures due to the fixed layout of the work area (Chung *et al*., 2001). Previously, Gallagher *et al*. (1988) reported that workers performing light assembly tasks have to work in awkward postures and endure stresses to their musculoskeletal system. Similarly, the type of automobile being manufactured, position of the assembled parts, methods of assembly and type of air tool used, have an effect on the operators' postures.

WORKING POSTURE

Posture is defined as the relative orientation of body parts in space and is a vital consideration in any risk evaluation (Pheasant, 1996). According to Laville (1985) and Li and Haslegrave (1999) the working posture adopted by an individual will depend on the interaction between the individual's anthropometry and the working environment, equipment and materials used for the task performed. Several researchers have noted that poor working postures contribute to the musculoskeletal problems in industry (Aarås *et al*., 1988; Ryan, 1989; Burdorf *et al*., 1991; Kee and Karwowski, 2004; Vieira and Kumar, 2004) and hence, Li and Haslegrave (1999) suggest that workplace layout should minimise the need to adopt awkward postures so that MSDs are kept to a minimum. Different strategies are employed which help to prevent awkward postures from being adopted and to maximise efficiency. One such strategy is to ensure the height at which an operator is working is optimal. Working at a height that is too high may result in the shoulders and arms being raised and can lead to fatigue and strain on the shoulder region (Pheasant, 1996; Li and Haslegrave, 1999). However, if the surface is too low, then the head, neck and trunk will have to accommodate this by inclining forward, resulting in stresses and strains on the musculoskeletal structures of the spine. Therefore, it is important to identify a working height that is neither too high, nor too low for the worker. Conflict arises in the literature with regards to the optimal working height since, according to Grieve and Pheasant (1983) and Pheasant (1996), working height is largely determined by the task being performed. Most authors agree, however, that for manipulative tasks involving a moderate degree of force and precision, the optimal height is between 50mm and 100mm below elbow height (Grandjean, 1988 and Pheasant, 1987; 1991), while for heavy manipulative tasks which involve downward pressure on the workpiece, these same authors have suggested a height 100mm-250mm below elbow height.

Howorth (1946) classified working posture into static and dynamic posture, with many assembly tasks involving components of both. Muscles are required to maintain body position over time therefore, according to Bridger (2003), tasks that require the taking up of postures can lead to muscle imbalances which may result in a reduction in joint function. Thus, by designing tasks and work areas that reduce the need for awkward body postures, workers can maximise their performance and minimise the stress on the musculoskeletal system (Haslegrave, 1994).

Static Postures

Many work situations, of which automotive assembly is one, require static postures to be held for long periods of time. These static postures are associated with discomfort and MSDs. Kadefors and Läubli (2002) stated that as soon as a muscle is activated, low-threshold motor units are recruited and remain active until there is total muscular relaxation. With prolonged static muscle activation there is a lack of recovery, resulting in metabolic overload at the membrane level, which causes a degenerative process leading to cell damage, pain and necrosis. Thorn *et al.* (2002) demonstrated that although there is some substitution of motor units, there are low-threshold motor units which are continuously active during low-level, long duration static work. Snook and Irvine (1969) showed that discomfort can be minimised by improving the working posture, supplying adequate rest breaks and by decreasing holding time.

In static work, maximum force produced during a voluntary contraction (MVC) can only be attained for a few seconds. It has been recommended that the static level of muscle contraction should not exceed 2-5% MVC while performing continuous work (Jonsson, 1982). Similarly, Aarås and Westgaard (1987) proposed a value between 1-2% MVC to be acceptable provided adequate rest breaks were allowed, and that the work was not performed for prolonged periods. Suggestions from Simonsen and Lind (1971) and Rohmert (1973) proposed that for static work a force representing 50% of MVC can be maintained for about one minute, while forces less than 15% of MVC may be held from 10 minutes up to a few hours. A more conservative view from Westgaard *et al*. (1984) indicates that the upper limit for isometric contraction maintained indefinitely is well below 10% of MVC.

Awkward Working Postures

The association between awkward working postures and the development of musculoskeletal disorders, especially in the trunk and shoulders, has been widely discussed in ergonomic literature (van Wely, 1970; Corlett and Bishop, 1976; Tichauer, 1978; Amell *et al*., 2000; Delleman *et al*., 2004; Splittstoesser *et al*., 2007). According to Keyserling (1986), any posture which deviates from the neutral anatomical standing position is considered to be an awkward working posture. The same author states that any posture that exerts undue stresses on the musculoskeletal system can lead to damage, while Delleman *et al*. (2004) identify cramped or obstructed workspaces as a common source of constraints on posture in many industries. Similarly, in industries such as car manufacturing and mining, awkward postures are ubiquitous and workers are often required to adopt awkward body postures whilst performing stipulated tasks. This has been shown to result in stresses and strains on the musculoskeletal and cardiovascular systems of the human operator (Häkkänen *et al*., 1997). In a recent study by Smallwood and Haupt (2007), working in awkward postures, together with repetitiveness, were identified as both India's and South Africa's joint highest cause of non-traumatic injuries for people aged below 20 years and between 40 and 50 years (29% and 25% respectively). Between the ages of 20 and 30, repetitiveness was the main cause of these injuries with 41%, followed by awkward postures at 27%.

Hägg *et al*. (1997) and Carey and Gallwey (1998) report that many assembly tasks force operators to adopt poor gross body postures, which they are required to maintain for the duration of the task. In the automobile assembly industry, workers are required to perform tasks in awkward body postures, such as forward flexion and twisting. According to Chung *et al*. (2001), during the assembly process these operators will perform the task over 400 times during an 8 hour shift, thereby causing harm to the workers musculoskeletal system.

Standing

Upright standing (trunk flexion between 0° and 20°) has been described by numerous authors as a neutral working posture and is one of the most common postures identified in industry (Karhu *et al*., 1977; Keyserling, 1986; Punnett *et al*., 1991; Kumar, 1993; Hignett and McAtamney, 2000; de Souza and Coury, 2005). Postural stability in standing is maintained by an integrated effort of the musculoskeletal, visual, proprioceptive and vestibular systems (Park and Yoon, 2001). In activities which require standing postures, lumbar lordosis reduces the trunk flexion moment and therefore a minimal amount of muscle activity occurs (Andersson *et al*., 1977). However, increases in flexed postures result in greater muscle activation since there is a need to counterbalance the increased postural load caused by a forward shift in the centre of gravity of the trunk. Although Delleman *et al*. (2004) agree that minimal muscle activity occurs during upright standing, they contend that the soleus and gastrocnemius muscles are always activated, albeit very slightly. Furthermore, according to Bridger and Whistance (2001), in a standing posture the line of gravity passes through the lumbar, sacral and hip joints, and in front of the knee and ankle joints. This is significant since it minimises any additional stress which may occur when the body is not in a neutral position.

Prolonged standing results in numerous physiological changes to the operator. It has been widely reported in literature that stroke volume decreases while heart rate and blood pressure increase during standing tasks as opposed to sitting tasks (Andersson *et al*., 1977; Grandjean, 1988; Bridger and Whistance, 2001). These authors also found that minute ventilation, tidal volume and oxygen consumption increased during standing tasks.

Sitting

According to Corlett (1981), the conventional sitting posture is an erect back with thighs parallel to the ground. To achieve this, the hips must flex through 90 degrees. Initially, as the hip joint flexes to adopt a sitting position, the hip flexors (quadriceps muscles amongst others) relax while the extensors, such as the hamstring muscles, experience an increase in tension (Corlett, 1990). During sitting tasks, little leg muscle activity is observed, provided sufficient foot rests are provided (Sanders and McCormick, 1993).

Keegan (1953) was one of the first researchers to identify that sitting could be related to lower back pain. In a sitting position, there is increased tension in the hamstring and gluteals against the weakened hip flexors causing the pelvis to reflexively tilt backward and the lumbar lordosis to be lost due to the lumbar spine flexing to keep the trunk and head erect (Benatar, 1999).

Stooping

When performing different tasks, restrictions in working height and obstructed or cramped workplaces may limit postures to stooping, squatting, kneeling, sitting or lying (Smith *et al*., 1992; Delleman *et al*., 2004). Stooping is one of the most common awkward postures observed in industry and, as a result, substantial amounts of research have looked at sagittal trunk flexion (Keyserling, 1986; Hignett and McAtamney, 2000; Chung *et al*., 2001; Stuebbe *et al*., 2002; de Souza and Coury, 2005). Keyserling (1986) categorised forward inclination into three ranges: neutral, mild and severe. Since then, numerous authors (Punnett *et al*., 1991; Tracy and Corlett, 1991; Hignett and McAtamney, 2000; de Souza and Coury, 2005) have provided guidelines for these trunk flexion angles. Although opinions differ slightly, there is a general consensus amongst these authors as to the flexion ranges. During flexion exertions lumbar paraspinal muscle activity may be necessary to maintain spinal stability (Gardner-Morse *et al*., 1995). In addition, Neumann *et al*. (2001), showed that the longer the time spent in intermediate levels of flexion (45°-75°) or severe flexion (>75°) the greater the risk involved to the individual, and higher levels of fatigue in the lower back were observed. Studies have shown an association between extreme postures and MSDs (Norman *et al*., 1998; Neumann *et al*., 2001; Bosch *et al*., 2007), with one such study indicating a sharp increase in MSDs when non-neutral postures were adopted for more than 45% of the work day (Stuebbe *et al*., 2002). These same authors further indicated that detrimental consequences, such as fatigue and discomfort in the lower back muscles, may occur as a result of trunk flexion.

Andersson *et al*. (1977) measured erector spinae EMG in several flexed postures and found that they control flexion and resist the effects of gravity. During mild flexion, trunk muscles have been shown to be responsible for stabilising the body. However, one of the first studies of muscle activity of the erector spinae muscles showed that when the trunk is placed in extreme flexion, these muscles become electrically silent (Floyd and Silver, 1955). In agreement with this, Basmajian (1979) and Kippers and Parker (1984) stated that erector spinae activation increases in both the lumbar and thoracic regions when flexion of the trunk is between 50° and 60°. However, with further increase s in stooping angle, the muscle activation levels decrease. Gordon *et al*. (1966) and Bridger (2003) hypothesised that when the trunk is fully flexed, the muscles are no longer activated, but rather the spinal ligaments and fascia assume responsibility for maintaining the flexed posture. Further explanations for this were provided by Morris (1948) and Edman (1966) who described how muscles have an optimum length at which they are capable of exerting their maximum tension. A longer muscle generates more tension when it contracts until its physiological length is exceeded, at which point the muscle tension decreases. This can be explained using the length-tension relationship seen in Figure 2.

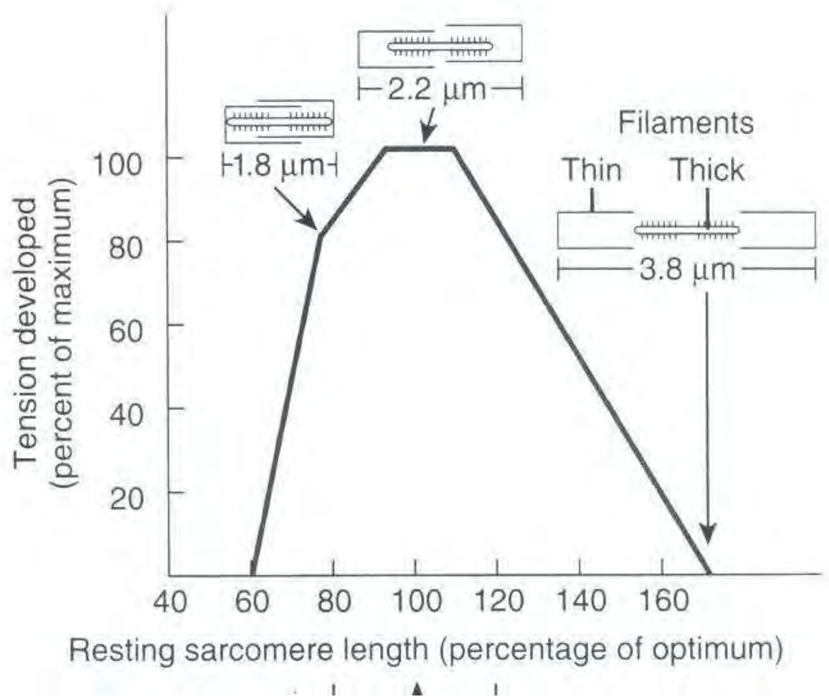

Figure 2: Illustration of the active length-tension relationship (Tortora and Grabowski, 2003).

Granata *et al*. (2005) provided an additional explanation for trunk muscle deactivation and stated that this occurs due to the flexion-relaxation responses arising during lumbar flexion. These responses place strain on the passive tissues in the trunk and spine, which in turn support the external flexion load, thereby allowing the muscle to become deactivated. Not only does this occur but, according to Cholewicki and van Vliet (2002), greater trunk flexion causes stretching of muscle and tendons as well, causing the spine to become unstable.

Delleman *et al*. (2004) showed that when the trunk is flexed, the activity of the gastrocnemius muscle increases. Furthermore, the posture adopted during a work task has a decided influence on the metabolic demands incurred by an individual (Gallagher, 2005). As stooping becomes more severe, so the metabolic cost increases. In terms of energy expenditure, Legg (1986) reported that individuals who are unaccustomed to working within confined spaces may have higher energy expenditures than those accustomed to these working conditions.

MUSCLE ACTIVATION

A critical role of the muscles is to ensure sufficient stability of the spine so that it can withstand loading and sustain postures and movement (McGill *et al*., 2003). Gallagher *et al*. (2002) and Delleman *et al*. (2004) verified that as individuals adopt varying working postures, different muscles are recruited. Earlier Graf *et al*. (1995) demonstrated that if a static posture is held for too long then a specific set of muscles will be required to work continuously to maintain that posture, eventually resulting in fatigue. However, movement causes a change in muscle activation and allows the muscle to relax, thereby reducing the amount of fatigue experienced (see section on static postures).

Granata and Orishimo (2001) acknowledge that in order to maintain stability, muscles must be recruited. This notion is supported by McGill *et al*. (2003) who suggest that stability results from highly coordinated muscle activation patterns involving different muscles, and for stability to occur, recruitment patterns must change constantly. As the number of active muscles increases, so the strength of the muscle increases as a result of the number of cross bridges which are activated (Granata and Orishimo, 2001). Muscle activation has been shown to increase joint stability in the elbow, ankle and the trunk (Cholewicki *et al*., 2000). It is both the active and passive muscles which contribute to trunk stability since, according to Cholewicki *et al*. (2000) and Wagner *et al*. (2005), without active muscular support the ligamentous support of the spine is insufficient and the spine becomes unstable. Active control of spinal stability is achieved through the regulation of force in the surrounding muscles (Cholewicki *et al*., 2000).

Antagonistic Muscle Co-contraction

Simultaneous activation of antagonistic muscles occurs when the body is placed under stress and equilibrium is disturbed (Granata and Bennett, 2005). This is commonly referred to as antagonistic co-contraction (Lavender *et al*., 1992; Song *et al*., 2004; Granata *et al*., 2005b). Research supports the proposition that co-contraction of antagonistic muscles results in an increase in the stability of the muscle which is required to prevent injury (Bergmark, 1989; Gardner-Morse *et al*., 1995; Cholewicki *et al*., 1997; van Diëen *et al*., 2003; Wagner *et al*., 2005; Lee *et al*., 2006; Song and Chung, 2007). Contrary to this, however, Delleman *et al*. (2004) state that the presence of antagonistic muscle activity will increase fatigue and the forces acting on the spine. Additionally, Granata and Bennett (2005) acknowledged that trunk muscle co-contraction dramatically increases the load placed on the trunk, which may contribute to the risk of low back injury. These authors emphasised that the co-contraction of trunk muscles must not be ignored, since by neglecting co-contraction during flexion and extension exertions, estimates of spinal load will be significantly less than actual values (Granata and Marras, 1995). These same authors suggested that about 12-14% of the spinal compression in the lumbar area during relatively light loadings with the trunk in the sagittal and frontal planes is due to co-contraction.

Previous research has identified the critical role that antagonistic co-contraction has on stabilising the human body (Bergmark, 1989; Wagner *et al*., 2005; Lee *et al*., 2006; Song and Chung, 2007). Stability is described as the ability of the body to maintain the centre of mass within the area of support (Shumway-Cook and Woollacott, 1995; Kuczyn'ski, 1999; Kerr and Eng, 2002). Similarly, Granata *et al*.

(2005a) define stability as the ability of the musculoskeletal system to maintain equilibrium when an external stress is placed on the system. Humans working in an industrial environment are required to perform varying tasks, each of which requires the individual to retain a balanced body posture. Stability is a critical factor required to avoid injury and to protect the musculoskeletal system from damage when external forces are exerted on the system (Cholewicki and McGill, 1996; Cholewicki *et al*., 1999). Therefore, in order to achieve this balance, several core muscles are employed resulting in an increase in the amount of energy and strain placed on the musculoskeletal system.

Evidence from research by Cholewicki and van Vliet (2002) suggests that all muscles have an important role to play in the stability of the spine as results from this study indicated that no single muscle group is responsible for more than 30% of the overall stability. Similarly, previous research identified several trunk muscle groups that are important for spine stability and include the deep inter-segmental muscles, erector spinae and the abdominal muscles (Tortora and Grabowski, 2003). When placed under stress, the trunk muscles must be recruited in sequence and the contractions must have sufficient strength to maintain stability (Cholewicki *et al*., 1999; Gallagher, 2005). In particular, the erector spinae muscles participate in a wide variety of everyday behaviours and are required to assist with trunk bending, reaching, balancing and locomotion (Farley and Koshland, 2000).

Contrary to previous research which found no difference in trunk stability between flexion and extension exertions (Gardner-Morse *et al*.,1995; Cholewicki *et al*., 2000), recent findings conclude that trunk stability is greater during voluntary flexion exertions than during extension exertions (Choi, 2003). This is supported by Granata and Bennett (2005) and Granata *et al*. (2005b) who assert that co-contraction during flexion exertions is twice the co-contraction during trunk extension exertions. An explanation for this was presented by Lavender *et al*. (2003) who pointed out that the interaction effects of different parameters may have a significant effect on trunk muscle activity.

Operators performing assembly tasks are required to manipulate fine instruments at extremely high degrees of precision. This involves constant fixing of the neck, shoulder and arm muscles for prolonged periods (Rodahl, 1989). Visser *et al*. (2004) found that in tasks requiring high precision demands, the noise effects in the neuromotor control were counteracted by an increase in co-contraction of muscles. Therefore, any detrimental consequences occurring as a result of the precision demands were reduced by the antagonistic muscles contracting simultaneously.

Although muscle activation is probably the most imperative consideration in terms of stability of the musculoskeletal system, intra abdominal pressure (IAP), antagonistic muscle coactivation, fatigue and reflex responses are also vital concerns (Gardner-Morse *et al*., 1995; Cholewicki *et al*., 1999; Hodges, 1999; Granata and Marras, 2000; Hodges *et al*., 2001; Kumar, 2001; Franklin and Granata, 2006). Therefore, during work activities it is thought that IAP and back muscles work in combination with each other in order to provide stability to the spine, while reflex responses may increase the effective stiffness of the spine on top of that provided by the intrinsic stiffness alone (Franklin and Granata, 2006).

Dempster (1955) showed how critical stability is in maintaining a working posture. Since individuals are constantly changing position during a working day, different muscles are activated at different times. With each varying posture, stability is crucial and prevents the worker from getting injured. When the spine is stable under a given load, then small neuromuscular or vertebral movement errors are automatically corrected without tissue damage. Conversely, if the spine is unstable, then a small neuromuscular error can be amplified by the biomechanical forces, resulting in injury (Crisco and Panjabi, 1991). Furthermore, Andersen *et al*. (2001) showed that an increase in erector spinae muscle activity increases the lumbar spine stability. Therefore, in order to stabilise the body, supplementary muscle activation is required, and hence the co-contraction of antagonistic muscles is necessary. Thus, in the context of the current research, due to the necessity of having to stabilise the body during the awkward posture, as well as having to perform a manipulative task, the combined effect of the two is thought to add significantly to the risk of injury.

INTERACTIVE OR COMPENSATIVE EFFECT OF TASKS PERFORMED IN COMBINATION

In previous literature, few attempts have been made to identify whether there is a difference between the sum of independently determined task factors and the simultaneous performance of the same task factors. As a result, very little is known about this relationship (Andrews, 1966). According to Sanchez *et al*. (1979) if a combined activity is considered, then the simplest hypothesis, and one which is supported by numerous authors, is that there is no difference between the combined and additive components. Research into this area has been performed by Scherrer (1967), who observed subjects performing muscular exercise after a meal, and Vogt *et al*. (1973) who studied subjects working in a thermal environment. Both these authors concluded that no differences are found between the additive and combined effects in these situations. Nevertheless, Sanchez *et al*. (1979) state that there are two other possibilities which may exist if these differences are significant: the responses can be greater (where the combined component is greater than the additive component), or lesser (where the combined component is less than the additive component).

Numerous authors (Andrews, 1966, Lind and McNicol, 1967, Haissley *et al*., 1974, Kilbom and Brundin, 1976, Legars *et al*., 1976, Sanchez, 1977 and Sanchez *et al*., 1979) have recognised the importance of assessing the physiological responses for static and dynamic factors in combination. Traditionally, the physiological aspect has received extensive coverage compared to the biomechanical or psychophysical aspects. The findings from these authors are contradictory, with Andrews (1966), Lind and McNicol (1967), Haissley *et al*. (1974) and Kilbom and Brundin (1976) suggesting that the physiological responses for combined work are smaller than those found for the additive component. On the other hand, Sanchez (1977) and Sanchez *et al*. (1979) proposed that the responses for combined work are in fact greater than those found for the additive component, hence corroborating results from Legars *et al*. (1976).

These studies by Sanchez (1977) and Sanchez *et al*. (1979), which looked at heart rate and oxygen uptake during dynamic and static contractions, provide the most comprehensive evidence for a multiplicative effect (combined > additive) when comparing combined and additive effects. Conclusions drawn from these studies indicate that one cannot simply add the two components together to gain an understanding of the effects of the two performed simultaneously. Furthermore, this study suggests that there is a multiplying effect, since the cardiac cost from pushing only and walking only is significantly less than the cardiac cost observed for both tasks exerted together (see Figure 3).

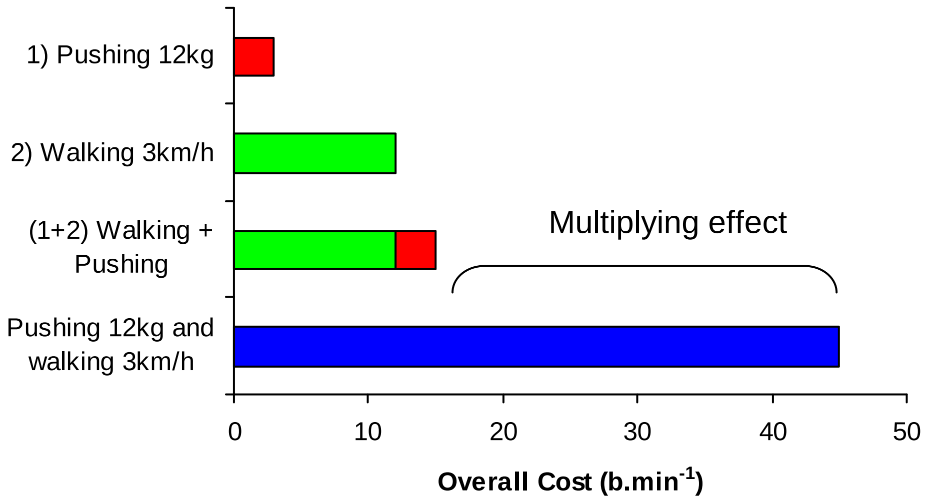

Figure 3: Multiplying effect of walking and pushing (Sanchez, 1977)

In contrast to this, Andrews (1966) examined whether or not the sum of net rates of energy expenditure for individual tasks equals the net rate of energy expenditure for the simultaneous performance of the same tasks. This author found that seven out of the eight configurations tested indicated that the additive effect was greater than the combined effect and hence the hypothesis that there would be no difference between these two components, was rejected.

