RISK ASSESSMENT AND THE EFFECTS OF OVERHEAD WORK – AN AUTOMOTIVE INDUSTRY EXAMPLE

BY

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THESIS

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ABSTRACT

The focus of this investigation was an analysis of the work demands being placed on South African automotive industry workers as there is a recognised problem with regard to the prevalence of musculoskeletal disorders (MSDs). Preliminary work was conducted to highlight the dominant risks and areas which elicited higher numbers of MSDs within the chosen automotive plant. An area of concern was highlighted through medical record analysis and the use of risk assessment tools, thereby prioritising the need for ergonomic intervention. In particular, the effects of varying restricted and overhead work heights on the biomechanical, physiological and psychophysical responses of an individual were investigated.

Twenty-eight subjects were required to complete sixteen conditions. The conditions consisted of the adoption of restricted and upright overhead static postures, with half requiring the holding of four kilograms of weight in the hands and the remaining eight conditions having no weight. Testing was carried out using an electromyography unit, ergospirometer and a perceptual Body Discomfort Map and Scale. This involved a habituation and testing session.

The results of the testing revealed the biomechanical and physiological responses were dependant on the change in height. Body discomfort was also shown to be variable over the changing height conditions. This indicates that there is a significant effect of height on an individual's responses during overhead work. The extreme restricted (-200mm and -100mm) and upright (+300mm and +400mm) overhead conditions within this study were limiting, as they elicited the highest muscle activation, physiological responses and body discomfort ratings. Positions that are preferable to adopt, which were identified from the results in this study, indicate conditions closer to head height (0mm and +100mm) were favourable. The results therefore illustrate how awkward working postures during work are likely to elicit higher demands from an individual, which could lead to an increased risk for the development of a musculoskeletal disorder. The added factor of weight elicited significant results over all variables, excluding a respiratory

response of tidal volume. This indicates that even a small, evenly distributed and symmetrically held weight will elicit significantly higher values and demands from an individual.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

Ergonomic principles in the design of automobile assembly, manufacturing operations and engineering systems have become an important part of a more comprehensive health and safety process within the industry (Joseph, 1989), with occupational health and safety focusing on employees being the fundamental responsibility of any organisation (Dzissah *et al.*, 2001). In the past more emphasis has been placed on productivity rather than on the effects of the task on the worker; however, without an awareness and concern for workers' health in the work environment this could lead to occupational diseases (Bridger, 1995).

The core activity within the automotive industry is the production process, where products are developed from materials on assembly lines. Simply viewed, this process can be described as a purpose driven, intentional interaction between matter, technology and an individual who is interacting with his/her environment. In order to attempt to control risk, one should impose precautionary technical and organisational plans to prevent intrinsic hazard potentials (Ruppert, 2002). Working on an assembly line generates hazard potentials, which, under certain instances, could be dangerous to an individual, the environment or property (Ruppert, 2002).

Industrial jobs are also dynamic, which compounds the aforementioned issues found on assembly lines. Ergonomists have therefore spent much time and effort investigating the effects of tasks on manual labourers, to establish specific guidelines for acceptable workloads and limits. It has been noted by Stoop (1990) that injury compensation and risk delegation (through the limitation of

liability by contract or transfer of risk to insurance companies) are no longer satisfactory as the only instruments through which to manage safety problems and that the emphasis is shifting from damage and injury reduction to accident prevention.

Worldwide, the automotive industry is one of the largest most influential, and labour intensive industries, which plays an important role in the economy of a country (Chung *et al.*, 2001), with work structures within the industry stemming from the division of labour in the 20th century (Freiboth *et al.*, 1997). The automotive industry is pressurised and ever-changing, and globalisation has now led to increased pressures within engineering departments to increase the efficiency of human work processes within this industry, with, for example, the European industry facing considerable pressure from Japanese and US manufacturers to remain competitive (Womack *et al.*, 1990). This pressure is also found within South Africa; for example, the current status of a local Eastern Cape plant is the third largest worldwide in terms of its production rate of the current line.

This highlights the key role that work structures play in competition. The need for improved work methods is indisputable although it does take a thorough knowledge in a number of work method aspects to change existing ways of working. Taking note from a car manufacturer in Sweden, a new plant opened with the deliberate aim of enhanced productivity and product quality through good ergonomic conditions and improved work organisation (Kadefors *et al.*, 1996). However, most new industrial projects, including the design of production systems, continue with a lack of scientifically based ergonomic data and thus some industries rely on values derived from other companies which may not be relevant to them (Forsman *et al.*, 2002). This is pertinent for the automotive industry where relevant information is necessary, especially with regard to the Eastern Cape region in South Africa, which has its own unique set of characteristics.

With specific reference to the automotive industry in South Africa, it forms a major part of the manufacturing sector, accounting for 7% of the total exports, and is a key player having a substantial influence on the country's economy, being the third largest sector and contributing 7% to the gross domestic product (Department of Labour, 2007). The automotive industry was also specifically chosen as it exerts an important influence on the economy and manufacturing sector of the Eastern Cape region of South Africa, where many manufacturers are located, providing much needed employment. The assembly industry and component sector employ 32 500 and 39 500 people respectively within South Africa (Department of Trade and Industry, 2000). International investment has also aided the rapid expansion of this industrial sector. Yet, as stated by James (2002), the development of new plants has little evidence indicating that the human operator has been kept in mind.

Automotive industries have complicated assemblies (Pantazopoulos and Tsinopoulos, 2005) and the long-term development of the automobile industry depends on the quality of the product, which is an important objective from the producer's viewpoint (Wang *et al.*, 2007). The analysis of risk is therefore vital with regard to any task or project within them (Patterson and Neailey, 2002). Within the automotive manufacturing industry it has also been noted that there are a large number and range of injuries and musculoskeletal disorders (MSDs) (Cort *et al.*, 2006) highlighting the need for ergonomic intervention.

The high risk sectors for the problem of musculoskeletal disorders (MSDs), as identified by Bernard (1997), include light manufacturing in the automotive industry. Many of these tasks within the automotive industry are physically demanding, requiring the adoption of awkward postures and are potential sources of physical stressors (Chung *et al.,* 2001). Partly for this reason, employees on an assembly line are at a particularly high risk of work-related musculoskeletal disorders (WRMSDs). With this in mind the focus was set on a

local automotive manufacturing plant with the aim of identifying and analysing a task which imposed MSD risks to workers.

Although the automotive industry has also become increasingly mechanised with a slight decrease in physically demanding jobs, there is still a substantial amount of manual handling with cumulative trauma disorders (CTDs) and MSDs continuing to plague the working population and constituting the largest category of occupational disease, often resulting in prolonged disability (Waters, 2005). This is also evident within the chosen automotive manufacturing plant, which is an international company, adhering to international laws and processing requirements. In 2001 in the US for example, the automotive industry reported the second highest absolute number of injuries and illnesses in the private sector with a high incidence rate of MSDs (Amell *et al.*, 2002). There is thus a necessity for intervention and analysis, which has led to initiatives to improve working conditions of assembly line employees with regard to MSDs (Janowitz *et al.*, 2006). Information regarding occupational injuries and illnesses is pertinent from an ergonomic viewpoint as this would facilitate the approach towards an "evidence based" initiative and an increased knowledge with regard to MSDs (Amell *et al.*, 2002).

The automotive industry provides a vast area for investigation and the risks need to be outlined more precisely as there are a large number of influences which may be the cause of WRMSDs, including physical, organisational and individual factors (Hagberg *et al.*, 1995). Consequently when utilising an ergonomics approach to assess MSDs one therefore has to take a holistic approach and assess all elements of the work system so that appropriate solutions can be achieved. Risk assessment forms part of this process and it is therefore necessary to quantify the risk associated with these physically demanding jobs in order to modify the job so as to reduce the stresses placed on the workers. Assessing exposure of individuals to risk factors for WRMSDs is an essential stage in their management and prevention (David, 2005). Through the use of

ergonomic risk assessments one can account for the relative role of each physical exposure type (e.g. force, posture etc.) with regard to the incidence of MSDs, given the appropriate application of resources, which is dependent on the identification of those problems which cause exposure. It is clear that there is therefore a need to quantitatively assess exposure of individuals to MSDs.