Farley and Koshland (2000) performed one of the few studies which looked at muscle activity and whether interactive effects occur. Muscles involved during elbow flexion and forearm supination were assessed to identify whether muscle activation levels during combined work are equal to the sum of the individual muscle activities. These authors concluded that there are no differences between the additive and combined effects. According to Winter *et al*. (2006), the physiological and muscle stresses of light manual assembly work and body posture performed in combination in the automotive industry have not been extensively studied, which makes comparisons and references to other studies difficult.

Hence, the possible existence of interactive effects during combinations of assembly tasks and body postures may contribute to the prevalence of MSDs in workplaces. Therefore, comprehensive research needs to be made in this area, which will allow for more precise conclusions to be drawn. This will result in a possible reduction of MSDs in the workplace.

APPROACHES TO STUDYING INDUSTRIAL TASKS

Manual materials handling (MMH), with its relevance to both industrial and everyday activities, has stimulated much research in the past (Snook, 1978; Mital *et al*., 1993; Resnick and Chaffin, 1995; Dempsey, 1998; Mital, 1999). However, most of these studies have either focused on the physiological aspects, or the biomechanical aspects of these activities, and have therefore failed to provide a holistic approach to research. Few studies have assessed the combination of manipulation tasks and body posture during assembly tasks and therefore the biomechanical, physiological and psychophysical responses to these tasks have not been conclusively investigated.

Biomechanical Approach

The purpose of including a biomechanical approach into any research is to identify the risks placed on the muscles, joints and other tissues during the performance of a task. Furthermore, this approach is a critical evaluation since this provides data for human performance and human tissue tolerance (Das, 2001). In the past it has been shown that the biomechanical approach is not only appropriate for MMH tasks, but also for fine manipulative tasks, such as hammering or screwing in the automobile assembly industry. Although the loads placed on the worker during these tasks are not large, the cumulative load, due to the co-contraction of antagonistic muscles, may also result in damage to the bone and surrounding soft tissues (Chung *et al*., 2001).

Electromyography (EMG)

Muscular activity is measured by electromyography (EMG) (Sanders and McCormick, 1993; Thorn *et al*., 2002; Splittstoesser *et al*., 2007). When muscle fibres contract, small electrical changes occur within the muscle (Rodahl, 1989) and EMG then assesses muscle function by analysing these electrical impulses occurring during muscle contraction (Corlett, 1990; Laursen *et al*., 2003). A positive relationship is found between the number and intensity of EMG spikes and the force of the contraction and thus, the intensity of the EMG signal increases as the muscle contracts (Stanton *et al*., 2001). It has been suggested that, due to the large number of muscles activated during given tasks, the appropriate selection of muscles is vital for accurate EMG recordings.

Numerous authors propose indirect and direct methods for EMG recording (Aarås *et al*., 1988; Thorn *et al*., 2002; Laursen *et al*., 2003). Direct recordings of EMG are done by inserting needles directly into the muscle, while indirect recordings use surface electrodes which are placed over the muscle. Surface EMG is more common in ergonomic evaluations of muscle activity since it is non-invasive and allows for convenient measurement during a range of different activities (Thorn *et al*., 2002). This technique is, however, more susceptible to cross-talk from adjacent muscles and complications arise because only the muscles located directly below the surface of the skin can be accessed (Laursen *et al*., 2003). Furthermore, the analysis of EMG data requires careful interpretation and the calibration procedure for evaluation of muscle activity is predisposed to errors (Aarås *et al*., 1988). According to Dul *et al*. (1982) and Harms-Ringdahl *et al*. (1986), this technique may be flawed when large muscle groups are analysed, since it may not estimate the true activity when inhomogeneous activation of the muscle occurs.

For inter- and intra-individual muscular comparisons to be made, maximum voluntary contractions (MVCs) are performed (Fernström and Ǻborg, 1999). MVCs are defined as the maximum value that a subject can voluntarily generate during an isometric contraction (Kumar and Mital, 1996). MVCs are taken prior to testing as it is important that the subject is not fatigued before exerting maximal exertions

(Escorpizo and Moore, 2006). The strength of the MVC depends not only on the quality of the muscle involved in the contraction (Kapitaniak, 2001), but on physiological and psychological factors as well.

Contrasting literature is found for the optimal duration for MVCs, as some researcher's use 5s maximal exertions (Ericson *et al*., 1986), while others use 1s segments from 3s exertions (Arsenault *et al*., 1986). However it seems that most authors agree that the optimal duration for MVCs is between 2 and 6 seconds (Visser *et al*., 2004; Escorpizo and Moore, 2007).

Physiological Approach

Physiological responses provide quantitative measures of how the individual's cardiovascular and respiratory systems are responding to a task (Ekelund *et al*., 2001). Table I provides typical physiological values for different work intensities. To the knowledge of the author, no studies have assessed the effects of combined precision tasks and awkward body postures on physiological values and, therefore, comparisons to this effect are not possible. However, as long ago as 1971 the American Industrial Hygiene Association hypothesised that precision tasks and light manual work do not place huge amounts of strain on the cardiovascular system. Currently, however, many authors believe that even these tasks place undue stresses on the worker.

Table I: Physiological values expected for different work intensities (Adapted from the American Industrial Hygiene Association, 1971)

Exercise Intensity	**Heart rate ($b.min^{-1}$)**	**Oxygen consumption ($L.min^{-1}$)**	**Energy expenditure ($kcal.min^{-1}$)**
Rest	60-70	0.3	1.5
Very light work	65 – 75	0.3 – 0.5	1.6 – 2.5
Light work	75 – 100	0.5 – 1.0	2.5 – 5.0
Moderate work	100 – 125	1.0 – 1.5	5.0 – 7.5
Heavy work	125 – 150	1.5 – 2.0	7.5 – 10.0
Very heavy work	150 – 180	2.0 – 2.5	10.0 – 12.5
Unduly heavy work	> 180	> 2.5	> 12.5

Heart Rate

Monitoring of heart rates is used to quantify the amount and patterns of physical activity in workers. Furthermore, in ergonomics, heart rate and cardiac cost are recognised as being good indicators of the physiological stress on a worker (Sanchez *et al*., 1979). The most common ways to convey heart rate is to look at working heart rates relative to resting heart rates or to assess working heart rates when expressed as a percentage of maximal heart rates (Ekelund *et al*., 2001). Emotional state and anticipation of an event have a significant effect on the cardiovascular system and, therefore, it is very difficult to obtain true resting values for heart rate. A “reference” heart rate is therefore, often used as a baseline measure (Meyer and Radwin, 2007). Table I suggests that resting values for heart rate fall between 60 and 70 $b.min^{-1}$ but increase as soon as work is performed.

Numerous external and internal factors will have an effect on both resting and working heart rate, including environmental factors such as temperature and time of day (Wergel-Kolmert *et al*., 2002), work intensity, posture adopted (Meyer and Radwin, 2007) and emotional state and anticipation (Amell *et al.*, 2000). In a study conducted by Meyer and Radwin (2007) which assessed stoop and prone postures, it was found that the difference in heart rate during the stoop posture was less than the heart rate observed during prone work tasks. Similarly, Amell *et al*. (2000) have shown that, compared to a prone posture, heart rate is 10% higher when sitting and 5% to 15% higher when standing.

Heart rate has been shown to be a good predictor of oxygen consumption (VO_2) and is therefore frequently used to predict VO_2 (Chaffin and Andersson, 1984; Rodahl, 1989; Sanders and McCormick, 1993). Heart rate is therefore useful as an indicator of the intensity of physical activity because of its known, predictable and reproducable relationships within certain limits, to energy expenditure and cardiac load or strain (Vuori, 1998).

Oxygen Consumption

Any type of physical activity will produce an elevation in oxygen uptake (VO_2) (Sedlock *et al*., 1989). The increase in VO_2 during any activity is crucial for the metabolism of carbohydrates, fats and proteins to yield the energy necessary for the body to function optimally during times of physical stress. It is the capacity of the oxygen transportation and utilisation systems that play an important role in the onset of fatigue and an individual's endurance capacity (Åstrand *et al*., 1965), although this point has been debated in the literature (Noakes, 1998). For optimal contractions the larger muscle groups require large amounts of oxygen.

Energy Expenditure

Energy expenditure (EE) refers to the amount of kilocalories used per minute during different tasks (McArdle *et al*., 2001). According to Edholm (1967) and Grandjean (1988), approximately $1.6kcal.min^{-1}$ and $2.25kcal.min^{-1}$ are used during sitting and standing respectively. In an attempt to understand the effect of working postures on energy expenditure, Vos (1973) measured the amount of energy expended by workers performing a task in five different postures. According to this study, stooping with no arm support elicited the greatest EE values. Furthermore, according to Kumar (1988), postures which require the operator to reach too far in front uses between 11-41% more energy expenditure.

Respiratory Responses

According to Cerny and Ucer (2004) the trunk muscles enable various activities, including maintaining arm and body positions and respiration, to be performed. These same authors state that respiration is known to employ the least amount of muscles to ensure energy cost remains low. However, when involved in activities which require the use of the upper arm musculature, respiration increases. During physical activity there is an immediate increase in ventilatory responses, such as breathing frequency (F_B), tidal volume (V_T) and minute ventilation (V_E), due to the body's increased need for oxygen supply and carbon dioxide removal (McArdle *et al*., 2001). These authors identified that, after the immediate increase, there is a further progressive increase until steady-state is achieved.

In a normal environment at rest, the average number of breaths (F_B) taken by an individual is approximately 12-15br.min^{-1}, while the average volume of air breathed in every breath (V_T) is approximately 0.5L. Considering that V_E is calculated as the product of F_B and V_T, the average amount of air breathed in every minute is 6L (Table II). By increasing either breathing frequency or tidal volume (V_T), or a combination of both, increases in V_E can be accomplished. It has been identified that with endurance training V_T is increased more than F_B during exercise (Åstrand and Rodahl, 1986). Similarly, Åstrand and Rodahl (1986) and McArdle *et al*. (2001) pointed out that during light to moderate work ventilatory increases are usually attributed to a rise in V_T, whereas increases in F_B become more important during heavy activities in an attempt to minimise the effects of carbon dioxide production and lactic acid build-up on the blood pH levels. Large tidal volumes indicate a more effective breathing pattern as greater volumes of air are moved into the lungs (McArdle *et al*., 2001).

Table II: The effect of different levels of physical activity on respiratory responses. (Adapted from McArdle *et al*., 2001).

Condition	**Breathing Frequency (F_B) ($br.min^{-1}$)**	**Tidal Volume (V_T) (L)**	**Minute Ventilation (V_E) ($L.min^{-1}$)**
Rest	12	0.5	6
Moderate	30	2.5	75
High	50	3.0	150

Psychophysical Approach

Assessing perceptions of effort during any work task is based on the assumption that individuals combine feedback from the biomechanical and physiological stresses to provide a subjective evaluation of the task demand (Ayoub, 1992; Sanders and McCormick, 1993). Since exertion is subjective, it is only possible to measure using indirect techniques, such as self-reports (Monahan, 1988; Lockhart *et al*., 2003). In recent years, the assessment of perceived exertion or related symptoms of subjective fatigue during physical work has relied almost exclusively upon psychophysical measurement techniques (Lockhart *et al*., 2003). Of these techniques (ratio-scaling techniques, category scaling, acceptability testing), the rating scale is the most commonly used (Gamberale, 1985). In particular, the rating of perceived exertion (RPE) scale, developed by Borg (1970), is the most well known and widely used example (Gamberale, 1985; Straker *et al*., 1997).

Body Discomfort

Corlett (1981) indicated that perceived pain, rather than human work capacity, is often a limiting factor for performance or productivity. Keyserling *et al*. (1992) stated that the ability to perform work is affected by an individual's perception of discomfort. Therefore, if workers reach levels of discomfort which are perceived to be high, then they may become unwilling or unable to continue the task. During a task requiring trunk flexion, Keyserling *et al*. (1992) indicated that the perceived discomfort was higher than in tasks which required less awkward postures (standing or sitting).

The Body Discomfort (BD) scale, developed by Corlett and Bishop (1976), is used to assess an individual’s perception of pain felt during a physically taxing task. The BD scale makes use of a body map which has been divided into 29 parts with anterior and posterior components, which can be used to identify the part of the body which feels the most discomfort during the task. The individual is able to rate the intensity of the discomfort using the discomfort scale, ranging from 1-10, with 1 indicating “no discomfort” and 10 indicating “extreme discomfort.”

There are many other methods which exist when studying industrial tasks. These include the use of biomechanical models, cognitive methods and task analysis. Each of these methods provides adequate means of quantifying data and evaluating processes, however, for the current research these methods were not considered further.

CHAPTER III

METHODOLOGY

INTRODUCTION

Despite numerous efforts to reduce the number, severity and cause of musculoskeletal disorders (MSDs), they continue to affect industrial workforces around the world. Graf *et al*. (1995) state that there has been a decrease in heavy physical work, however, this has not translated into fewer MSDs. These problems are still common in workplaces where no heavy loads are manipulated and where the work is generally considered to be light (Graf *et al*., 1995). It has, therefore, been suggested that something other than manual materials handling (MMH) may be the cause of these MSDs and this is a principal reason that research has, in recent times, turned towards light assembly and precision tasks.

Although numerous researchers have attempted to study the effects of load and posture during MMH tasks, very few have studied the interaction of manipulative tasks and body posture during assembly work, even though there is an expected interaction. During light assembly tasks, muscle activation is required to maintain the working posture, and also to stabilise the body while performing these tasks, therefore necessitating the co-contraction of antagonistic muscles. Furthermore, the body is a biomechanical chain whereby physical stresses imposed on the upper extremity are transferred through the body via the bone structures (Cerveri *et al*., 2003). Both of these (biomechanical chain and co-contraction of antagonistic muscles) are thought to influence the interactive effect of combined manipulative task and constrained body posture and contribute to the overall risk of injury.

Due to the continuing occurrence of injuries amongst assembly workers, it is essential to gain an understanding of these injuries. A common theory is that the stresses resulting from individual task factors and body posture can be assessed in isolation and simply summed up to provide an overall risk profile. However, this does not take into account that there may be a non-linear interaction in strain responses when manipulation task and body posture interact. Therefore, the aim of this research is to determine whether one can add up the individual responses of a task and body posture to gain the overall strain response, or whether it is important to consider the two in combination, which may result in non-linear responses.

GENERAL EXPERIMENTAL CONCEPT

This research is concerned with constrained body postures and assembly activities which were deemed to be representative of ‘real life’ situations observed in the automotive industry. In order to gain a complete understanding of the current research, it is important to provide some ideas which have been considered during the conceptual phase of the study.

Firstly, there are numerous perspectives from which one can assess the current problem. For instance, if the strain difference between performing an activity and remaining passive is equal in both a neutral and in a constrained body posture, then it can be assumed that no interaction between body posture and activity occurs. According to Table III, the corresponding mathematical hypothesis is expressed as follows:

$$X - W = Z - Y \qquad \textbf{(equation 1)}$$

Furthermore, this same approach can be developed from another angle: no interaction occurs between body posture and activity if the strain difference between a neutral and a constrained body posture during the performance of a specific activity is equal to the difference between the same body postures as mentioned before, but when performing no activity. With reference to Table III, this mathematical hypothesis is expressed as follows:

$$Z - X = Y - W \qquad \textbf{(equation 2)}$$

Table III: Basic experimental matrix.

		ACTIVITY	
		Passive	**Active**
POSTURE	**Neutral**	W	X
	Constrained	Y	Z

A baseline activity, which was identified as no task performed in a neutral posture (Table III: W), was considered a necessary value to obtain. This baseline value allowed the researcher to determine the exact effect of activity only and the effect of body posture only without considering those values required to maintain basic physiological and muscular functions. Therefore, the effect of activity only was calculated as X – W (from Table III), and the effect of body posture only was calculated as Y – W (Table III). The effect of combined activity and constrained body posture was calculated as Z – W, also from Table III.

This formed the basic concept behind the current research, which looked at the sum of the effects of constrained body posture only (Y – W) and assembly activity only (X – W) (additive effect) and, subsequently, compared these responses to the effects of performing both tasks concurrently (Z – W) (combined effect). This allowed the researcher to determine if any cumulative (additive < combined) or compensatory (additive > combined) reactions occur between the additive and the combined effects which is represented by the following equation:

$$\underbrace{(Y - W)}_{\text{Effect of Body Posture}} + \underbrace{(X - W)}_{\text{Effect of Activity}} = \underbrace{(Z - W)}_{\text{Effect of combined Activity \& Body Posture}} \qquad \textbf{(equation 3)}$$

If equation 3 is simplified, the resulting equation is Y + X – W = Z, which is the same equation one would get if equation 1 and equation 2 are simplified. Thus, either one of the three mathematical equations would be sufficient to use for this research. Equation 3 was, however, selected as it expresses more clearly the effects of the individual components looked at in the study.

During the current research, two different body postures and two different types of activities were researched. These constrained body postures included sitting and stooping, while the activities selected were torque wrenching and a precision task. Chung *et al*. (2001) identified these activities and body postures as being the most frequently observed and performed in the automotive industry. Furthermore, torque wrenching requires physical force exertion with no precision requirements, while the precision task requires no force exertion, but has high precision demands. Therefore, using Table III, an entended experimental matrix was obtained (Table IV), specifically for the current research. In Table III, *Activity* was restricted to “Passive” and “Active” and *Posture* was restricted to “Neutral” or “Constrained”, however in Table IV the “Active” component was expanded to include “Torque Wrenching” and “Precision”; the two activities assessed during the current research. Additionally, in Table IV, the “Constrained” component was expanded to incorporate the two specific postures assessed in this study: “Sitting” and “Stooping”.

Table IV: Experimental matrix relevant to the current research.

			ACTIVITY		
			Passive	Active	
				Torque wrenching	Precision
POSTURE	Neutral		N_{nt}	N_{tw}	N_p
	Constrained	Stooping	St_{nt}	St_{tw}	St_p
		Sitting	Si_{nt}	Si_{tw}	Si_p

Where: N_{nt} = no task + standing (Condition 1);

N_{tw} = torque wrenching + standing (Condition 2);

N_p = precision + standing (Condition 3);

St_{nt} = no task + stooping (Condition 4);

St_{tw} = torque wrenching + stooping (Condition 5);

St_p = precision + stooping (Condition 6);

Si_{nt} = no task + sitting (Condition 7);

Si_{tw} = torque wrenching + sitting (Condition 8);

Si_p = precision + sitting (Condition 9)

EXPERIMENTAL SETUP

Body Postures

The neutral posture was determined using the recommendations of Keyserling (1986), Keyserling *et al*. (1992) and de Souza and Coury (2005), who considered neutral trunk flexion angles to range between 0 and 20°. Therefore, during this research project, the neutral posture was defined as a standing posture (refer to Table IV: Conditions 1, 2 and 3) and was performed with the trunk erect (trunk angle = 0° from the vertical), knees straight and f eet flat on the floor and slightly apart.

For the seated conditions (refer to Table IV: Conditions 7, 8 and 9), subjects were positioned on an adjustable chair in a natural seated posture. A 90° angle at the knee and hip, as suggested by Pheasant (1996), was achieved by either raising or lowering the chair, or by introducing a footrest. Shoulders were extended at an angle of no more than 30° which was determined by the horizontal distance they sat (away) from the worktable and by using the anthropometric data collected previously.

According to Gallagher (2005), assembly workers are consistently observed performing tasks which require extreme trunk flexion angles. Therefore, the stooping tasks (refer to Table IV: Conditions 4, 5 and 6) were performed with the trunk flexed at a 60° angle from the vertical, thereby maximising the variables, but keeping them within the stated literature. The angle was controlled by placing markers on the subjects' ears and hips which were then lined up with a goniometer, which measured the 60° angle accurately.

Figure 4: General view of the experimental layout (where A = Torque wrenching equipment; B = Precision equipment)

Torque Wrenching and Precision Tasks

Subjects were tested at two different workstations (Figure 4A and 4B). Selected components of the workstation were adjustable allowing working height to be set relative to the individuals' anthropometric measurements (sitting and standing elbow heights, as well as iliac crest height). Similarly, the distance from the workbench at which subjects' were positioned was determined by their arm length (and shoulder angle), which restricted the distance they had to reach to perform the given task.

At Workstation A, individuals performed a *passive task* which involved statically holding the torque wrench in front of the equipment, whilst positioned in either a standing (refer to Table IV: N_{nt}), stooped (Table Iv: St_{nt}), or seated posture (Table IV: Si_{nt}). At the same workstation the subjects were also required to perform the *torque wrenching* task whilst positioned in one of the three postures (refer to Table IV: N_{tw}, St_{tw} or Si_{tw}). At Workstation B the individual performed the *precision task* whilst positioned in one of the same body positions as described above (Table IV: N_p, St_p or Si_p).

Torque Wrenching Task

The torque wrenching equipment as depicted in Figure 5A was fixed onto the workstation. The subjects' standing and sitting height was adjusted so that the equipment was positioned just below elbow height. It consisted of a wooden board with a spinning wheel with adjustable torque set at 8.6Nm (Force = 43N; length of torque wrench = 0.2m). On the anterior of the board was an attachment point for the torque wrench. Two lines were drawn on the front of the board, providing a visual restriction for subjects, thereby limiting the torque wrenching movement to a range of motion of 85°, which is a typical range of motion for industrial usage of these tools. A torque wrench, similar to those used in industry, with a mass of 0.62kg and length of 200mm was used for both the torque wrenching and precision tasks.

On the researcher's signal, each subject was required to wrench at a constant rate of forty wrenches per minute, which was controlled by a metronome, in the stipulated body posture for ninety seconds. On completion of the task, the researcher instructed the subjects to sit and rest for a further ninety seconds. Sanders and McCormick (1993) showed that for a light manual task, such as torque wrenching which is performed for up to 3 minutes, less than 20% of this time is needed to allow for recovery of the muscles. Based on these findings by Sanders and McCormick (1993), 90 seconds of rest was deemed sufficient to allow for recovery during the current study. During the rest period the individual pointed out areas and ratings of body discomfort. After the break, the subsequent condition was performed.

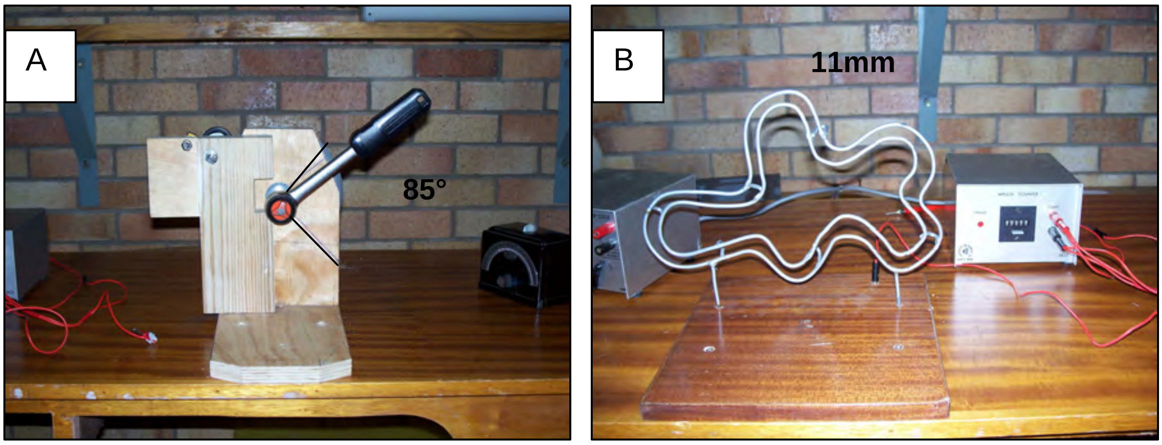

Figure 5: (A) Torque wrenching equipment and (B) precision design

Precision Task

A wire design (with a gap width of 11mm) was used for the precision task, and was attached to an error counter (Figure 5(B)). The tool used for the precision task was modified slightly from the one used for the torque wrenching task by placing a stylus (of negligible mass) inside the torque wrench. The stylus was linked to a wire which led to an error counter. The mass of the torque wrench was kept constant so that any changes observed during the two tasks were due to the task itself and not to the difference in mass of the torque wrench.

Similar to the torque wrenching task, the equipment used for the precision task was fixed onto the workstation. Again, standing and sitting height was adjusted so that the equipment was situated just below elbow height, depending on the posture required. On the researcher’s signal, subjects were required to move a pointer through the wire design (no time limitation was stipulated), without touching the edges (controlled by an error counter), for ninety seconds. Subjects on average moved at a speed of $0.01 m.s^{-1}$.

DEPENDENT VARIABLES

Muscle activity was deemed a necessary measure, since the risk of developing work-related musculoskeletal disorders is elevated when high levels of muscle activity are sustained (Straker and Mekhora, 2000). All muscles deemed important actors in stabilising the upper arm in precision tasks and those muscles required to maintain body posture were considered for assessment. The rotator cuff muscles, leg muscles (those which move the thigh and hamstring), rectus abdominis and muscles of the vertebral column (quadratus lumborum, iliocostalis muscles, longissimus muscles and spinalis thoracis) were all considered. However, owing to the selection of surface EMG for monitoring muscular involvement, rather than indwelling electrodes, many of these muscles (which are situated deep within the muscular system) could not be monitored during the current research and were therefore excluded from the investigation. Only those muscles which could be assessed using surface electrodes were considered for further investigation.

Taking into consideration the recommendations made by Kendell *et al*. (1993), the researcher performed pilot studies on those muscles which could be measured using surface electrodes. This allowed for further selection of the most relevant muscles used during arm movements and stabilisation of the body. Ultimately, those muscles which were selected for the current research were the biceps brachii, middle deltoid, trapezius, latissimus dorsii, upper and lower erector spinae and the semitendinosus muscles. More specifically, the biceps brachii muscle flexes the elbow joint and facilitates supination of the forearm and hand at the elbow joint (Tortora and Grabowski, 2003), while the deltoid muscle performs adduction and abduction arm movements. All these movements are observed during torque wrenching and precision tasks. The trapezius muscle acts on the pectoral girdle by elevating and adducting the scapula and the latissimus dorsii muscle extends, adducts and rotates the humerus medially at the shoulder joint. These movements are associated with the movements observed during the tasks outlined during the current research. The upper and lower erector spinae muscles help to stabilise the upper body, especially during forward flexion. The only muscle associated with leg movement and stabilisation that was assessed was the semitendinosus muscle, which flexes the knee joint and extends and rotates the thigh at the hip joint. During forward flexion of the torso, both the semitendinosus and the erector spinae muscles are employed to help stabilise the posture and therefore, these muscles were deemed important for the current research. Muscle activity was recorded for these seven muscles, using electromyography.

It is important to consider physiological responses during work tasks, since the results provide quantitative measures of how the individual's cardiovascular, respiratory and metabolic systems are responding to a task (Ekelund *et al*., 2001). Furthermore, electromyography is not able to provide estimates on the total energy cost of performing activities. Therefore, physiological variables assessed in the current study included: heart rate (HR), tidal volume (V_T), minute ventilation (V_E), breathing frequency (F_B), energy expenditure (EE) and oxygen uptake (VO_2), all of which were assessed using an ergospirometer.

According to Charteris *et al*. (1976) it is important to take a holistic approach when evaluating human effort, as one approach may deliver a biased perspective and identify those responses which are relevant to that specific approach only. For this reason, in addition to EMG and physiological measures, psychophysical variables were assessed as a means of determining the discomfort felt by the subject. The body discomfort scale and map, developed by Corlett and Bishop (1976), was used for this purpose which provided a quantitative measurement for a subjective feeling. Similarly, a psychophysical rating questionnaire (see Appendix B5) was used to determine each subject's comfort levels.

MEASUREMENT AND EQUIPMENT

Electromyography

A surface electromyography (EMG) device (Muscle Tester Mega ME6000P16, Mega Electronics Ltd, Finland) was used during the current research. Muscular activity is measured by attaching EMG electrodes to the surface of the skin and recording the changes in electrical activity in the muscle directly beneath them. For these EMG recordings two disposable, pre-filled Silver-Silver Chloride electrodes were attached to each of the relevant muscles, whilst a third "neutral" electrode was attached at least 100mm away to an inactive muscle. The Megawin© software was used in conjunction with the electromyography equipment and a wireless transmitter was connected to a laptop computer, linking the two pieces of equipment.

Ergospirometer

The Cosmed Quark b^2 unit provides the opportunity to determine physiological responses since it performs breath by breath analysis and is calibrated according to the atmosphere around the testing area. This unit consists of a face-mask, attached to an ergospirometer, which connects to the computer unit, thereby allowing the results to be displayed and stored. The ergospirometer displays various physiological results, however, for the purposes of this research, only breathing frequency (F_B), heart rate (HR), tidal volume (V_T), minute ventilation (V_E), energy expenditure (EE) and oxygen consumption (VO_2) were analysed. In the current study, the electrode strap from the Polar® Accurex Plus heart rate monitor was used to transmit data to the ergospirometer.

Body Discomfort Scale

The Body Discomfort (BD) Map and Scale, developed by Corlett and Bishop (1976) was used to assess the individuals' perception of discomfort or pain during the given tasks. Discomfort is an indicator of the incompatibility between worker capabilities and task demands and can, therefore, be used as a predictor of possible musculoskeletal injuries resulting from poor working postures. According to Evans and Patterson (2000), identifying areas of discomfort is of great importance when considering an individual's perceptions of various work tasks. The BD scale (see Figure 6) makes use of a body map divided into 29 parts, which allows subjects to identify body areas experiencing the greatest strain. The BD map is used in conjunction with a Likert Scale, ranging from 1 (no discomfort) to 10 (extreme discomfort), thus providing the researcher with a quantifiable measurement. On completion of each condition, subjects were asked to point to the three areas where they felt greatest discomfort and to then rate the intensity of the discomfort on the numeric scale.

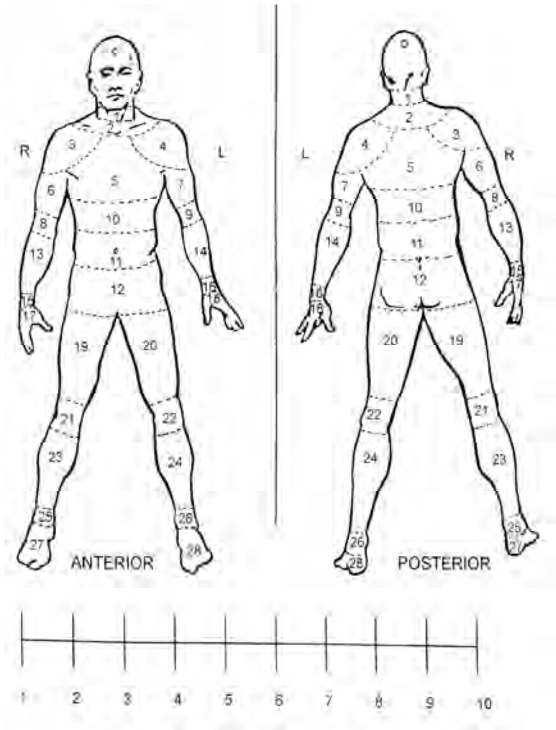

Figure 6: Body Discomfort Scale (Corlett and Bishop, 1976)

Psychophysical Rating Questionnaire

A psychophysical questionnaire indicating the subjects' personal feelings towards each of the tasks was presented to each subject at the completion of the nine conditions. The questionnaire consisted of the nine conditions listed from Condition 1 to Condition 9 and the subjects were required to rate these conditions in order of ascending comfort and lower back muscle exertion (see Appendix B5).

EXPERIMENTAL PROCEDURE

Experimentation was conducted in the Ergonomics Laboratory of the Human Kinetics and Ergonomics (HKE) Department at Rhodes University. The subjects were required to participate in two sessions. Nine conditions were assessed, with each condition investigating a combination of body posture and manipulative task as shown in Table IV, and further illustrated in Figure 7.

Figure 7: Illustration of the nine conditions tested.

Pilot Studies

Prior to the experimental investigation, preliminary studies were conducted in the HKE Department at Rhodes University. The aim of these pilot studies was to identify particular aspects of the research which needed to be controlled. The first of these studies was performed on a consenting group of thirty-seven HKE students. The objective was to identify stature ranges where significant changes in trunk angle were observed whilst performing a simulated industrial assembly task. Ultimately, this would determine the stature range required for this testing. This was achieved by measuring stature, using a Harpenden stadiometer, thereby allowing individuals to be classified into different stature groups. Subsequently, each subject was required to stand in a demarcated area on the floor and was asked to simulate a torque wrenching task. A photograph of each individual was taken and analysed, using "Meazure", a software program enabling body angle analysis. This helped to determine the degree of trunk flexion variance between subjects in different stature ranges. It was found that subjects with a stature below 1600mm and above 1850mm showed significantly different trunk flexion angles compared to those subjects whose stature fell within this range. Therefore, it was established that for the current research, subjects should have a stature between 1600mm and 1850mm to minimise interference. Similarly, it was determined that a workstation made relative to each subject's anthropometry was more appropriate than having a set workstation height for all subjects.

To determine the most suitable torque wrenching speed, a metronome was set at varying paces (25, 30, 35, 40, 45 and 50 beats.min^{-1}) and subjects were asked to identify the rate which they felt was physiologically taxing, yet did not elicit extreme discomfort, whilst wrenching for two minutes. From this it was determined that the optimal torque wrenching speed for the current research was 40 wrenches per minute.

Additional preliminary studies were performed on four subjects to establish the most pertinent muscles to assess during the research, as well as appropriate electrode placement. The researcher identified different muscle groups which were activated during the simulated task and from these the most readily accessible muscles were considered further.

Studies on physiological measures were also performed prior to testing to determine the most appropriate testing period as well as the required resting duration. It was decided that in order to eliminate the presence of muscular fatigue, ninety seconds of activity was sufficient, although steady-state was not reached in all of the physiological responses.

Subject Characteristics

The study involved thirty-six volunteers (18 males and 18 females) aged between 20 and 28 years (mean: 21.1 ± 1.79 years) who were randomly selected from the student population at Rhodes University. Subjects were restricted to a stature range of 1600-1850mm, as beyond this range, pilot studies had shown excessive variation in trunk flexion angles during the simulated assembly tasks. All subjects were right hand dominant and it was imperative to the research that all subjects were free from any recent or long-term injuries, verified through self-report. None of the subjects had any prior professional experience in assembly work.

Anthropometric and Demographic Data

According to Kroemer (1989), because individuals vary in size their body segments do not have the same proportions. Thus, workstations or equipment need to be carefully considered and cannot be designed for the “average” person. It was therefore imperative that anthropometric and demographic data were collected during the current investigation (Table V) in order to personalise the workstation for each subject. Iliac crest height, sitting and standing elbow height, and arm length measurments were collected using a Takei anthropometry set. This allowed the researcher to identify work heights which would be most appropriate for each individual. A Harpenden stadiometer was used to measure stature to the nearest millimeter (mm) and a Toledo scale recorded body mass, measured to the nearest 0.1kg. For standardisation purposes, all anthropometric measurements were taken on the right side of the body and corresponded to all subjects being right hand dominant. Age and sex were deemed necessary demographic data, as studies have shown differences in strength and physiology between older subjects as well as between the different sexes (Pheasant, 1983; McArdle *et al*., 2001).

Table V: Anthropometric data collected for all subjects (n = 36). (mean with standard deviations in brackets; CV = coefficient of variation).

Stature (mm)	1722 (±64) CV = 3.7%
Iliac crest height (mm)	1045 (±44) CV = 4.2%
Sitting elbow height (mm)	784 (±27) CV = 3.5%
Standing elbow height (mm)	1067 (±40) CV = 3.7%
Arm length (mm)	71 (±4) CV = 6.3%
Mass (kg)	70 (±11) CV = 16.5%
BMI	23.63(±3) CV = 14.5%

Session One: Introduction and Familiarisation

Subjects were required to attend the first session in groups of about six persons. On arrival, the individuals were fitted with the heart rate monitor and were asked to sit quietly while the purpose of the study, experimental procedures, and the body discomfort scale were explained in detail, both verbally and in a written letter (see Appendix A2). Once questions from the subjects were answered by the researcher a letter of informed consent (see Appendix A3) was then handed to each individual, to read and sign. The Rhodes University Ethics Committee was informed of the procedures. Reference heart rates were recorded during this introduction, since subjects were not lying down during this measurement and anticipation could have influenced heart rate. This measure was taken so that the researcher could be sure that subjects reached these values during the rest period. Subsequently, subjects were provided with the opportunity to familiarise themselves with the different conditions and tasks which were to be carried out during Session Two (experimental session). Finally, subjects' anthropometric data (mass, stature, sitting and standing elbow height, arm length and iliac crest height), and demographic information (age and sex) were collected to aid in the correct positioning of the apparatus to be used during experimentation.

Session Two: Experimentation

Prior to the testing session, the order in which the nine conditions were to be completed was assigned to each subject. This was done by permutation which ensured that every condition had equal opportunity to be performed first, second, third etc (see Appendix A4). This guaranteed any differences found in physiological, psychophysical or biophysical responses could be attributed to the conditions and not to the effects of familiarisation and/or fatigue. Thirty-six subjects were required, since it was necessary to have a multiple of nine (as there were nine experimental conditions), and still have enough subjects to make the research credible. The experimental area was set up in accordance with the data collected during the first session, which included placing the goniometer at the subjects' iliac crest height (for stooping) and adjusting the chair height (for sitting), and horizontal distance (for standing, sitting and stooping) from the workstation to make it relative to the individual's elbow height and arm length.

The subjects were tested individually during the experimental session. On arrival they were fitted with a heart rate monitor. A marker was placed on the subject's left ear and hip which provided a visual reference point for the stooping angle. A brief recap of the protocol was given to the subject and the area where the electrodes were to be placed was shaved and cleaned with alcohol to ensure good conductivity. Electrodes were then attached to the skin covering the seven selected muscles and in the direction of the muscle fibres. This was done by the subject contracting the individual muscle groups, getting them to perform specific movements and/or by palpatation of the muscles by the researcher. Finally, the wires were attached to the electrodes (see Figure 8).

Figure 8: Illustration of the electrode placement with wires attached.

Preceding the execution of the tasks, every subject was required to perform two maximum voluntary contractions (MVCs) for each of the seven muscles. The data was used to calculate the percentage of maximum contraction at which the subject was working during the tasks. To obtain MVCs, subjects were asked to exert their maximum force against a manual resistance (as described by Kendell *et al*., 1993), in this case provided by the researcher. Subjects were required to adopt either a prone or seated posture, depending on the muscle being tested, and to then place themselves in a position which allowed for maximum force to be exerted from each of the muscles (see Figure 9). According to the literature, the optimal duration for MVCs is between 2 and 6 seconds (Visser *et al*., 2004; Escorpizo and Moore, 2006). Therefore, it was decided that performing MVCs with a duration of five seconds was satisfactory for this research, with each MVC being performed twice with at least 30 seconds rest between the two contractions. From analyses on the data obtained, it was determined that the greatest contraction over a period of four seconds of time was sufficient to calibrate the MVC, as this eliminated any adjustments which may have occurred during the onset and offset of contraction.

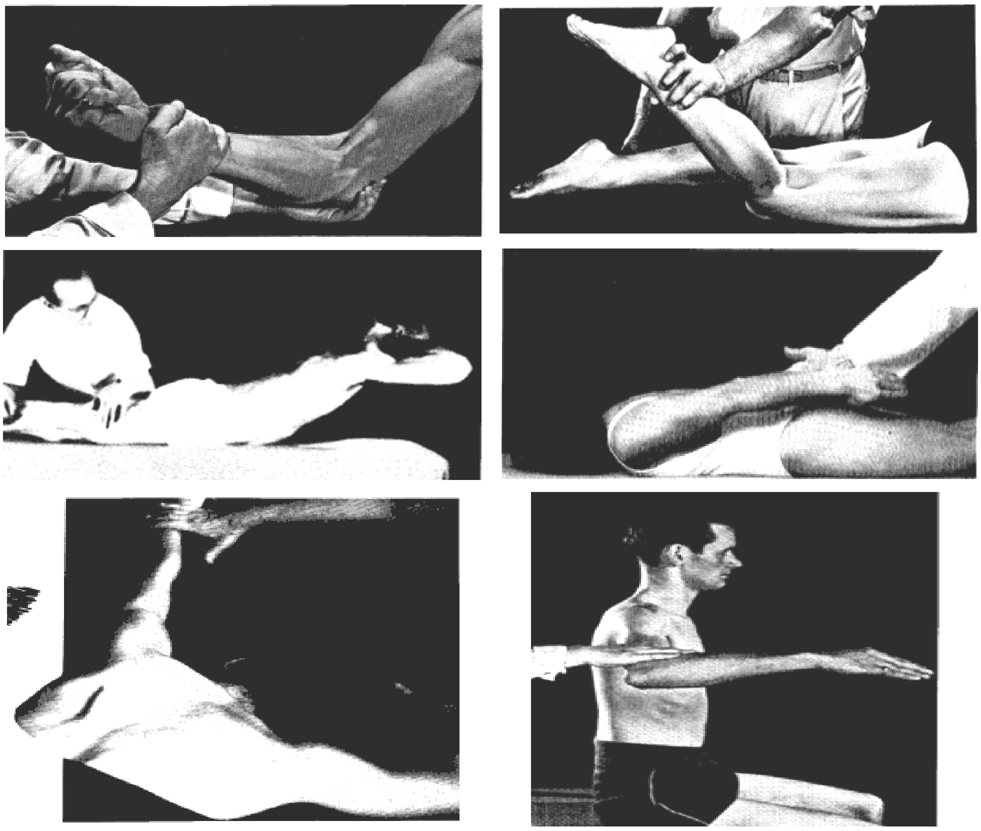

Figure 9: Positions adopted for MVC recording from L to R: biceps brachii; semitendinosus; erector spinae; latissimus dorsii; trapezius; deltoid muscles.

The difficulty with obtaining MVCs using this method of collection is that the maximum contraction that the subject can exert is reliant on the force the researcher can produce. Therefore, actual MVCs may be greater than what was recorded during the collection of maximal contractions. Since the results are calculated using the MVC measurements there could have been some discrepancies within the findings. When performing the given tasks, subjects may be able to exert a greater force than was recorded during the MVC collection and hence, by having the lower MVC recording, the overall percentage of MVC (% MVC) used may have been greater than expected. Consequently, in some cases subjects may have been able to exert a force greater than 100% MVC, which would have the effect of there being a negative result when equation 3 was applied.

Once MVCs were collected, the face-mask was fitted to the subject and attached to the ergospirometer. The subject was then required to sit quietly while reference data were collected. Once the researcher was satisfied that the lowest values, which would be used as reference values, had been reached, the subject was positioned at the work area, in the correct posture, according to the randomised condition to be performed, and testing began.

Cardiorespiratory and metabolic data were recorded throughout the testing duration. A marker was placed at the beginning and end of each test to aid data analysis. At the end of each ninety second condition, subjects were seated and body discomfort was recorded. The same procedure was followed with the next condition after a 90 second rest period. After completion of all nine conditions, the psychophysical rating questionnaire was presented to the subjects, who were then required to rate each of the conditions according to preference and comfort felt.

Figure 10: Attachment of face-mask and subject indicating body discomfort.

STATISTICAL ANALYSIS

All experimental data were correlated into a Statistica (version 7.1) table where descriptive statistics were calculated, thus providing general information concerning the sample. A paired t-test, comparing the combined effect to the additive effect, was employed and a significance level of $p<0.05$ was set throughout the statistical analysis, providing a 95% level of confidence. Hence there were still five chances in a hundred that a Type I (rejecting a true hypothesis) could have been committed. One-factorial and two-factorial repeated measures analyses of variance (ANOVAs) were also performed in order to identify the general effect obtained for individual biophysical, physiological and psychophysical measures for all conditions and for all conditions and muscles (or physiological or psychophysical data), respectively. The two-factorial ANOVAs were used to draw overall conclusions for the final responses to hypotheses.

CHAPTER IV

RESULTS AND DISCUSSION

INTRODUCTION

Workers in the automotive industry are likely to suffer from workplace injuries more frequently than other industrial workers (Chung *et al*., 2001). Previously, it was thought that these injuries were a direct result of the physical nature of tasks performed in this industry. However, it has been acknowledged that there may be other factors involved; more specifically, light manual assembly tasks have been identified as risk factors for workplace injuries. Therefore, for the current research, assembly activities (torque wrenching and precision tasks), and body postures (stooping and sitting) which are frequently observed in the automotive industry were selected and performed in different combinations with each other, to assess whether an interaction between body posture and activity occurs when these tasks are performed simultaneously.

While the main emphasis of the current research was on the muscle responses of the subjects, it was essential to consider the physiological and perceptual responses as well. Therefore, a holistic approach to evaluating the responses of thirty-six subjects whilst performing combinations of torque wrenching and precision activities in either a stooped or seated posture was adopted.

For the interpretation of the results, the following terms have been used to refer to the different effects and reactions:

- *Additive effect* refers to the effects of the sum of body posture only and activity only.
- *Combined effect* refers to the effects of combined task of body posture and activity.

- *Compensatory reaction* refers to the additive effect being greater than the combined effect (additive effect > combined effect).

- *Cumulative reaction* refers to the additive effect being smaller than the combined effect (additive effect < combined effect).

DATA PRE-PROCESSING

Before any further processing was performed, the data obtained during the experimental phase was normalised using subject-wise normalisation. This was considered useful since the aim of the research was not to identify different values between subjects, but rather to assess whether one can consider the responses of two individual factors (body posture and task) independently, or whether they have to be assessed in combination. Similarly, this research was not interested in the absolute values, but rather the differences for different test conditions. As different subject's may work on different levels of muscle activity, for example, and considering that there are inter-individual differences in the percentage maximum muscle usage, one subject may have a much larger impact on the average data compared to another subject, although both might have the same relative variance (or coefficient of variance). Therefore, those subjects which have higher values (and hence larger variances) will have a larger impact on the statistics. Hence, subject-wise normalisation of the data was deemed a helpful step, so that all subjects had an equal impact on the overall data. Normalisation was achieved by calculating the average of all subjects' responses across the nine conditions and subsequently dividing the values recorded for each subject for each biophysical, physiological and psychophysical variable by this factor so that the average of all nine conditions tested was equal to 1. The relative variance of the data for each subject was not affected, however, the variance between subjects that could cause unequal consideration of different subjects due to their different working levels, was eliminated.

OVERALL RESULTS

Table VI provides an overall view of the significant differences ($p<0.05$) observed for each biophysical response, as well as each physiological and psychophysical responses found between the additive and the combined effects over all four conditions (see Appendix C2 for the detailed tables), as well as each biophysical, physiological and psychological response for each of the four conditions (see Appendix C3 for the detailed p-values). For the statistical evaluation, 1-factorial ANOVAs, as well as paired t-tests ($p<0.05$) were employed. The calculation for determining the different effects are established using Table III and the corresponding equation ($(Y - W) + (X - W) = (Z - W)$; see Chapter III: Methodology).

Table VI: Significant differences found between combined and additive conditions.

			SITTING		STOOPING	
		GENERAL (all cond.)	Torque Wrenching	Precision	Torque Wrenching	Precision
BIOPHYSICAL	Biceps brachii	n.s	n.s	n.s	n.s	n.s
	Middle Deltoid	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$	n.s	--- $p < 0.05$
	Trapezius	n.s	--- $p < 0.05$	n.s	n.s	--- $p < 0.05$
	Latissimus dorsii	n.s	n.s	n.s	--- $p < 0.05$	n.s
	Upper Erector spinae	n.s	n.s	n.s	n.s	n.s
	Lower Erector spinae	n.s	n.s	n.s	n.s	n.s
	Semitendinosus	n.s	n.s	+++ $p < 0.05$	n.s	n.s
PHYSIOLOGICAL	Heart Rate (HR)	n.s	+++ $p < 0.05$	n.s	--- $p < 0.05$	n.s
	Oxygen Consumption (VO_2)	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$
	Energy Expenditure (EE)	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$
	Breathing Frequency (F_B)	n.s	n.s	n.s	n.s	n.s
	Minute Ventilation (V_E)	--- $p < 0.05$	--- $p < 0.05$	n.s	--- $p < 0.05$	--- $p < 0.05$
	Tidal Volume (V_T)	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$
PSYCHO PHYSICAL	Body Discomfort	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$	--- $p < 0.05$	n.s

Where: n.s = no significant difference; "---" = compensatory reaction; "+++" = cumulative reaction

From the results for the 1-factorial ANOVA (Table VI: GENERAL column) it is observed that for all of the individual muscles, except the deltoid muscle, no significant general effect was found, however for the majority of physiological and psychophysical variables, a significant effect was observed across the four conditions. When the analysis was made to identify whether the different conditions had different effects, it was found that for the biceps brachii, deltoid, trapezius, and upper and lower erector spinae muscles the effect of the different conditions was not significant. However, the effect of the different conditions on the latissimus dorsii and semitendinosus muscles were significant (see Table VI). For the physiological variables, the effect of the different conditions was not significant for energy expenditure, oxygen consumption, breathing frequency and tidal volume. Significant effects were, however found for heart rate and minute ventilation. For the psychophysical response there was a significant effect generally, as well as for the different conditions.

The results found for each biophysical, physiological and psychophysical responses for each condition shows in more detail where the significant differences are found. For the biceps and the upper and lower erector spinae no significant differences were found between the additive and combined effects for any of the four conditions under investigation. This is in agreement with results obtained by Farley and Koshland (2000) who determined that the muscle activation levels during a combined task were equal to the sum of the individual muscle activities. Significant differences were found for three of the four conditions (torque wrenching in a seated posture and performing a precision task in a seated and stooped posture) for the middle deltoid muscle, while there were two conditions which showed significant differences for the trapezius muscle (torque wrenching in a seated posture and performing a precision task in a stooped posture). Further, referring to Table VI, the latissimus dorsii muscle recorded a significant difference between the additive and combined effects for the stooped torque wrenching condition only, while the semitendinosus muscle only recorded a significant difference for the sitting precision condition.

This can be considered from another perspective where, for the overall muscle activity responses 25% (or 7 out of 28) of the biophysical parameters elicited significant differences between the additive and combined effects. The distribution of the significant differences was equal across conditions, as two significant differences were recorded per condition, except when torque wrenching in a stooped posture, where only the latissimus dorsii muscle showed a significant difference. When assessing this in more detail, significant differences were found for both stooping precision and sitting torque wrenching conditions, for both the middle deltoid and trapezius muscles. However, for the sitting precision condition, the trapezius and semitendinosus muscles elicited significant differences.

For the biophysical responses, a compensatory reaction (represented by --- in Table VI) was observed in all significant cases, except for the semitendinosus muscle, which displayed a cumulative reaction (represented by +++ in Table IV) when performing a precision task in a seated posture. A possible reason why compensatory reactions are observed in the majority of cases, is due to the ability of the body to use the least amount of energy during the performance of different tasks. According to McArdle *et al*. (2001) and Cerny and Ucer (2004) the human has evolved so that the most cost-effective and efficient means of movement is carried out. Therefore, when the muscles are required to work (as was the case during the torque wrenching and precision tasks) they will adopt the most efficient way of using energy. This optimisation of energy use plays a role in total body/motor control. The brain jointly controls the different movements of the trunk for stabilisation and the arm-hand system for manipulation so that the most efficient amount of energy is spent. Therefore, when the two activities are performed simultaneously, a compensatory reaction is observed between the additive and combined effects for most muscle responses. Furthermore, the leg muscles are activated only slightly during seated work (Sanders and McCormick, 1993), and therefore, the brain does not detect the need to economise on the amount of energy used during the performance of a precision task whilst seated. This provides an explanation for only the semitendinosus muscle recording a cumulative reaction between the two effects.

From these responses for muscle activity it becomes obvious that no clear pattern, in terms of where the significant differences lie, emerges, making it difficult to draw general conclusions. Sanchez *et al*. (1979) provided a possible explanation for these conflicting responses. Results from their study indicate that when static work is combined with dynamic work the responses vary with the type of muscle associations involved. Hence, for the current study, depending on the muscle being assessed and the combination of the effect of awkward body posture and the effect of the activity, results will be varied.

In terms of significant differences found for the physiological responses, these were dissimilar to those observed for muscle activity. A greater number of physiological parameters showed a significant difference (71% or 17 out of 24) compared to the muscle activity responses (25%). This could possibly be due to none of the physiological responses reaching steady-state during the testing (see Appendix C6). If steady-state were to be achieved, these responses may have elicited different results. However, for the purposes of this study it was imperative that the muscles were not fatigued and hence it was not possible to obtain physiological steady-state. Breathing frequency was the only physiological variable which did not elicit any significant differences for any of the conditions. This is in direct contrast to tidal volume, oxygen consumption, energy expenditure which recorded significant differences for all the conditions. Minute ventilation only showed significant differences for three of the four conditions (torque wrenching in a seated and stooped posture and performing a precision task in a stooped posture), while only the sitting torque wrenching and stooping torque wrenching conditions elicited significant differences for heart rate.

For the physiological responses, compensatory reactions were observed in the cases where significant differences were found, which was in agreement with the majority of reactions identified for muscle activity. The only exception was found for the heart rate response during torque wrenching in a seated posture which showed a cumulative reaction between the two effects (see Table VI). Sanchez (1977) identified a similar response for heart rate in his study, whereby the sum of the individual effects was found to be less than the combined response. This study by Sanchez (1977) assessed a dynamic and a static task, which is, in effect, what was considered during the current research and hence comparisons can be made.

The results obtained for body discomfort indicate significant differences for seventy-five percent (3 out of 4 parameters) of the conditions assessed. This is a similar percentage to that found for the physiological responses. More specifically, performing a torque wrenching activity in a seated posture, performing a precision task in a seated posture and torque wrenching in a stooped posture, elicited these significant differences. In all cases, the reaction observed was a compensatory reaction, which is in accordance with those found for the majority of the muscle activity and physiological responses.

Overall, taking the biophysical, physiological and psychophysical responses into consideration, a greater number of significant differences were found for the sitting torque wrenching condition (eight significant differences) than the others, although torque wrenching in a stooped posture showed seven variables which had significant differences. Performing a precision task in a seated posture and performing a precision task in a stooped posture both recorded six significant differences across the muscle activity, physiological and psychophysical responses. There were no general trends observed, since for the sitting torque wrenching condition, significant differences were found for the middle deltoid and trapezius muscles, heart rate, tidal volume, minute ventilation, oxygen consumption, energy expenditure and body discomfort. For the stooping torque wrenching condition, these same physiological and psychophysical variables showed significant differences, but instead of the middle deltoid and the trapezius muscles, only the latissimus dorsii muscle showed significant differences for this condition. Furthermore for the sitting precision condition the middle deltoid and the semitendinosus muscles, tidal volume, oxygen consumption, energy expenditure and body discomfort elicited significant differences between the additive and combined effects.

MUSCLE ACTIVITY RESPONSES

According to Monad (1985) muscular activity can be classified as static or dynamic and activities in everyday life result from an association between both types of contraction (called combined activities). In the present research, both static (sitting and stooping) and dynamic (torque wrenching and precision activity) tasks were observed. These tasks provide large amounts of assessment data for researchers as different muscles are activated simultaneously during their execution. Biceps brachii, middle deltoid, trapezius, latissimus dorsii, upper and lower erector spinae and semitendinosus muscles (all right sides), associated with combinations of either stooping or sitting and torque wrenching or precision tasks, were investigated. Owing to various limitations, surface EMG was used for monitoring muscular involvement, rather than indwelling electrodes. For this reason, the rotator cuff muscles could not be monitored, although these muscles are important actors in stabilising the upper arm in precision tasks.

Table VII provides numerical data on the overall muscle activity responses for both the combined and additive effects. It is observed that during the sitting torque wrenching and sitting precision conditions the semitendinosus muscle elicits the least amount of muscle activation of all the muscle groups assessed for both effects. According to Table VII, the sitting torque wrenching condition shows a negative value for the additive effect (-0.36% Maximum voluntary contraction (MVC)) as well as for the combined effect (-0.72% MVC), while for the sitting precision condition these responses are similar in that both the additive and combined effects are negative (-1.07% MVC and -0.16% MVC respectively). During the two stooped conditions (stooping torque wrenching and stooping precision conditions) the biceps brachii elicited the least muscle activity for both the additive and the combined effects (stooping torque wrenching condition: 4.36% MVC (additive) and 4.96% MVC (combined); stooping precision condition: 3.41% MVC (additive) and 2.68% MVC (combined)).

Table VII: Mean biophysical data (in %MVC) obtained for the seven muscles assessed across the four conditions for both the additive and combined effects (n = 36).

	Sitting				Stooping			
	Torque Wrenching		Precision		Torque Wrenching		Precision	
MUSCLE	*A + B*	*C*	*A + B*	*C*	*A + B*	*C*	*A + B*	*C*
Biceps brachii	1.67	0.88	0.72	0.55	4.36	4.96	3.41	2.68
Middle Deltoid	11.91	9.86	2.42	1.58	20.85	19.60	11.35	8.60
Trapezius	12.65	10.37	6.25	4.84	24.39	22.12	17.99	14.78
Latissimus dorsii	11.73	10.22	3.20	3.88	22.51	16.75	13.97	13.12
Upper Erector spinae	6.23	6.21	2.85	4.30	16.78	16.35	13.40	14.85
Lower Erector spinae	3.30	3.76	2.30	2.95	12.61	14.10	11.61	11.53
Semitendinosus	-0.36	-0.72	-1.07	-0.16	8.97	8.59	8.25	7.98

Where: A refers to effect of posture only; B refers to effect of activity only; C refers to combination of A and B; shaded regions = lowest percentage of muscle activation for each condition

Biceps brachii muscle

Referring to Table VI, no significant differences were found between the additive and combined effects for any of the conditions assessed for the biceps brachii. This suggests that when the biceps brachii are involved in a task concerning static and dynamic contractions, it is not necessary to take the individual effects into consideration but one need only assess the combined task in order to identify where risks are involved. This could be because during the execution of the torque wrenching and precision tasks, the elbow joint is fixed and hence the biceps brachii are not very active and therefore, during these two activities, movement rather came from the shoulder and wrist. Therefore, no compensation from the biceps brachii is necessary during the combined performance of a torque wrenching task in either a stooped or seated posture, as well as a precision task in the same postures.

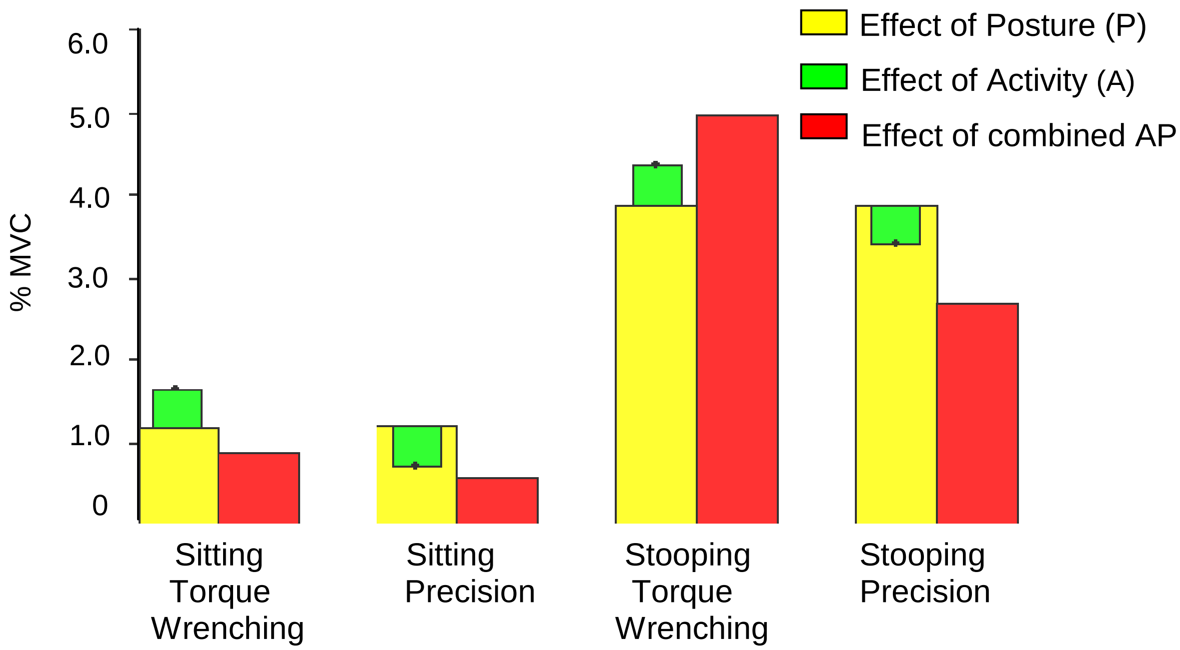

Figure 11: The additive and the combined effects for the biceps brachii muscle across the four tested conditions.

The biceps brachii are mostly responsible for movements of the elbow joint. Since there is little elbow flexion or extension occurring during these tasks, the relative contributions from either the torque wrenching or precision task to the overall additive effect is small. However, from Figure 11 it is evident that the contributions made by the effect of posture towards the total additive effect for the stooping postures, are much greater than those made by the effect of either torque wrenching or performing a precision task. For the seated postures, the respective contributions from the effect of sitting and the effect of activity are, however, more equal. This discrepancy is due to the biceps brachii having to help stabilise and balance the body when the centre of mass falls outside the base of support, as occurs during stooping. This was achieved by having the arm outstretched in front of the subject during the torque wrenching task. Therefore, the effect that the working posture has on the total biceps brachii muscle activation is greater during the conditions involving the stooped posture, than during the conditions involving the seated postures.

Middle deltoid and trapezius muscles

Statistical analyses revealed that, of the total number of parameters that displayed significant differences for muscle activity (seven parameters), five were observed for either the middle deltoid or the trapezius muscles. In particular, for the middle deltoid muscle, significant differences ($p<0.05$) were found between the additive and combined effects for torque wrenching in a seated posture, performing a precision task in a seated posture and performing a precision task in a stooped posture (Figure 12). Furthermore, when the trapezius muscle is assessed, significant differences were found for the sitting torque wrenching and stooping precision conditions only (Figure 13). For both of these muscles a compensatory reaction is observed between the additive and combined effects for all the conditions where significant differences were found. This suggests that both the trapezius and middle deltoid muscles adjust and compensate for the stresses that are placed on them during these combined tasks. Cerny and Ucer (2004) provide an understanding for this whereby they state that the body will attempt to use the least amount of energy in the performance of a task, and thus during the combined effect of activity and body posture, these muscles will be compensated accordingly, so as to efficiently use the energy.

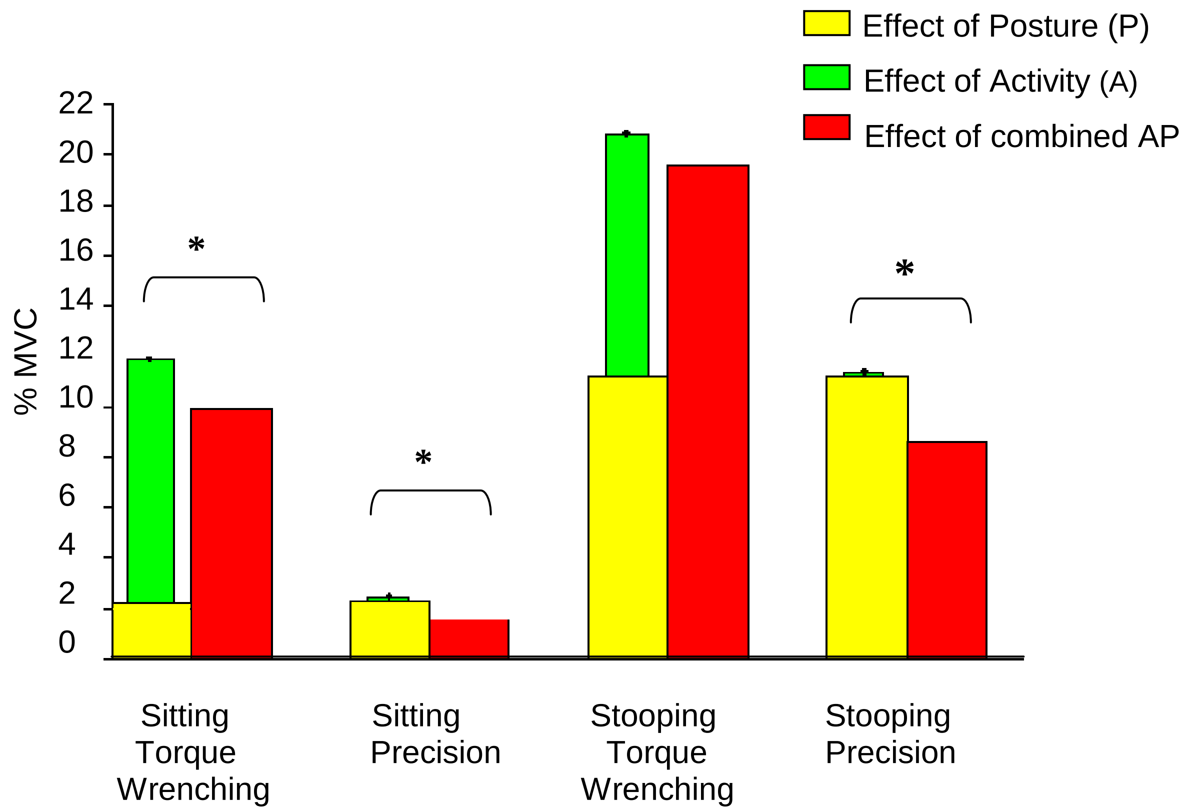

Figure 12: The additive and the combined effects for the middle deltoid muscle across the four tested conditions (* denotes a statistically significant difference, p<0.05).

Sanchez *et al*. (1979) proposed that the difference between the cost of the combined effect and the additive effect be called "extra cost". Although they were referring to physiological responses, the same terminology may be used for these differences in muscle responses. The middle deltoid and trapezius muscle groups displayed similar results in terms of "extra cost" found between the additive and combined effects, with these differences ranging between 17% and 35% (Figures 12 and 13). The trapezius muscle recorded relative differences of 18% for both the conditions where significant differences were found, while for the middle deltoid there was a 35% difference for the sitting precision condition, a 24% difference when the precision task was performed in a stooped posture and a 17% difference was found when torque wrenching was performed in a seated posture.

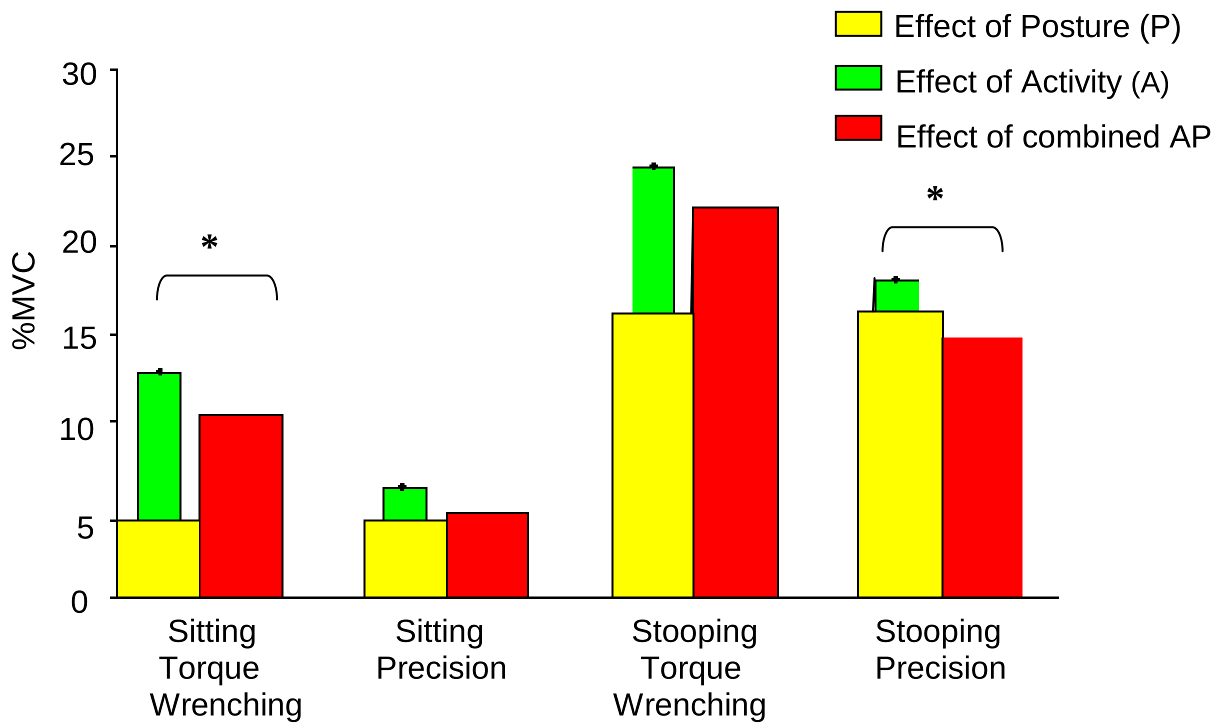

Figure 13: The additive and the combined effects for the trapezius muscle across the four tested conditions (* denotes a statistically significant difference, p<0.05).

The relative contributions of the effect of posture and the effect of activity to the total additive effect are, in most muscles, not equal. For the middle deltoid, the effect of the posture varies depending on the condition being assessed. During the sitting torque wrenching condition, the effect of posture only contributes 19% to the total additive effect, while during the stooping precision and sitting precision conditions, the contribution of the effect of posture is 99% and 95% respectively. There is an equal contribution from the effect of activity (54%) and effect of posture (46%) when torque wrenching is performed in a stooped posture. These results are to be expected, since during a torque wrenching activity a greater amount of shoulder movement occurs than during the precision task, where the elbow joint flexes and extends (during the precision task). From these results it can be concluded that the specific combination of task and activity being performed needs to be taken into consideration. For the trapezius muscle these contributions are similar during the performance of a precision task in a stooped posture with 90% of the total additive effect coming from the effect of posture. However, when a precision activity is combined with a seated posture and torque wrenching is combined with a stooped posture, then the relative contributions from the effect of posture and the effect of activity, for the trapezius muscle, are in a 1:2 and a 2:1 ratio respectively (35%:65% and 66%:34%). Again, the conclusions that are drawn from this identify the need to consider the specific combination of activity and posture that is being assessed.

Latissimus dorsii

For the latissimus dorsii muscle a significant difference was only found between the additive and the combined effects for the stooping torque wrenching condition (see Figure 14). This was in direct contrast to the responses for the middle deltoid muscle which showed significant differences for all conditions except for torque wrenching in a stooped posture. A compensatory reaction was found between the additive and combined effects for this condition, which is in keeping with the findings from both the middle deltoid and trapezius muscles, where compensatory reactions were also found for those conditions which displayed significant differences. According to this finding, when a torque wrenching task is combined with a stooped posture, there may be compensation within the latissimus dorsii muscle, due to the amount of arm adduction occurring during torque wrenching.

At 22.5% MVC, torque wrenching in a stooped posture elicited the greatest muscle activity for the additive effect for the latissimus dorsii muscle. Similarly, when looking at the combined effect, although producing slightly less muscle activity (16.8% MVC) than when the two factors are added together, the combination of stooping and torque wrenching again proved to be the highest activation between the four conditions for this muscle. This is consistent with the literature, which shows that the latissimus dorsii muscle is responsible for arm adduction, as is seen during a torque wrenching task. Referring to Figure 14 the relative difference found between the additive and combined effects for the stooping torque wrenching condition was 26%, which is similar to those differences found for the middle deltoid and trapezius muscles, which ranged between 17% and 35%.

Furthermore, during the stooped torque wrenching condition for the latissimus dorsii muscle, the contribution made towards the overall additive effect by the working posture is the same as that found for the trapezius muscle (66%) for the same condition.

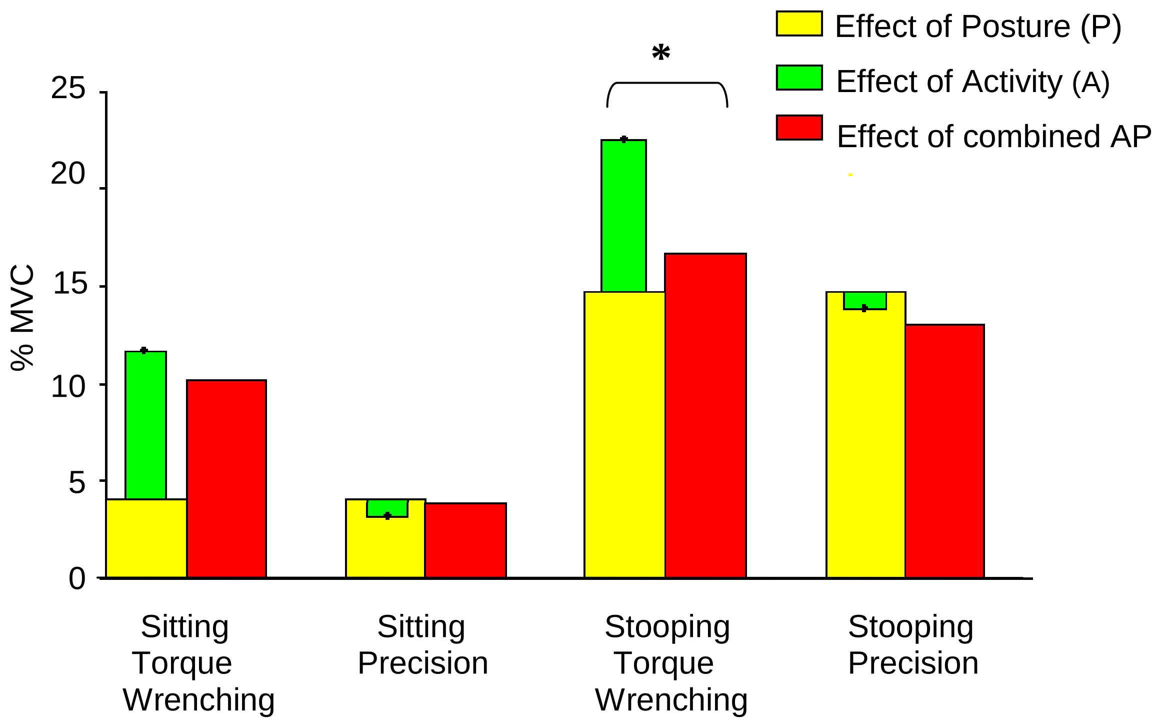

Figure 14: The additive and the combined effects for the latissimus dorsii muscle across the four tested conditions (* denotes a statistically significant difference, $p<0.05$).

Upper and lower erector spinae

The upper and lower erector spinae muscles are predominantly involved in postural control, and were therefore activated during the conditions involving stooped postures. This was highlighted in a study by Andersson *et al*. (1977) on erector spinae electromyography who found that these muscles control flexion and resist the effects of gravity. Statistical analysis indicates that no significant differences were found between the additive and combined effects for either the upper or lower erector spinae muscles (Figures 15 and 16). This is in agreement with the results found for the biceps brachii, where no significant differences were observed for any of the conditions.

Both the additive and the combined upper and lower erector spinae muscle responses increased significantly during the stooped precision and stooped torque wrenching conditions, suggesting that these muscles respond to the posture adopted by an individual, rather than to the type of activity being performed. This is illustrated by an absolute difference of over 10% MVC between the stooping and sitting postures. This was to be expected as Floyd and Silver (1955), Basmajian (1979), Kippers and Parker (1984) and Bridger (1995) demonstrated that at about 50° to 60° of flexion all cross bridges are activat ed, resulting in a higher percentage of muscle contraction and as a result the erector spinae activation increases in both the lumbar and thoracic regions. As the subjects were stooped to 60°, the majority of cross bridges would be overlap ping.

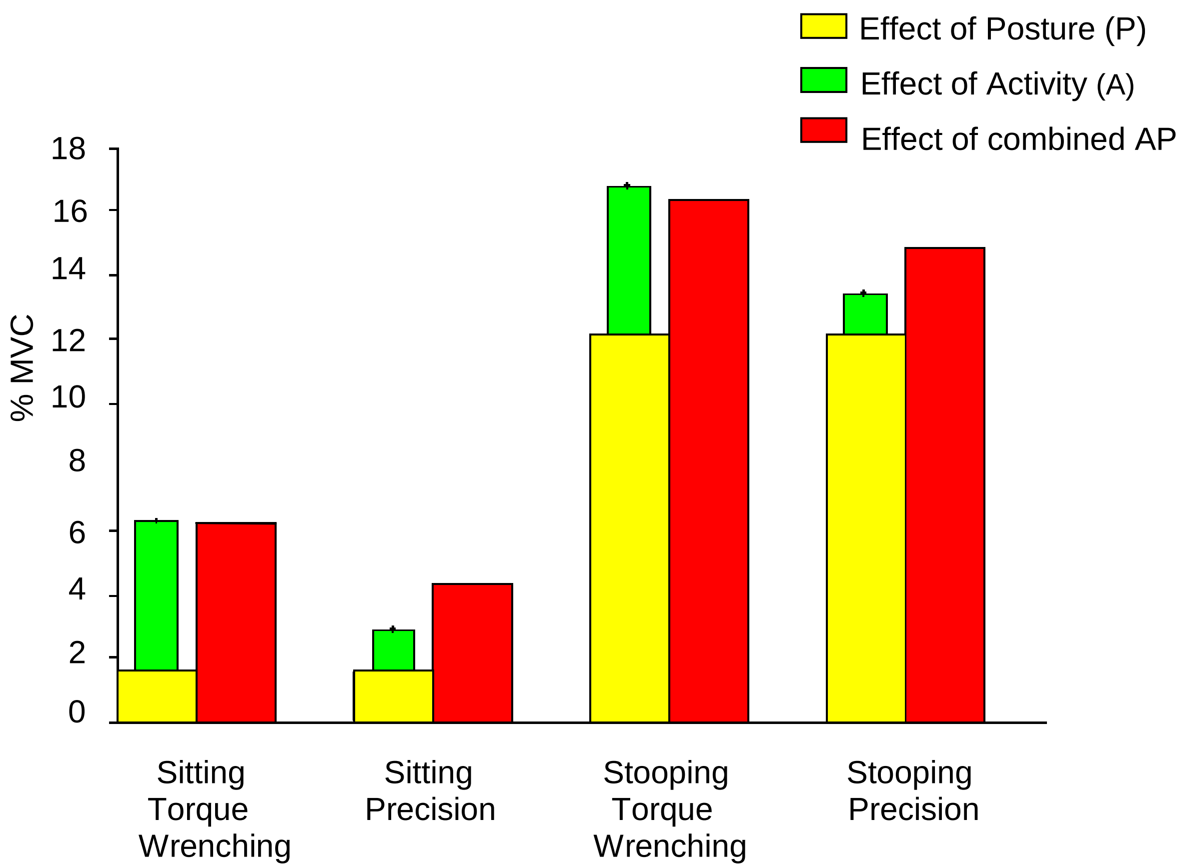

Figure 15: The additive and the combined effects for the upper erector spinae muscle across the four tested conditions.

For the upper erector spinae, it was observed that the muscle activity during the seated posture is lower than the muscle activity during the standing (neutral) posture, which is portrayed in Figure 15 as a negative bar. A possible reason for this could be that the lower back muscles are almost completely relaxed during the seated conditions and, therefore, lower muscle activity is recorded than during the reference (standing) posture, where the erector spinae muscles are more active as there is a greater amount of stabilisation that is needed to keep the trunk upright.

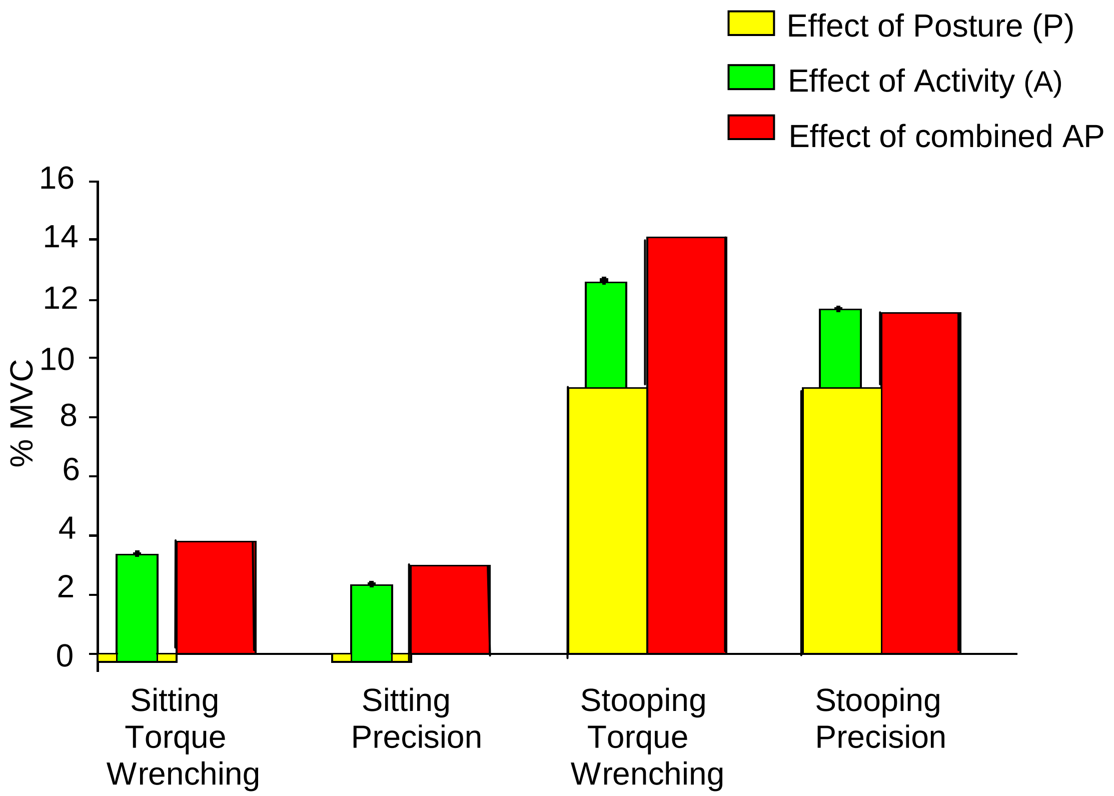

Figure 16: The additive and the combined effects for the lower erector spinae muscle across the four tested conditions.

Semitendinosus

The semitendinosus muscle is one of three muscles making up the hamstrings group and their primary function is to flex the leg at the knee joint and extend the thigh at the hip joint (Tortora and Grabowski, 2003). After statistical analysis was performed, only the sitting precision condition showed a significant difference between the additive and the combined effects for this muscle. This was the only muscle to record a cumulative reaction, which can be explained by the fact that the semitendinosus muscle is inactive during sitting tasks (McArdle *et al*., 2001). Lavender *et al*. (1992), Song *et al*. (2004) and Granata *et al*. (2005a) also stated that when the hip is flexed (as in the case of sitting), the flexor muscles become more relaxed and the muscles of the extensors take over.

A more detailed comparison between the additive and the combined effects shows that the relative difference between the two effects is 85%, which is substantially greater than any of the other differences found for the previous muscles discussed. A possible explanation for this could be that the other muscles are all active during the four conditions. However, when a precision task is performed in a seated posture, the semitendinosus muscle is inactive as seen in Figure 17 by the negative bar illustrated for the effect of posture.

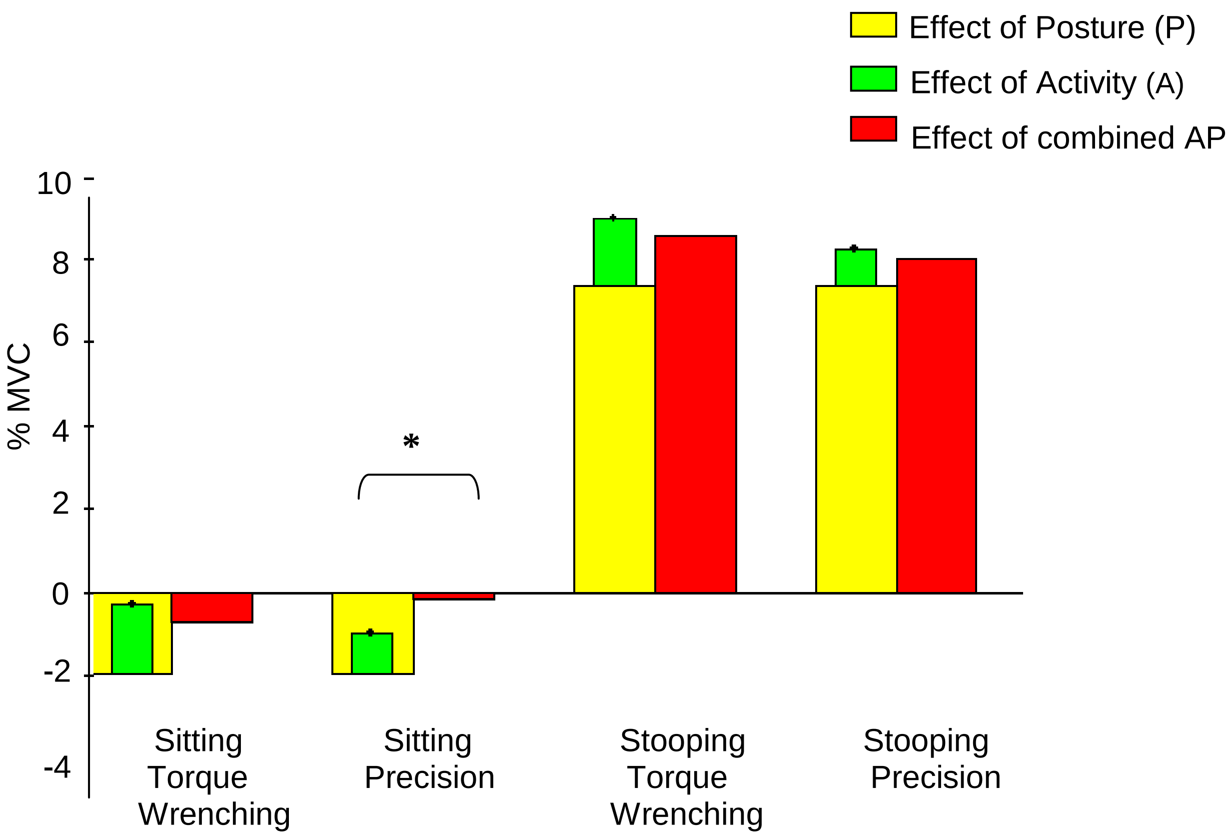

Figure 17: The additive and the combined effects for the semitendinosus muscle across the four tested conditions (* denotes a statistically significant difference, p<0.05).

PHYSIOLOGICAL RESPONSES

Physiological responses are important considerations, since the results provide quantitative measures of how the individual's cardiovascular, respiratory and metabolic systems are responding to a task (Ekelund *et al*., 2001). During this research, these three groups of physiological responses were assessed. Table VIII provides the mean physiological data for the four tested conditions for both the additive and the combined effects. The shaded regions indicate where the significant differences were found (compensatory reaction: yellow; cumulative reaction: orange) for each condition between the additive and combined effects.

Table VIII: Mean physiological data observed for the additive and combined effects across the four tested conditions (n = 36).

	Sitting				Stooping			
	Torque Wrenching		Precision		Torque Wrenching		Precision	
	A + B	*C*	*A + B*	*C*	*A + B*	*C*	*A + B*	*C*
Heart Rate (HR) (bt.min^{-1})	11.79	16.24	-13.69	-11.95	28.27	23.34	2.79	4.69
Oxygen Consumption(VO_2)(ml.kg^{-1}.min^{-1})	6.89	6.24	1.06	0.67	9.28	8.43	3.45	2.90
Energy Expenditure (EE) (kcal.min^{-1})	2.29	2.07	0.36	0.24	3.20	2.90	1.26	1.04
Breathing Frequency (F_B) (br.min^{-1})	8.32	8.95	1.15	1.83	9.94	9.31	2.77	4.31
Minute Ventilation (V_E) (L.min^{-1})	13.65	11.51	2.18	1.57	18.92	15.72	7.45	4.91
Tidal Volume (V_T) (L)	0.34	0.25	0.06	-0.01	0.55	0.45	0.28	0.12

Cardiac Responses

Heart Rate

The results obtained for heart rate show significant differences for 50% of the conditions assessed: sitting torque wrenching and stooping torque wrenching. A compensatory reaction was found when comparing the additive and the combined effect for the stooping torque wrenching condition. Therefore, a higher physiological cost is experienced when the combined task of torque wrenching and stooping is compared to the sum of the two effects (additive effect). However, contrary to this finding, a cumulative reaction was found for the sitting torque wrenching condition. Although this is not consistent with the previous findings for muscle activity, it is in agreement with research by Sanchez (1977) and Sanchez *et al*. (1979). These authors indicated that the sum of the individual effects is less than that found for the combined task. Although these authors' research focused on walking and pushing and not on assembly tasks and awkward body postures, as in the current research, comparisons may be drawn as both of these studies assess dynamic and static tasks. Furthermore, according to Sanchez *et al*. (1979), the increased oxygen cost in the combined exercises is due to the increase in the trunk's postural work. Although this may be the reason for the sitting torque wrenching condition producing a cumulative reaction, it does not hold true for the stooping torque wrenching condition where a compensatory reaction was found. Therefore, a possible explanation for this discrepancy is that the body is compensating for the stress of having to control two factors (stooping and torque wrenching) simultaneously (refer to statement by Cerny and Ucer, 2004 in earlier section).

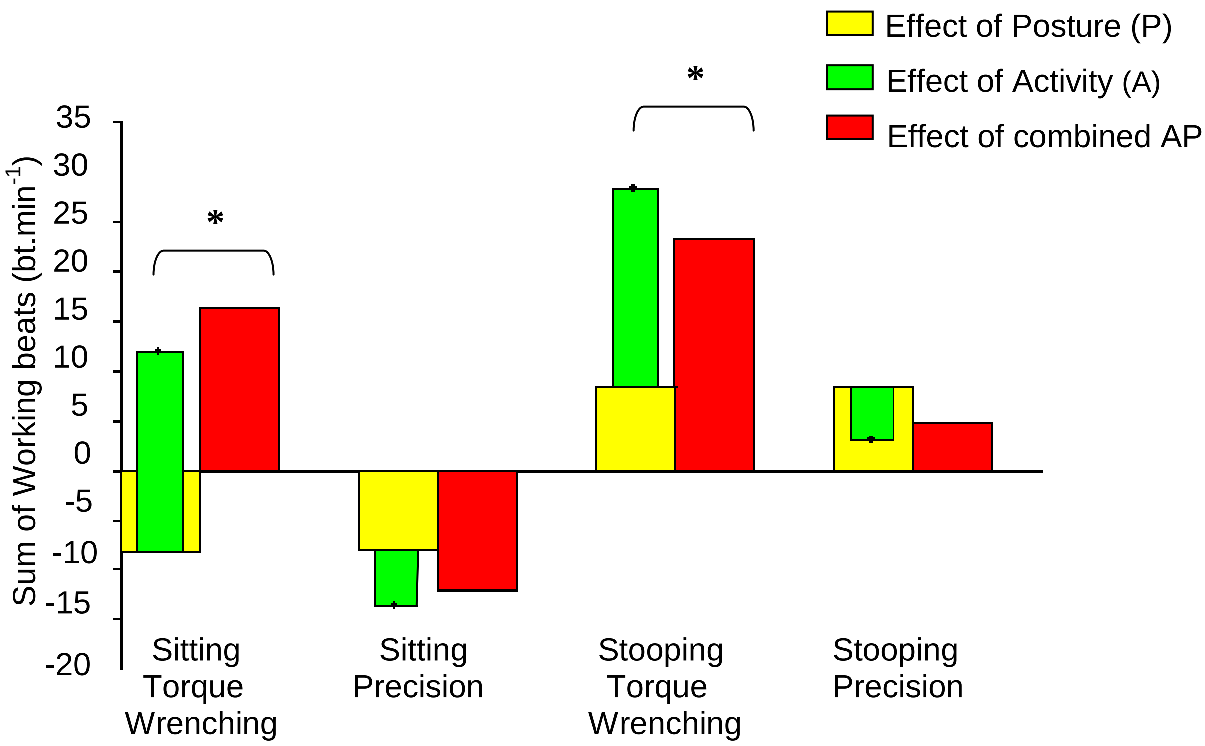

Figure 18: The additive and the combined effects for heart rate across the four tested conditions (* denotes a statistically significant difference, $p<0.05$).

As previously noted, Sanchez *et al*. (1979) proposed that the difference between the cost of the combined effect and the additive effect be called "extra cost". The "extra cost" found between the additive and combined effects for the stooping torque wrenching and sitting torque wrenching conditions is 17% and 27% respectively, although for the sitting torque wrenching condition the combined effect was found to be greater than the additive effect. These differences correspond with the differences found for the muscle activity, which ranged between 17% and 35%. The relative contribution towards the total additive effect from the effect of posture and the effect of the activity being performed, depends on the combination of task and body posture. In the sitting torque wrenching condition the effect of posture contributes negatively to the total additive effect. This can be explained by the fact that heart rate has been shown to be higher during standing than during sitting, as a result of the effects of gravity (Åstrand and Rodahl, 1986). For this reason, when standing is considered as the reference posture, there will always be a negative contribution during combinations which involve sitting. Although the physiological measurement indicates less strain on the cardiovascular system when a seated posture is considered, the effect on the operator's muscular system may be more severe.

Metabolic Responses

Oxygen Consumption and Energy Expenditure

Statistical analysis revealed significant differences between the additive and combined effects for all the conditions assessed for both oxygen consumption (VO_2) and energy expenditure (EE), with all conditions eliciting a compensatory reaction. Comparing these results for EE to those found by Andrews (1966), who undertook to examine whether there was a difference between the sum of the net rates of energy expenditure for the simple tasks, and the net rate of energy expenditure for the simultaneous performance of the same simple tasks, a 50% difference was found in the number of conditions showing a compensatory reaction. In the previous study by Andrews (1966) he found that only 4 of the 8 parameters tested indicated a compensatory reaction, while in the current study 100% of the conditions showed the same reaction between the additive and the combined effects for energy expenditure. This can only partly be explained by findings from Sanchez *et al*. (1979) who state that an increase in postural strain of the trunk results in a greater rise in energy expenditure than during neutral postures. However, referring to Figure 19, this is dependent on the specific combination of task and body posture performed. Since for the sitting torque wrenching combination, the effect of posture only contributes 11% to the total additive effect, while during the sitting precision condition, this increases to 68%. This difference is even more pronounced during the combinations involving stooping, since for the stooping torque wrenching condition the effect of posture contributes 36%, but when a precision task is performed in a stooped posture, the contribution from the effect of posture increases to 91%.

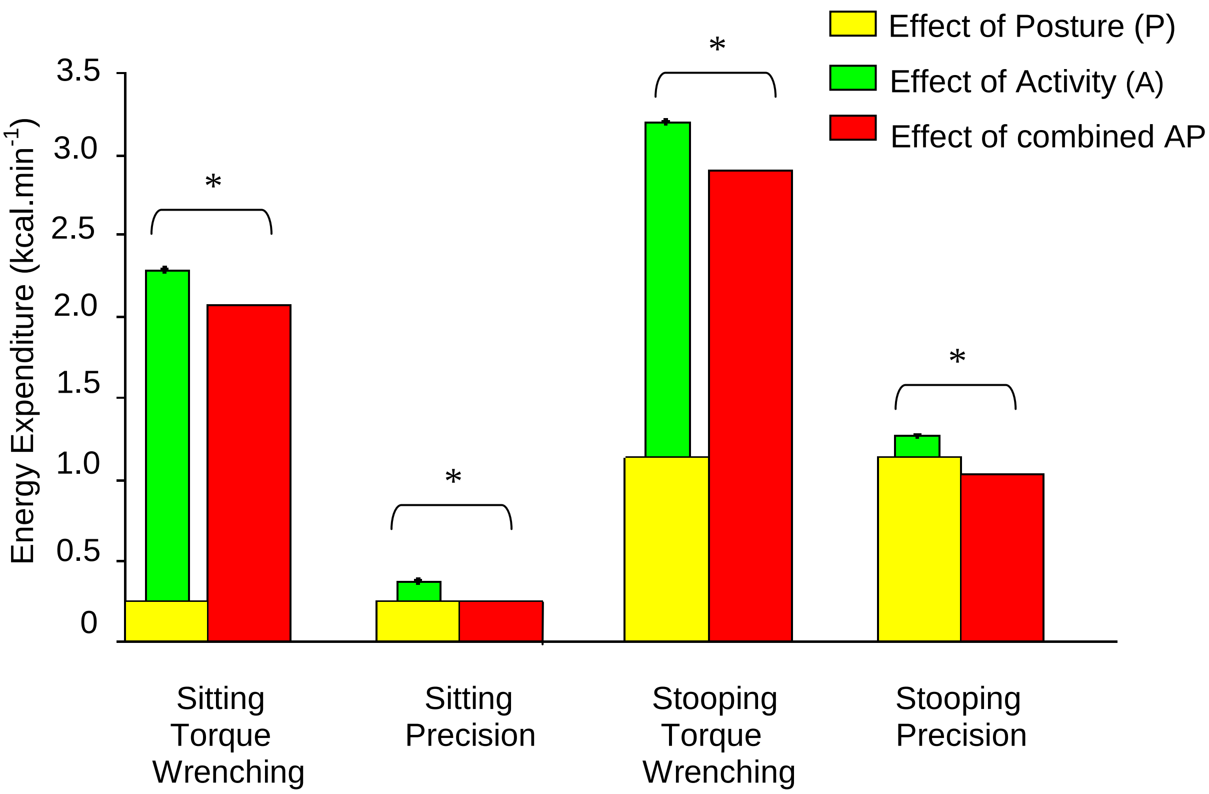

Figure 19: The additive and the combined effects for energy expenditure across the four tested conditions (* denotes a statistically significant difference, $p<0.05$).

The difference between the additive and combined effects (or "extra cost") ranges between 10% and 37% for both EE and VO_2. For both these variables, the greatest difference was found for sitting precision, with 33% and 37% for EE and VO_2 respectively. Furthermore, for both the conditions involving torque wrenching, "extra cost" was found to be lowest with a 10% difference for both EE and VO_2.

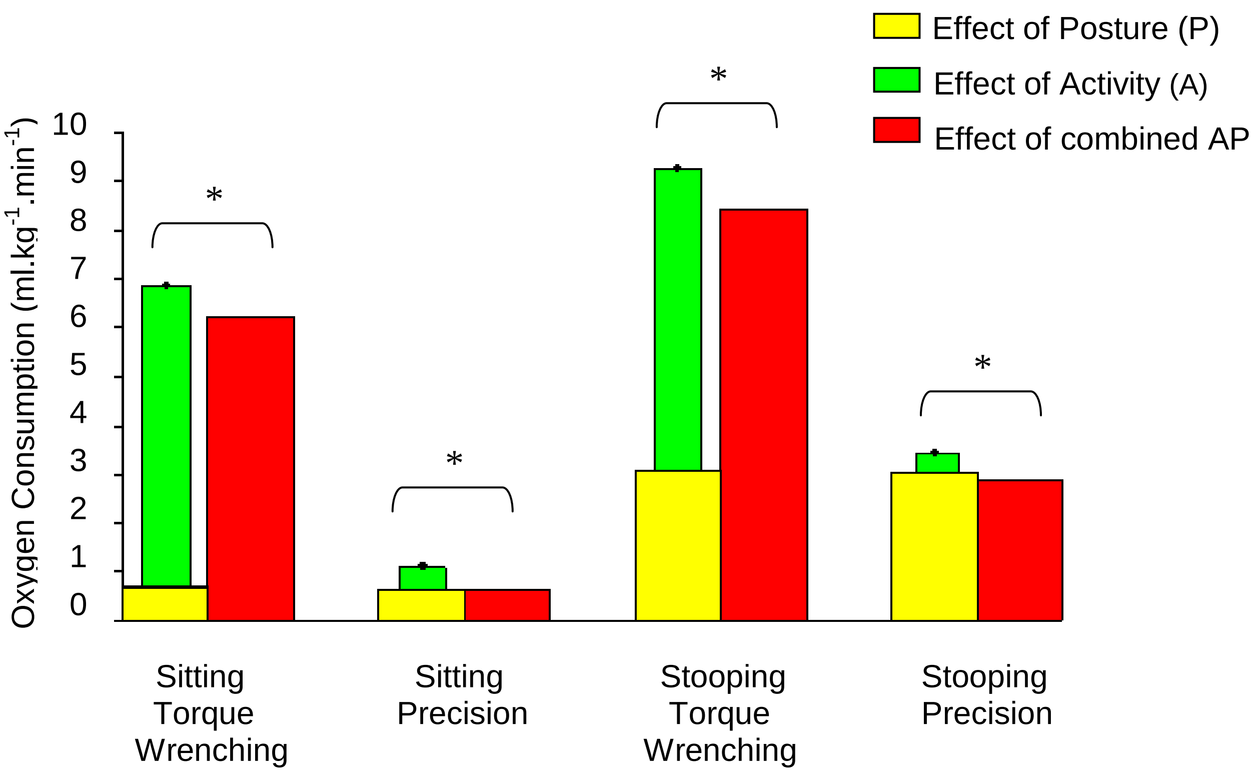

Figure 20: The additive and the combined effects for oxygen consumption across the four tested conditions (* denotes a statistically significant difference, $p<0.05$).

Respiratory Responses

Breathing Frequency (F_B), Tidal Volume (V_T) and Minute Ventilation (V_E)

The relationship between V_E, V_T and F_B has been widely established in literature (McArdle *et al*., 2001; Tortora and Grabowski, 2003). No significant differences were found for F_B (Figure 21), but significant differences were found for all conditions for V_T (Figure 23). The responses obtained for V_E indicate that all conditions were found to be significant except when a precision task was performed in a seated posture. In cases where significant differences were observed, these were all found to result in compensatory reactions. These results were in keeping with those from the previous physiological responses, except in the case of torque wrenching in a seated posture for heart rate, where a cumulative reaction was observed.

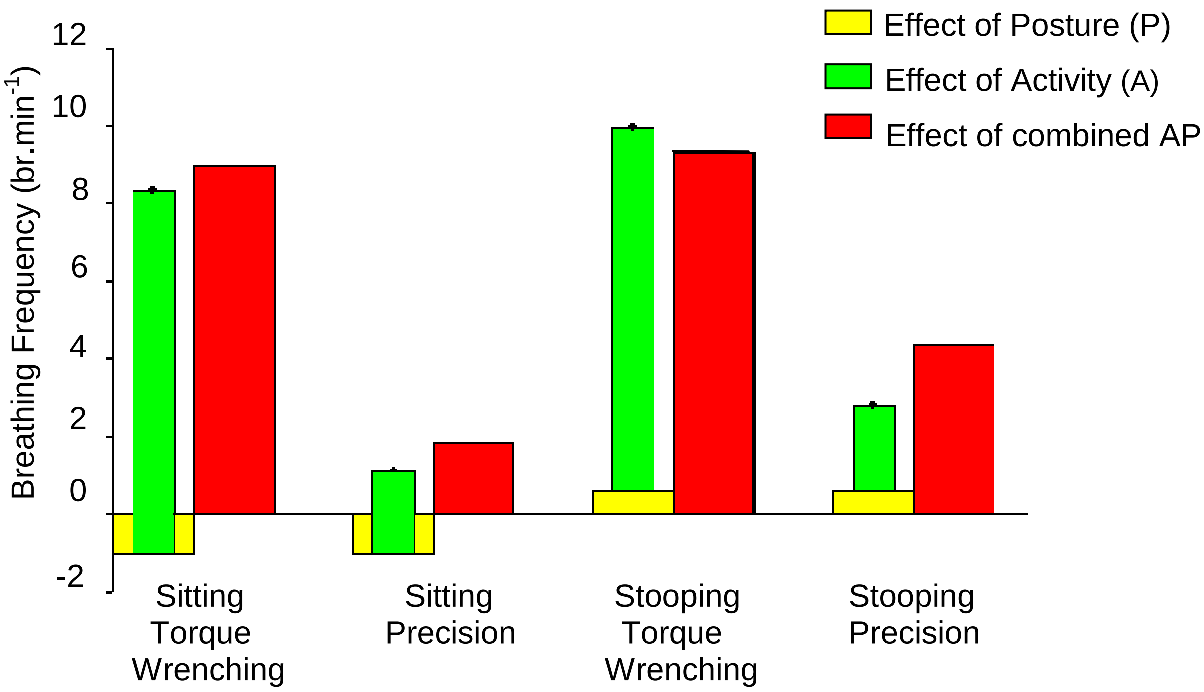

Figure 21: The additive and the combined effects for breathing frequency across the four tested conditions.

Further analyses of the respiratory responses indicates that the greatest “extra cost” was observed for V_T for the sitting precision condition, where an 85% difference was recorded (see Figure 23). This difference was large, since when the baseline values were taken away from the combined task and activity, a negative result was found. The smallest difference in “extra cost” for V_E was found for torque wrenching in a seated posture (16%) which is similar to the differences found for oxygen consumption and energy expenditure for the stooped precision condition (16% and 17% respectively), as well as the stooped torque wrenching condition for both V_T and V_E (18% and 17% respectively).

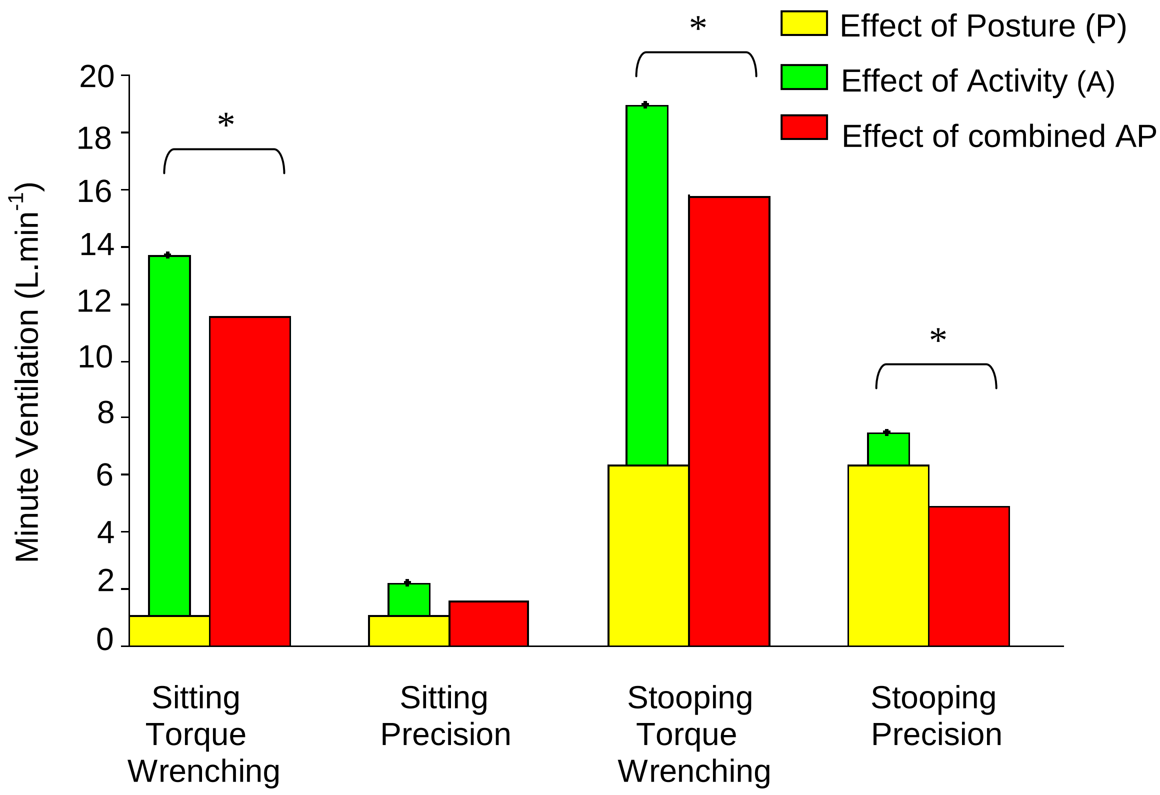

Figure 22: The additive and the combined effects for minute ventilation across the four tested conditions (* denotes a statistically significant difference, $p<0.05$).

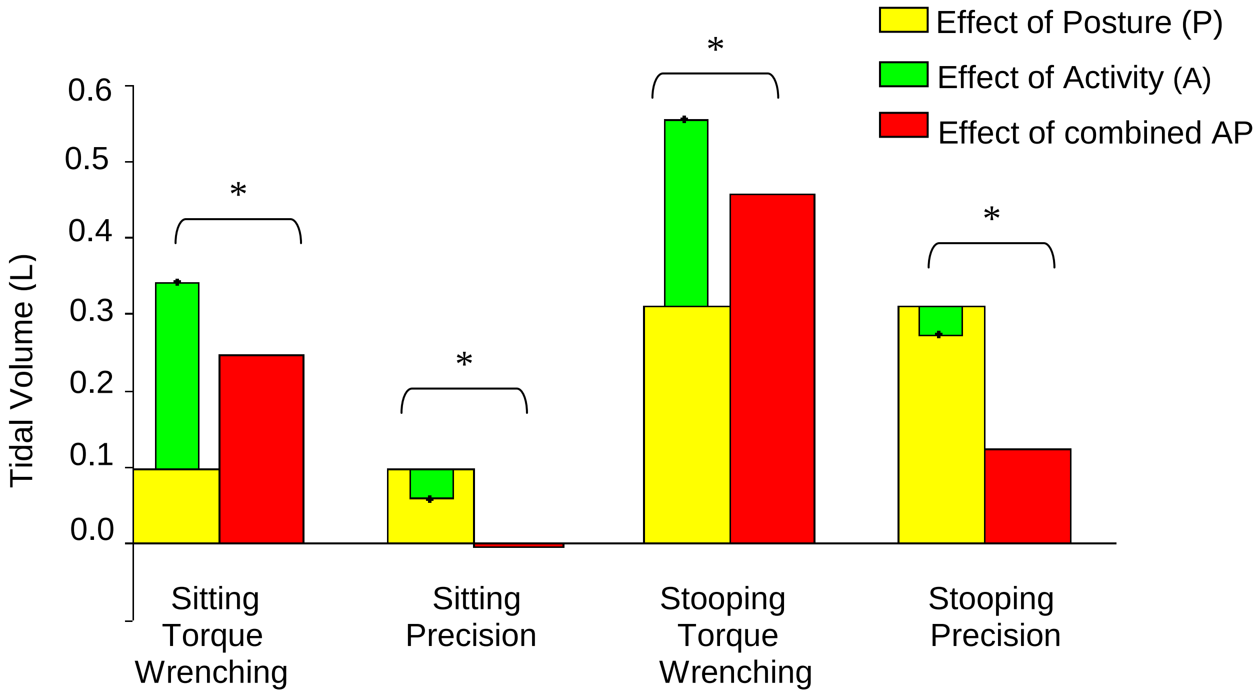

Figure 23: The additive and the combined effects for tidal volume across the four tested conditions (* denotes a statistically significant difference, $p<0.05$).

PSYCHOPHYSICAL RESPONSES

The results obtained for body discomfort were calculated by adding up the intensities of all the body regions identified for each individual, for each condition. The results calculated from the psychophysical rating questionnaire were added to these intensities to provide a total quantitative intensity reading. This was then used to calculate the difference between the combined and additive effects.

Significant differences were recorded for three of the four conditions, namely, torque wrenching in a seated posture, performing a precision task in a seated posture and torque wrenching in a stooped posture (Figure 24). In the significant cases the difference between the two effects ranges from 51% to 75%. These values are greater than those observed for either the muscle activity or the physiological responses, which may be due to the subjective nature of psychophysical testing.

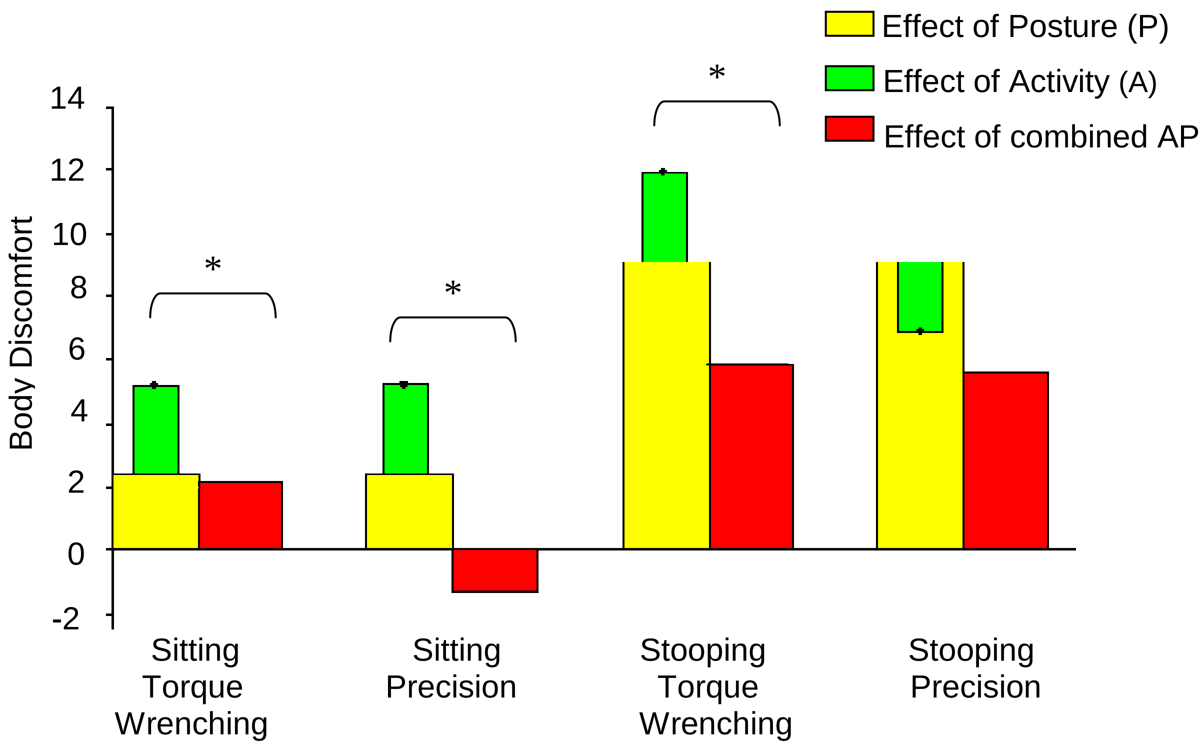

Figure 24: The additive and the combined effects for body discomfort across the four tested conditions (* denotes a significant difference, p<0.05).

RESULTS OF ANALYSES OF VARIANCE (ANOVA) TESTING

Two-factorial ANOVAs

The results from the two-factorial ANOVAs (see Table IX) demonstrate that when the seven muscles are considered across the four conditions, generally there is no significant effect. However, there is an overall significant effect for the deltoid muscle (see Table VI). When all six physiological measures are considered across the four conditions there is a significant effect (see Table IX). It is also shown that this effect depends on the physiological parameter ($p < 0.05$) rather than the conditions tested ($p > 0.05$). A two-factorial analysis was not performed on body discomfort as this was a single measure, however, results from the 1-factorial analysis for body discomfort indicate that an overall significant difference ($p < 0.05$).is found between the additive and combined effects.

Table IX: Overall results for the analyses of variances (shaded blocks = significant difference)

		SS	Deg of freedom	MS	F	p
Biophysical	Intercept	1.7468	1	1.746802	0.758551	0.389717
	Muscle	6.2095	6	1.034918	2.474637	0.024693
	Condition	2.1914	3	0.730475	1.719876	0.167409
	Muscle*Condition	4.7458	18	0.263654	1.177338	0.274063
Physiological	Intercept	5.92736	1	5.927358	8.358950	0.006554
	Phys. Parameter	5.45427	5	1.090853	6.561095	0.000013
	Condition	0.99040	3	0.330133	1.752396	0.160859
	Phys*Condition	0.66380	15	0.044253	0.842758	0.629658
Psycho physical	Intercept	21.17791	1	21.17791	18.61473	0.000125
	Condition	8.90269	3	2.96756	8.11289	0.000065

CRITICAL DISCUSSION

Any research that has limited comparative abilities will in effect have some possible sources of contention. This research is no exception and, therefore, effort has been made to discuss these possible contentious issues so that in future research, they may be considered.

Effect of a different passive reference position

In the current research the reference position was selected as holding a torque wrench in either a standing, sitting or stooped posture. These were chosen since only the effect of performing a specific activity was required for the current study. By adding the mass of the torque wrench to the reference position this calculation was possible, as the mass of the torque wrench was eliminated from the equation which then allowed for torque wrenching or precision activity only to be calculated. Adding the mass of the torque wrench to the reference position resulted in the muscle activity recorded during the reference positions, at times, being greater than the activation occurring during the performance of either a torque wrenching or precision task only. According to Thorn *et al*. (2002) with static work there is no opportunity for the muscle fibres to relax, whereas during a dynamic task different muscle are activated at different times, thereby allowing for relaxation of the muscle.

Suggestions that the reference position should be changed from statically holding a torque wrench in either a standing, stooping or sitting posture to simply a standing, sitting or stooped posture where the arms are at the side have been considered. Although the consequence of doing this would possibly reduce the amount of static muscle activation recorded during the performance of the reference position and may result in greater significances, no systematic difference would be found for the overall direction of the result. This is because a change to one side of the equation (refer to Equations 1, 2 and 3: Methodology section) will result in equal changes to the other side too. Therefore, the reference position selected for the current study was accepted as being appropriate.

Sitting as a constrained posture

Since sitting has been shown to result in lower physiological and biophysical responses than standing tasks, it was debated whether sitting, rather than standing, should be adopted as the neutral body posture. However, in the automotive industry workers are forced to adopt sitting postures due to cramped or restricted work areas. Therefore, considering the current study assessed constrained postures, rather than the most physiologically or biomechanically taxing postures, sitting was ultimately accepted as an appropriate variable.

Variance between sitting and stooping postures

A large variance in physiological, biophysical and psychophysical responses between stooping and sitting is experienced. Where stooping will result in large increases in these responses, decreases in responses to sitting will be experienced. The result being that the variance between the conditions was maximised. Furthermore, the torque wrenching and precision activities selected for the current research resulted in one activity where force was required with small precision demands (torque wrenching) while for the other activity, no force was required, but the precision demands were greater (precision task). This, in effect, maximised the variance between the variables.

Compensatory reactions versus cumulative reactions

Compensatory reactions were observed in the majority of cases where significant differences were found, for biophysical, physiological and psychophysical responses. Had these reactions been more randomly distributed amongst the parameters (i.e a greater number of cumulative reactions spread out over the parameters), then one could argue for a flaw in the concept. However, since they were uniformly distributed with 93% of parameters indicating a compensatory reaction, this was not the case.

Gender differences

Preliminary investigations assessing the differences between the additive and combined effects for males and females separately, showed slightly different characteristics to those found when assessing them together. However, there was no significant change in the number of parameters which indicated a significant difference between the different effects. Similarly, the direction of the reaction was the same as those found for the males and females together. However, further studies are needed to provide conclusive evidence.

CONCLUSIONS

Statistical analyses on the data produced during the current research indicate that the differences between the additive and the combined effects are small, although slightly more pronounced for the physiological and psychophysical responses. In the majority of cases, compensatory reactions were found for biophysical, physiological and psychophysical responses where significant differences were observed. Therefore, suggesting that the body adjusts and compensates for the stresses on the cardiovascular and musculoskeletal systems when these tasks and body postures are performed in combination.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Establishing the relationship between the combined effect of awkward body posture and light manual assembly task provides knowledge which will help to prevent MSDs in the workplace. Although, this relationship has not been widely researched, there are suggestions that the combined interactive effect of body posture and assembly task may be the cause of MSDs. This is particularly evident in the automotive industry, where light manual assembly tasks are often coupled with awkward postures, and where MSDs are rife amongst workers, despite efforts made to eliminate these injuries (Chung *et al*., 2001). It is therefore imperative that researchers investigate the interactive effects of these tasks and attempt to understand those factors which may place the operator at risk of injury. The main objective of such studies therefore, should be to determine the precise relationship between assembly tasks and constrained body postures, and make suggestions as to whether one can simply add the responses of two separate tasks together to gain an understanding of the risks involved, or whether there is a combined effect when the two interact. In the latter case, one would have to assess the two tasks as a combined task and make judgments based on this.

The current study undertook a multi-factorial approach to investigate the relationship between constrained body posture and assembly task. Two awkward working postures (sitting and stooping) and two manipulative tasks (precision and torque wrenching) were selected from the automotive industry. It was hypothesised that there would be no difference, for biophysical, physiological and psychophysical measures, between the sum of the individual factors and the combined effect of the posture and activity performed simultaneously. The objective was to identify whether one can simply take the individual task factors and infer from them the risk of MSDs occurring to the operator, or whether one needs to take the interactive effect into consideration.

SUMMARY OF PROCEDURES

Initially, assessments of various body postures and light manual assembly tasks performed in the automotive industry were carried out *in situ*. The most commonly observed constrained body postures and light assembly tasks were then considered for further investigation.

The experimental phase of the current study took place in the Ergonomics Laboratory of the Human Kinetics and Ergonomics Department at Rhodes University. Nine experimental conditions were studied and used to assess the combined effect of sitting while torque wrenching; sitting whilst performing a precision task; stooping and torque wrenching and stooping during the execution of a precision task. Similarly, the responses to individual torque wrenching and precision tasks, and sitting and stooping postures were assessed.

Eighteen male and eighteen female students between the ages of 18 and 28 years, with a mean stature of 1750mm and 1693mm respectively and body mass of 74kg and 65kg respectively were required to participate in two sessions. During Session 1 subjects were provided with general information about the experiment and were required to sign an informed consent form. During this session basic anthropometric and demographic data were collected and subjects were familiarised with the different tasks they would have to perform during the following session. Session 2 involved experimentation of nine conditions, which included either a torque wrenching or precision task performed in combination with either a seated or stooped posture. Reference positions were assessed, which were calculated as standing, sitting or stooping while no task is executed or performing a torque wrenching or precision task whilst an upright standing posture was adopted. Each condition lasted for ninety seconds, with a ninety second rest period between the conditions. Electrodes were positioned on the selected muscle groups, allowing for electromyographic analysis. Subjects were fitted with a heart rate monitor and an ergospirometer, which allowed the physiological responses to be assessed.

Muscle activity and physiological data were recorded for the duration of each ninety second testing condition; however, only the last thirty seconds were assessed during statistical analysis. Upon completion of each task subjects had to identify areas of body discomfort and rate the intensity of the discomfort. The order in which the nine conditions were executed was assigned according to a permutated system, whereby every condition had equal chance of being performed first, second, third etc. At the completion of all nine conditions, subjects were asked to complete a questionnaire rating each condition according to comfort and where they felt their lower back muscles were working the hardest.

The following specific variables were selected for analysis: Muscle activity was assessed using electromyography; more specifically the biceps brachii, deltoids, trapezius, latissimus dorsi, upper erector spinae, lower erector spinae and the semitendinosus muscles were evaluated. Physiological variables, including heart rate, energy expenditure, oxygen consumption, minute ventilation, breathing frequency and tidal volume were measured using an ergospirometer. Psychophysical variables were assessed which included body discomfort and a psychophysical rating questionnaire.

These variables were analysed using descriptive statistics and related t-tests ($p<0.05$) were employed to determine whether significant differences existed between the combined effect and the additive effect for the four conditions.

SUMMARY OF RESULTS

Comparisons of responses during combined tasks of constrained body posture and assembly activities revealed significant differences for just less than 50% of the total parameters assessed. Overall, performing a torque wrenching task in a seated position elicited the greatest number of significant differences across the biophysical, physiological and psychophysical responses. Only two of the twenty-seven significant differences produced a cumulative reaction (additive effect < combined effect), while the other twenty-five significant differences showed a compensatory reaction (additive effect > combined effect).

More specifically, for the physiological variables, significant differences were observed for all variables for the sitting torque wrenching and stooping torque wrenching conditions, except for breathing frequency, where no significant differences were recorded. Performing a precision task in a stooped posture elicited significant differences for tidal volume (V_T), oxygen consumption (VO_2) and energy expenditure (EE) only, while performing a precision task in a seated position revealed significant differences for all variables except heart rate (HR) and breathing frequency (F_B). With the exception of torque wrenching in a seated position for heart rate, compensatory reactions were found for all the physiological responses. Furthermore, for the physiological responses the differences between the additive and combined effects ranged from 10% for the sitting torque wrenching and stooping torque wrenching conditions for EE and VO_2, to 37% for the sitting precision condition for VO_2. Tidal volume was an exception, however, as there was a difference of 85% found for this variable for the sitting precision condition.

Further statistical analysis indicated that for the muscle activity responses, fewer significant differences were reported than for the physiological responses. The deltoid muscle recorded the most significant differences between the additive and combined effects. These were shown for torque wrenching in a seated position, performing a precision task in a seated position and the stooping precision condition. The only other muscles to display significant differences were the trapezius muscle for the sitting torque wrenching and the stooping precision conditions, the latissimus dorsii muscle for the stooping torque wrenching condition and the semitendinosus muscle for the sitting precision condition. In keeping with the results found for the physiological responses, compensatory effects were observed in all significant cases, except for the semitendinosus muscle, where a cumulative effect was observed for the sitting precision condition. The differences found between the additive and combined effects for muscle activity were similar to those found for the physiological responses. These mostly ranged between 17% and 35%; however one exception was found for the semitendinosus muscle where an 85% difference was observed during the sitting precision condition.

Results for the psychophysical responses indicated that a significant difference was found for three of the four conditions, namely torque wrenching in a seated position, the sitting precision condition and torque wrenching in a stooped posture.

These differences resulted in a compensatory reaction occurring in all cases where a significant difference was found.

These results indicate therefore, that the specific combinations of activity and body posture need to be considered before any judgments can be made for the overall risk to a worker. It would also seem that there are discrepancies between the physiological responses and the muscular responses, indicating that a holistic approach needs to be taken towards assessing these tasks in industry. This would provide a better understanding of the overall problems and risk areas.

RESPONSES TO HYPOTHESES

The large variation between the physiological, psychophysical and biophysical responses indicate the need to consider these three as independent when the hypotheses are considered.

Hypothesis 1:

The hypothesis tested was that there would be a difference between the additive (A + B) and combined effects (C) for biophysical responses.

$$H_a: \mu_{biophys(A+B)} \neq \mu_{biophys(C)}$$

Therefore, since there was no significant difference found overall between the additive and combined effects for the muscle responses, the null hypothesis was tentatively accepted.

Hypothesis 2:

The hypothesis tested was that there would be a difference between the additive (A + B) and the combined (C) effects tested for physiological variables.

$$H_a: \mu_{phys(A+B)} \neq \mu_{phys(C)}$$

The null hypothesis is rejected, as overall significant differences were found for the physiological variables assessed.

Hypothesis 3:

The final hypothesis dealt with perceptual responses. It was hypothesised that significant differences would be found between the additive (A + B) and combined (C) effects for body discomfort.

$$H_a: \mu_{psychophys(A+B)} \neq \mu_{psychophys(C)}$$

In this case the null hypothesis is rejected as, overall, there were significant differences found for body discomfort.

CONCLUSIONS

The results from the current study emphasise the need to carefully consider the specific combination of light manual assembly task and constrained body posture being performed. Furthermore, it is evident that both the physiological and biophysical responses need to be assessed in conjunction with each other, since discrepancies were found between the results for these responses. For muscle activity, significant differences were found for only 25% of the parameters, while 71% of the physiological responses displayed a significant difference. Furthermore, when the psychophysical responses were considered, 75% of the parameters showed significant differences, although the high percentage of significant differences observed for this response may be because only body discomfort was assessed. For the majority of significant differences found, a compensatory reaction, rather than a cumulative reaction was observed. Only two of the twenty-seven significant differences observed across the biophysical, physiological and psychophysical responses showed a cumulative reaction. This was found for the semitendinosus muscle when a precision task was combined with a seated position and for heart rate when torque wrenching was performed in a seated position.

Prior research indicated that for muscle activity responses there would be no difference observed between the additive and combined effects, therefore, in the majority of cases, the results from this study concur with these previous findings. Furthermore, according to previous literature for physiological responses, a cumulative reaction is expected between the additive and combined effects.

Therefore, although the results from this study indicate a difference, in the majority of cases there is a compensatory reaction, rather than a cumulative reaction.

These results may have an impact on industrial tasks and the manner in which they are assessed in the future. Depending on the task and the responses assessed, different conclusions may be drawn and hence, one needs to be cautious when judgments are made with regards to the risk to a worker.

RECOMMENDATIONS

Future investigations into the biomechanical, physiological and perceptual responses of manipulative tasks and awkward body postures should consider the following recommendations:

Further laboratory investigations, where the majority of factors can be rigorously controlled, are required in order to gain a greater understanding of the effects of manipulative tasks and awkward body postures during assembly tasks. These laboratory investigations should include:

a) Conditions of longer duration in order to assess the physiological responses more comprehensively, as well as longer rest breaks to allow for complete recovery.

b) The impact of different awkward body postures, such as kneeling and squatting, as this will allow for comparisons with the postures already tested.

c) Different muscles should be investigated as this will indicate the extent of muscle activation during these activities. This will also allow the researcher to identify where the greatest muscle strain is occurring and may help with eliminating potential risk.

d) Since it is difficult to translate laboratory findings to “real world” application, the above recommendations should also be investigated *in situ*, as it may not always be valid to extrapolate results from the laboratory setting.

e) Considering that muscle fatigue contributes to impeded performance in precision tasks, it is in the interest of the company to minimise fatigue. Therefore, future studies should focus on the effects of fatigue in more detail.

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Note: Asterisked citations (*) are secondary sources. These were not directly consulted and are referenced as fully as primary sources, indicated in brackets, permit.

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APPENDICES

APPENDIX A: GENERAL INFORMATION

1) Equipment Checklist

2) Letter to Subject

3) Subject Consent Form

4) Details of Testing Permutation

5) Order of Procedures

1) EQUIPMENT CHECK LIST

ADMINISTRATION

Letter to Subject

Informed Consent Form

General Information Data Sheet

Subject Data Sheet

Psychophysical Rating Questionnaire

Instructions to Subject for Body Discomfort

STATIONARY

Clipboard

Examination Pad

Pens/Pencils/Eraser/Sharpener

Coloured Stickers

Medical Tape

DATA COLLECTION EQUIPMENT

Toledo Scale

Stadiometer

Anthropometer

Laptop – Megawin Programme

Electromyography Machine

Quark b^2 Unit and Accessories – including Calibration Equipment

Heart Rate Monitors

Body Discomfort Scale

OTHER EQUIPMENT

Milton Disinfectant

Water

Cotton wool

2) LETTER TO SUBJECT

Dear ____________

Thank you for agreeing to participate as a subject in my Masters Thesis entitled

"EFFECTS OF COMBINED STRESSES OF ASSEMBLY TASKS AND AWKWARD WORKING POSTURES."

AIMS

The aim of the thesis is to assess the biomechanical (muscle activity), physiological (energy expenditure, heart rate, and oxygen consumption) and psychophysical (body discomfort) responses to a combination of three body postures and work tasks, commonly observed in the automotive assembly industry.

Manual materials handling, in particular the interaction between load manipulation and body posture, has been well documented, however, very little research has looked at the interaction between manipulation tasks and working posture during assembly work. Therefore, with this research I am hoping to provide some invaluable information which will help to reduce the severity and incidence of musculoskeletal disorders.

Although it is acknowledged that an interaction between manipulative task and working posture exists, their precise relationship has not been widely explored. A common assumption is that the stresses resulting from individual task factors and body posture can be assessed in isolation and simply summed up to provide an overall risk profile. Therefore, the main objective is to establish whether there is a non-linear interaction in strain responses when manipulation task and body posture interact.

PROCEDURE

You will be required to come to the Human Kinetics Department on two occasions. During the first session, I will explain the protocol to you in detail, after which you will be required to sign an informed consent form, stating that you are willing to voluntarily participate in the study.

I will require some anthropometric data, which will allow me to make the study relative to each subject. An anthropometer will be used to gather these data, which includes stature, mass, sitting and standing elbow height, arm length, as well as leg length. Also, I will need to get a measure of your static maximum voluntary contraction for seven individual muscles. During the second session, testing will be carried out on nine randomly assigned conditions. You will be required to perform a combination of manipulation task (torque wrenching or precision task) and body posture (stooping or sitting) as well as a reference posture (standing upright, no task).

Muscle activity will be measured using electromyography, which includes electrodes attached to the relevant muscles, which are then attached to a device linked to a computer. The Quark b^2 will be used to determine the physiological responses. This equipment requires that you wear a mask over your face and mouth. There is no risk to the subject whilst attached to either of these two devices. Body discomfort will be measured using a body discomfort scale, which has been widely utilised in the HKE department and is established universally as an acceptable indication of discomfort felt.

Furthermore, with your permission, I will be taking some photographs during the testing session which will be used solely for the purpose of my research. The photographs will be stored on a computer for the duration of the testing and will not be accessible to anyone but myself. At the completion of my research, I will get rid of all photo’s which have not been used in the printed version of the research. If your photo is used in the printed copy, I will blank out the face, thereby ensuring anonymity.

RISKS AND BENEFITS

In the unlikely event that an injury occurs during the testing, appropriate rehabilitative measures will be provided by the researcher. If the injury is serious enough, that a doctor's consultation is required, the Human Kinetics and Ergonomics Department will reimburse the subject to the full amount (doctor's consultation fees, anti-inflammatory medication etc.). However, should this injury occur due to the negligence of the subject themselves, then all costs and responsibility shall fall on the subject. I would like to reiterate that the likelihood of an injury occurring is minimal.

I am unable to provide you with feedback directly after the testing session, but following the completion of all data collection, should you be interested, I will provide you with feedback.

If you are under the age of 21, it is strongly recommended that you inform your parents/guardian of your intention to participate in this study and provide them with the details of the procedures.

Thank you for showing an interest in this study. I hope you will learn a lot from this and that you enjoy the experience. If you have any further questions please do not hesitate to contact me directly.

Yours sincerely

Sarah Skelton

(Human Kinetics and Ergonomics Masters student)

3) SUBJECT CONSENT FORM

RHODES UNIVERSITY
DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

I, _______________, having been fully informed of the nature of the research entitled: **"THE COMBINED AND ADDITIVE EFFECTS OF ASSEMBLY TASKS AND AWKWARD BODY POSTURES"** do hereby give my consent to act as a subject in the above mentioned research.

I am fully aware of the procedures involved, as well as the potential risks and benefits associated with my participation, as explained to me verbally and in writing. In agreeing to voluntarily participate in this study, I accept joint responsibility with the Human Kinetics and Ergonomics Department in the event of any personal injuries sustained during testing, unless it can be shown to have been deliberately self-inflicted, whereby I will take full responsibility. I realize the necessity to promptly report to the researcher any signs or symptoms indicating any abnormality or distress and I am fully aware that I may withdraw from participation in the study at any time. I am aware that my anonymity will be protected at all times, and agree that the information, collected may be used and published for statistical or scientific purposes.

Furthermore, I am willing to allow photographs to be taken of me during the testing, and consent to having these used in the printed copy of the thesis, provided all attempts have been made to protect my anonymity.

I have read the information sheet accompanying this form and understand it. Any questions that may have occurred to me have been answered to my satisfaction.

SUBJECT

____________________	________________	______________
(Print name)	(Signed)	(Date)

RESEARCHER

____________________	________________	______________
(Print name)	(Signed)	(Date)

WITNESS

____________________	________________	______________
(Print name)	(Signed)	(Date)

4) DETAILS OF TESTING PERMUTATION

	SUBJECT																																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
CONDITION	7	1	4	8	9	2	3	6	5	7	1	4	8	9	2	3	6	5	7	1	4	8	9	2	3	6	5	7	1	4	8	9	2	3	6	5
	6	9	8	2	5	3	1	7	4	6	9	8	2	5	3	1	7	4	6	9	8	2	5	3	1	7	4	6	9	8	2	5	3	1	7	4
	3	7	2	9	6	4	5	1	8	3	7	2	9	6	4	5	1	8	3	7	2	9	6	4	5	1	8	3	7	2	9	6	4	5	1	8
	4	6	5	7	8	9	2	3	1	4	6	5	7	8	9	2	3	1	4	6	5	7	8	9	2	3	1	4	6	5	7	8	9	2	3	1
	9	8	3	1	4	6	7	5	2	9	8	3	1	4	6	7	5	2	9	8	3	1	4	6	7	5	2	9	8	3	1	4	6	7	5	2
	8	5	7	6	3	1	4	2	9	8	5	7	6	3	1	4	2	9	8	5	7	6	3	1	4	2	9	8	5	7	6	3	1	4	2	9
	2	4	1	5	7	8	6	9	3	2	4	1	5	7	8	6	9	3	2	4	1	5	7	8	6	9	3	2	4	1	5	7	8	6	9	3
	5	2	9	3	1	7	8	4	6	5	2	9	3	1	7	8	4	6	5	2	9	3	1	7	8	4	6	5	2	9	3	1	7	8	4	6
	1	3	6	4	2	5	9	8	7	1	3	6	4	2	5	9	8	7	1	3	6	4	2	5	9	8	7	1	3	6	4	2	5	9	8	7

5) ORDER OF PROCEDURES

Habituation

1. Welcome
2. Attach heart rate monitor
3. Seat subject
4. Describe project, protocol and equipment

Physiological equipment:

a) Heart rate: a polar heart rate monitor picks up your heart rate and sends the signal to the computer and the watch on your arm.

b) Quark b^2 which does gas analysis, and monitors every breath you take. It monitors things like breathing frequency, your metabolism, CHO and Fat use, and most importantly what we are looking at is your EE, and oxygen consumption.

Biomechanical equipment:

Using EMG, which monitors muscle activity throughout testing. This is done by placing electrodes on specific muscles. We will locate the muscles by palpating the muscles or asking you to move certain body areas in order for them to be identified.

Psychophysical equipment:

Using the body discomfort scale. At the end of the test while you are seated we will ask you for the areas of the body where you felt the most discomfort. You will still not be able to talk at this point, so we will ask you for a maximum of three locations, starting with the most discomfort, to the area with the least discomfort. If you only have one area to identify, that's fine you don't need to give three.

5. Are there any questions?
6. If you could please read the letter of information on the project, and then if you are happy or have any more questions please ask. Once you have read the information on the protocol please sign the informed consent form for ethical reasons. This clears you of responsibility for any injury, and states that you are able and willing to participate.
7. Opportunity to practice protocols.
8. Any questions?
9. Room 30: take stature and mass.
10. If there are no more questions, find out suitable date to come in for testing.

Pre-test: 07h20 (every morning)

- charge batteries
- calibrate Quarkb^2

Testing

1. Welcome and recap
2. Heart rate monitor on
3. Put on harness EMG and set up EMG
4. Clean sites with alcohol and shave off excess hair over area.
5. Locate muscles and place electrodes
6. Attach EMG
7. Turn on EMG unit
8. Select EMG protocol on laptop.
9. MVC testing: 2 reps each, 5s long.
10. Start MVC: follow order of print out, explain each and show picture
11. Seat subject
12. Attach mask
13. Start testing
14. Instruct subject which condition
15. Assistant on quark, Researcher on EMG and stopwatch.
16. Start quark and EMG at same time.
17. 90 second condition, 90 second rest
18. Ask body discomfort after each condition
19. When completed all conditions then stop and seat subject
20. Quark and heart rate to resting
21. Stop quark and EMG
22. Remove HR, EMG and mask from subject.

End of testing:

Save data, rename folders

Save data to flashsticks and hard drive and folders on quark comp and EMG comp.

Clean up for next testing.

APPENDIX B: DATA COLLECTION

1) Instructions to Subject Prior to Testing Session

2) Body Discomfort Map

3) Instructions to Subject for Body Discomfort

4) Data Collection Sheets

   Anthropometric and demographic

   EMG

   Ergospirometry

5) Psychophysical Rating Questionnaire

1) INSTRUCTIONS TO SUBJECTS PRIOR TO TESTING SESSION

Please refrain from engaging in the following activities **24 hours before** coming into the laboratory to allow for the conditions to be standardised. Please inform the researcher on the day of the test if you did partake in any of these practices, as this will affect the accuracy of the results obtained:

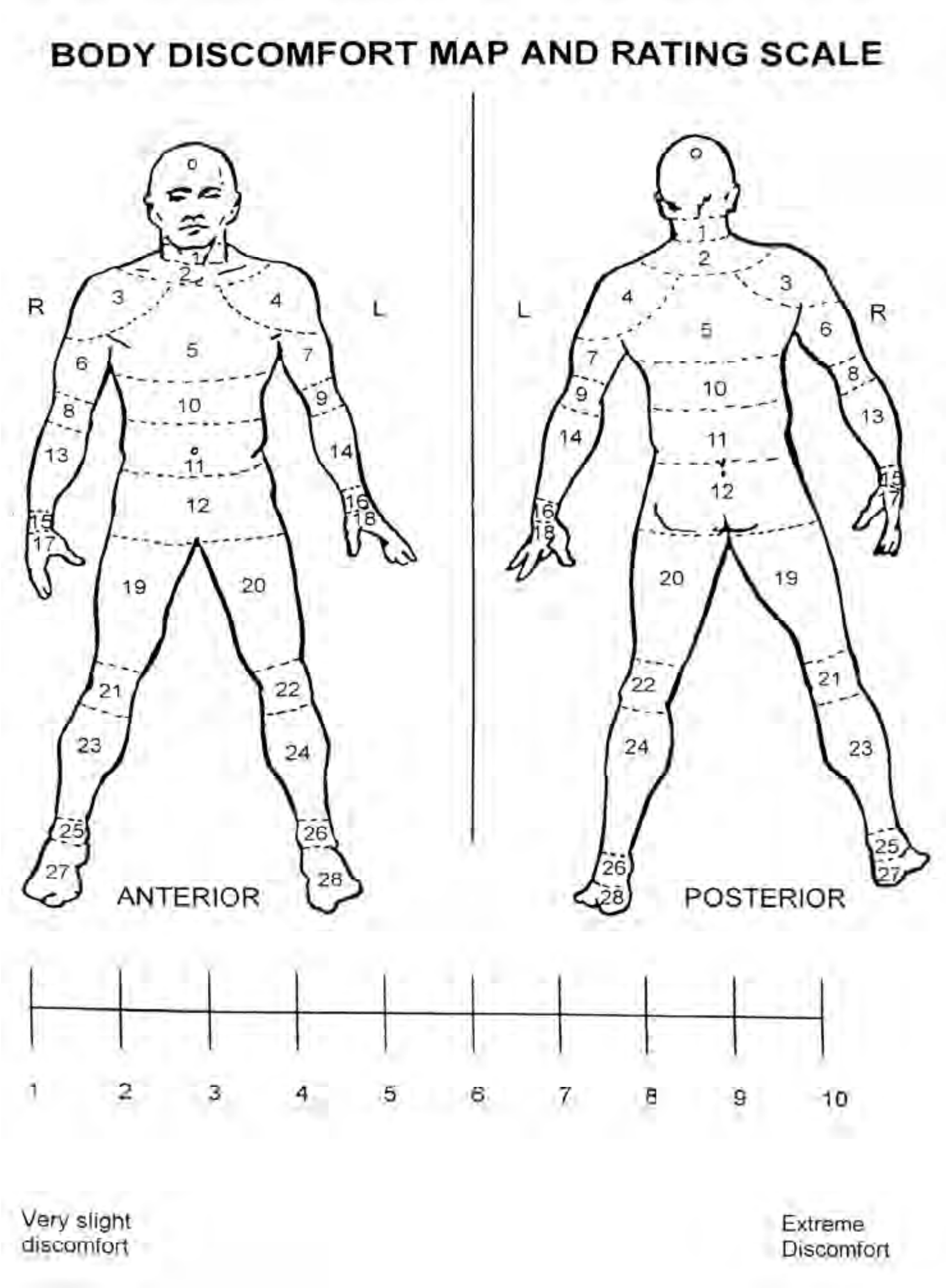
1. DON'T DRINK ALCOHOL
2. TRY NOT TO TAKE ANY MEDICATION (such as painkillers, panado, any flu tablets, etc.)
3. DON'T DO STRENUOUS EXERCISE

Two hours prior to the testing please:

1. Do not consume any stimulants (such as coffee, red bull, coke etc.) or take any medication as they will increase your heart rate.
2. Please ensure that you eat a good meal 2 hours prior to the testing and then nothing after that.
3. Please wear trainers and comfortable clothing to the experimental session

If you do not adhere to these please notify the researcher on arrival.

2) BODY DISCOMFORT MAP



(Corlett EN and Bishop RP (1976). A technique for assessing postural discomfort. **Ergonomics**, 19(2): 175 – 182).

3) INSTRUCTIONS TO SUBJECT FOR BODY DISCOMFORT

On completion of each condition, you will be requested to identify any discomfort you felt during that particular condition. You will be required to point to the site(s) of body discomfort on this map of the body, which has been divided into anterior and posterior views, each of which have been separated into a further 29 different body parts. The sites are numbered 0-28 and then you will be asked to rate the intensity of the discomfort you felt at each of the identified sites. The intensity rating is on a ten point scale where one (1) indicates “very slight discomfort” and ten (10) refers to “extreme discomfort”.

You need to be as objective as you can and try not to over or underestimate your degree of discomfort or pain.

4) DATA COLLECTION SHEETS

Subject Code__________

EFFECT OF COMBINED STRESSES OF ASSEMBLY TASKS AND AWKWARD BODY POSTURES

DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

Name:________________ Order of testing:___________

Age:__________________ Body Mass (kg):__________

Stature (mm):___________ Resting Heart Rate________

Hand Dominance:_______

Anthropometric Data

VARIABLE	Measurement (mm)
Sitting elbow height	
Standing elbow height	
Arm length	
Hip height	

Subject __
(EMG)

CONDITION	START TIME	END TIME	TIME	ERRORS
Standing no task (1)				
Rest				
Sitting precision (9)				
Rest				
Sitting no task (7)				
Rest				
Stooping precision (6)				
Rest				
Sitting wrenching (8)				
Rest				
Stooping wrenching (5)				
Rest				
Stooping no task (4)				
Rest				
Standing wrenching (2)				
Rest				
Standing precision (3)				
Rest				

Subject __
(Ergospirometry)

Condition	Time	Heart rate (bt.min^{-1})	Body discomfort			
			Area	A/P	R/L	Rating
Sit TW (8)						
Rest						
Stand TW (2)						
Rest						
Sit P (9)						
Rest						
Sit no task (7)						
Rest						
Stand no task (1)						
Rest						
Stoop P (6)						
Rest						

			Body discomfort			
Condition	**Time**	**Heart rate (bt.min^{-1})**	**Area**	**A/P**	**R/L**	**Rating**
Stoop TW (5)						
Rest						
Stand P (3)						
Rest						
Stoop no task (4)						
Rest						

5) PSYCHOPHYSICAL RATING QUESTIONNAIRE

These scales are for you to rate at which condition you felt your **lower back muscles** were exerting the most effort and which activity you felt most comfortable.

Where did you feel your **lower back** muscles were exerting the most effort? Rate the following activities in order of performance from 1-9 where 1 is most **lower back** muscle effort and 9 is the least effort.

Standing no task	
Standing torque wrenching	
Standing precision	
Sitting no task	
Sitting torque wrenching	
Sitting precision	
Stooping no task	
Stooping torque wrenching	
Stooping precision	

Where did you feel the most comfortable? Rate the following activities in order of comfort from 1-9 where 1 is most comfortable and 9 is least comfortable.

Standing no task	
Standing torque wrenching	
Standing precision	
Sitting no task	
Sitting torque wrenching	
Sitting precision	
Stooping no task	
Stooping torque wrenching	
Stooping precision	

APPENDIX C: SUMMARY REPORTS

1) Physiological Formulae and Variables

2) 1-Factorial ANOVA tables

3) Detailed p-values from paired t-tests

4) Electromyography Printouts

5) Example of Physiological Data Output

6) Indication of Steady-state for Physiological Variables

1) PHYSIOLOGICAL FORMULAE AND VARIABLES

Breathing Frequency (F_B) in br.min^{-1}:

Amount of breaths taken per minute

Tidal Volume (V_T) in L:

The amount of air moved in and out the lungs with each normal breath and which is approximately 0.5L at rest in a young, healthy adult.

Minute Ventilation (V_E) in L.min^{-1}:

The amount of air breathed in every minute; a function of breathing frequency and tidal volume.

VE = Breathing frequency x Tidal volume

Oxygen Consumption (VO_2) in ml.kg^{-1}.min^{-1}:

The amount of oxygen consumed by the body each minute.

$$\frac{\text{ml.kg}^{-1} \times \text{body mass}}{1000} = \text{L.min}^{-1}$$

Energy Expenditure (EE):

VO_2 (L.min^{-1}) x 20.1 = EE (kJ.min^{-1})

kJ.min^{-1}/ 4.186 = EE (kcal.min^{-1})

kcal.min^{-1} / 0.01433 = power output (W)

2) 1-FACTORIAL ANOVA TABLES

Biceps brachii

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.13172	1	0.131725	0.144544	0.706102
Error	31.89581	35	0.911309		
CONDITIO	0.56063	3	0.186876	0.717353	0.543785
Error	27.35325	105	0.260507		

Middle deltoid

	SS	Degr. of - Freedom	MS	F	p
Intercept	4.48931	1	4.489311	4.693226	0.037176
Error	33.47930	35	0.956551		
CONDITIO	0.82111	3	0.273704	0.573381	0.633762
Error	50.12181	105	0.477351		

Trapezius

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.97396	1	0.973957	2.237581	0.143655
Error	15.23453	35	0.435272		
CONDITIO	0.26002	3	0.086675	0.872134	0.458091
Error	10.43512	105	0.099382		

Latissimus dorsii

	SS	Degr. of - Freedom	MS	F	p
Intercept	1.58659	1	1.586588	3.426391	0.072616
Error	16.20672	35	0.463049		
CONDITIO	2.62151	3	0.873838	6.805699	0.000309
Error	13.48179	105	0.128398		

Upper Erector Spinae

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.32296	1	0.322959	0.635378	0.430764
Error	17.79031	35	0.508295		
CONDITIO	0.63178	3	0.210592	0.913170	0.437315
Error	24.21471	105	0.230616		

Lower Erector Spinae

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.45169	1	0.451692	0.595050	0.445650
Error	26.56788	35	0.759082		
CONDITIO	0.36729	3	0.122430	0.306011	0.820991
Error	42.00867	105	0.400083		

Semitendinosus

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.00008	1	0.000080	0.000103	0.991967
Error	27.24811	35	0.778517		
CONDITIO	1.67486	3	0.558287	3.245205	0.024934
Error	18.06360	105	0.172034		

Heart Rate

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.025321	1	0.025321	0.717725	0.402647
Error	1.234800	35	0.035280		
CONDITIO	0.215978	3	0.071993	4.712445	0.003983
Error	1.604097	105	0.015277		

Energy Expenditure

	SS	Degr. of - Freedom	MS	F	p
Intercept	5.40382	1	5.403822	6.515905	0.014832
Error	31.51446	38	0.829328		
CONDITIO	0.61338	3	0.204460	0.758752	0.519518
Error	30.71943	114	0.269469		

Oxygen Consumption

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.836180	1	0.836180	6.514279	0.014843
Error	4.877722	38	0.128361		
CONDITIO	0.094998	3	0.031666	0.780806	0.507028
Error	4.623335	114	0.040556		

Breathing Frequency

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.025228	1	0.025228	0.125252	0.725363
Error	7.653993	38	0.201421		
CONDITIO	0.154488	3	0.051496	1.114683	0.346210
Error	5.266546	114	0.046198		

Tidal Volume

	SS	Degr. of - Freedom	MS	F	p
Intercept	2.838292	1	2.838292	12.93022	0.000917
Error	8.341322	38	0.219508		
CONDITIO	0.428402	3	0.142801	2.42262	0.069508
Error	6.719703	114	0.058945		

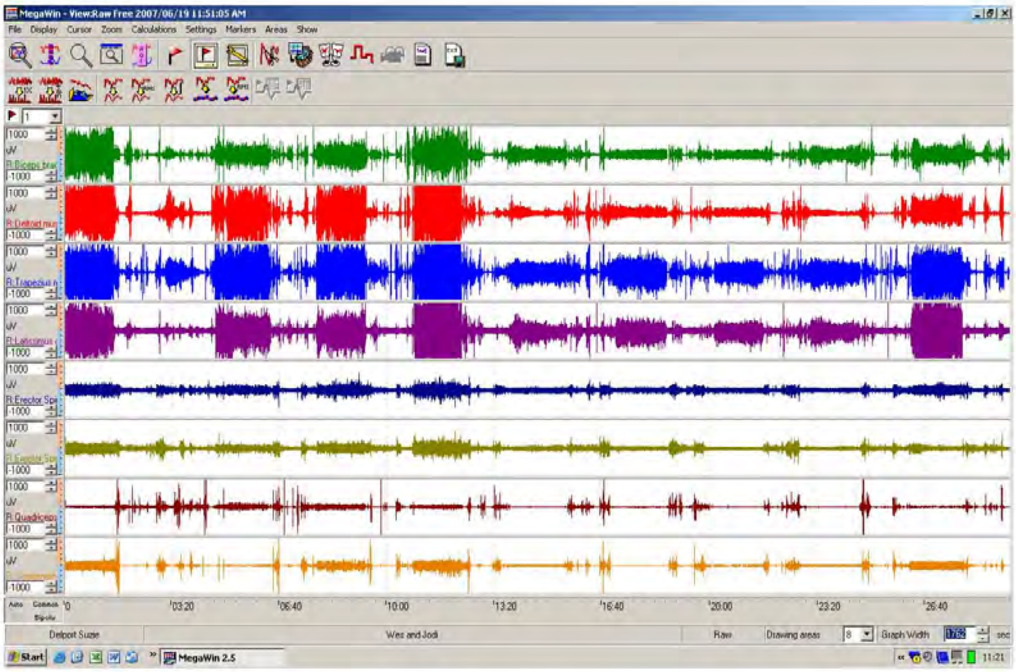
Minute Ventilation

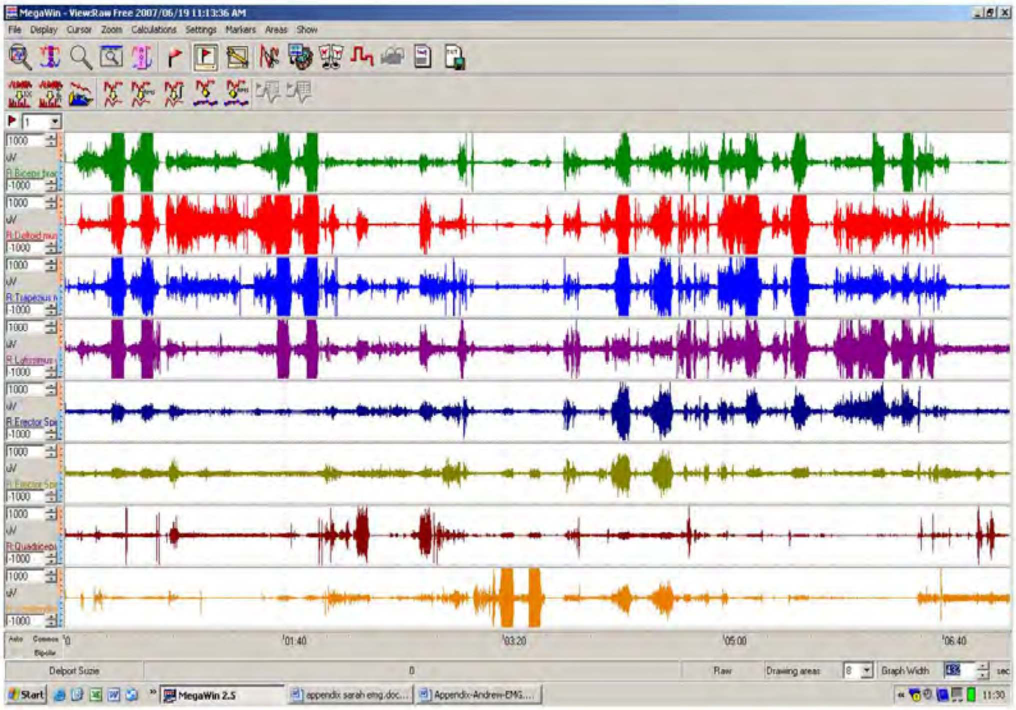
	SS	Degr. of - Freedom	MS	F	p
Intercept	2.564565	1	2.564565	15.74672	0.000310
Error	6.188811	38	0.162863		
CONDITIO	0.661212	3	0.220404	3.77263	0.012638
Error	6.660087	114	0.058422		

3) DETAILED P-VALUES FROM PAIRED T-TESTS

		SITTING		STOOPING	
		Torque Wrenching	Precision	Torque Wrenching	Precision
BIOPHYSICAL RESPONSES	Biceps brachii	n.s	n.s	n.s	n.s
	Middle Deltoid	--- p = 0.000615	--- p = 0.016839	n.s	--- p = 0.028881
	Trapezius	--- p = 0.043401	n.s	n.s	--- p = 0.032977
	Latissimus dorsii	n.s	n.s	--- p = 0.000196	n.s
	Upper Erector spinae	n.s	n.s	n.s	n.s
	Lower Erector spinae	n.s	n.s	n.s	n.s
	Semitendinosus	n.s	+++ p = 0.008753	n.s	n.s
PHYSIOLOGICAL RESPONSES	Heart Rate (HR)	+++ p = 0.000560	n.s	--- p = 0.034365	n.s
	Oxygen Consumption (VO_2)	--- p = 0.011016	--- p = 0.042815	--- p = 0.029431	--- p = 0.036014
	Energy Expenditure (EE)	--- p = 0.005673	--- p = 0.049051	--- p = 0.019992	--- p = 0.037154
	Breathing Frequency (F_B)	n.s	n.s	n.s	n.s
	Minute Ventilation (V_E)	--- p = 0.001340	n.s	--- p = 0.0006767	--- p = 0.0015758
	Tidal Volume (V_T)	--- p = 0.000384	--- p = 0.004357	--- p = 0.022813	--- p = 0.000328
PSYCHO PHYSICAL RESPONSE	Body Discomfort	--- p = 0.00089	--- p = 0.04917	--- p = 0.000395	n.s

4) ELECTROMYOGRAPHY PRINTOUTS





5) EXAMPLE OF PHYSIOLOGICAL DATA OUTPUT

t hh:mm:ss	Rf b/min	HR bpm	VT l	VE l/min	VO2 ml/min	EEm Kcal/min
00:00:01	23.62205	90	0.553154	13.06663	353.434	1.808498
00:00:03	27.64977	85	0.416396	11.51326	282.5038	1.38427
00:00:05	25.97403	80	0.539886	14.02302	378.2871	1.957107
00:00:09	18.46154	73	0.265351	4.898779	29.51585	0.188756
00:00:11	22.72727	72	0.452117	10.27538	230.667	1.165464
00:00:15	16.52893	79	0.690932	11.42036	335.5082	1.717181
00:00:18	21.58273	84	0.303112	6.541985	67.67392	0.320489
00:00:19	42.55319	90	0.574586	24.45047	844.9554	4.349151
00:00:23	15.46392	96	0.879739	13.60421	475.8887	2.429512
00:00:26	20.76125	98	0.677664	14.06916	483.7271	2.447758
00:00:29	19.60784	98	0.774619	15.18862	559.0626	2.807034
00:00:33	14.21801	96	0.871575	12.39205	397.3481	2.054094
00:00:37	16.99717	95	0.971591	16.5143	587.4081	3.006286
00:00:41	14.11765	95	0.929748	13.12585	438.6511	2.273195
00:00:44	18.07229	98	0.89811	16.2309	547.6707	2.786692
00:00:48	16.57459	99	0.678685	11.24892	309.1445	1.567985
00:00:51	20.68966	98	0.638882	13.21826	412.6575	2.093502
00:00:54	17.3913	95	0.763393	13.2764	464.0709	2.356844
00:00:57	20.76125	94	0.822587	17.07792	569.4818	2.93953
00:01:01	17.34104	91	0.820546	14.22911	478.8922	2.425089
00:01:04	19.80198	90	0.733796	14.53062	456.2951	2.332409
00:01:07	16.39344	92	1.342061	22.00101	832.3722	4.32945
00:01:14	22.55639	97	0.871575	19.65958	672.7692	3.47565
00:01:16	21.89781	97	0.719508	15.75565	524.9986	2.670731
00:01:20	17.04545	97	0.658273	11.22057	239.3284	1.273729
00:01:23	19.23077	96	0.865451	16.64329	562.2028	2.912454
00:01:31	12.26994	91	1.001188	12.28452	417.0685	2.145527
00:01:34	22.38806	91	1.025682	22.96303	853.8156	4.404564

6) INDICATION OF STEADY-STATE FOR PHYSIOLOGICAL VARIABLES

	C1 Stand nt	C2 Stand tw	C3 Stand p	C4 Stoop nt	C5 Stoop tw	C6 Stoop p	C7 Sit nt	C8 Sit tw	C9 Sit p
RF		+		+	+				
HR	+		+	+	+	+	+		
VT			+						
VE		+		+	+				
VO2		+	+					+	
EE		+	+					+	

Where: shaded regions = steady-state