ERGONOMIC RISK ASSESSMENT IN THE AUTOMOTIVE INDUSTRY

The objective of the preliminary work was therefore to highlight the dominant risks within the chosen automotive assembly plant. When conducting a general survey and risk assessment of an industry it is important to set priorities and to use appropriate resources effectively (Li and Buckle, 1999a). This holds true as the specified plant had thousands of workers present working within hundreds of different workstations and tasks. Medical records were therefore used to gain a perceptive insight as to where to concentrate first in order to conduct a relevant ergonomic risk assessment. The work setting, task requirements and diagnostic criteria play a vital role in identifying the prevalence of any MSDs (Werner *et al.*, 2005), and cyclic assembly work, such as that found on an assembly line in an automotive industry, is known to be a high risk for MSDs (Moller *et al.*, 2004). An observation period of the manual assembly tasks within the lines was then conducted to identify problem areas and facilitate in the quantification and categorisation of the risks. The manual assembly area was chosen as this had the most manual materials handling and placed the greatest demands on the workers. Once specific lines and tasks had been identified, more detailed information was required through the use of risk assessment tools. Hence prioritisation of the lines occurred and high risk tasks were identified for further scrutiny in the laboratory. The following text refers to the initial phase of the thesis which includes the methodology followed to identify risk and narrow the focus, including the details and results obtained through the aforementioned process.

Medical record analysis

Due to the need for a prioritisation of areas for assessment, the analysis was concentrated first to a review of medical records. Westgaard *et al.* (1993) reiterate that an important risk factor to take into account when studying musculoskeletal pain in all body regions is that of previous pain symptoms, recorded in medical records, logs and documented worker histories. Medical records contain information obtained through a plan, programme or periodic examination (which may include clinical examinations, biological monitoring or medical tests) of employees by an occupational health practitioner, or in prescribed cases, by an occupational medicine practitioner (South Africa, Occupational Health and Safety Act, No. 85, 1993). With the main aim of the identification of documented occupational musculoskeletal (MS) risks, attention was placed on tasks incurring the risk of MS injury or complaints. The records relating to the manual assembly lines were attained and analysed thereby gaining valuable information regarding the leading injuries and MSDs, enabling one to identify those tasks which exposed an individual to the most risk.

In order to obtain information on areas which needed attention from the industry perspective, the analysis was extended by the acquisition of SHEQ (safety, health, environment and quality) risk assessment information through an industrial engineer within the Manufacturing Engineering Department of the plant. This included assessment of Facility Risk assessment forms and the Process Top Ten Risks assessment form, which is a document that included areas with a risk of muscle strain, back injury, shoulder injury and back/shoulder pain. The assessment also stemmed from enquiries from management, workers and supervisors relating to problems reported by or to them regarding pain, sickness, absence or low productivity for a specific area together with the information gained from the analysis of medical records.

As a starting point, examination of the pre-placement medical history of the workers within these lines, an overview of their physical examinations conducted prior to placement and the person-job match assessment (see Appendix A) gave an overview of worker health and previous history of disease/injury which may have affected the work cycle and been an additive cause to the complaints reviewed in the morbidity records. Review of all current employees' morbidity records (which included the date they were attended to, the doctor on call, the ailment reported and the treatment administered) and sick certificate records was conducted (see Appendix A). Employee confidentiality was maintained throughout and employee numbers were referred to when analysing the medical records. The records were correlated in terms of the ailment reported and the time and date of the medical examination and if this in turn correlated with the sick leave they had taken due to the illness. Due to the fact that all this information was individual and was categorised only to a very limited extent, this was performed by the author in the form of an expert screening. The information extracted from these records was then documented in a table. This information gave an indication whether the task contributed to the cumulative trauma experienced by the worker with regards to incurring musculoskeletal complaints and injuries. The acquisition of medical records also gave insight into the tasks identified and enabled one to determine any trends with regard to MSDs which were apparent in any specific areas, e.g. overhead work, and which was more critical.

Information was then drawn from the medical department with regards to organisational issues, most importantly the length of time that an individual had worked on the line at a specific workstation. This would give a better indication of whether the task added to the cumulative trauma experienced by the worker with regards to incurring musculoskeletal complaints and injuries.

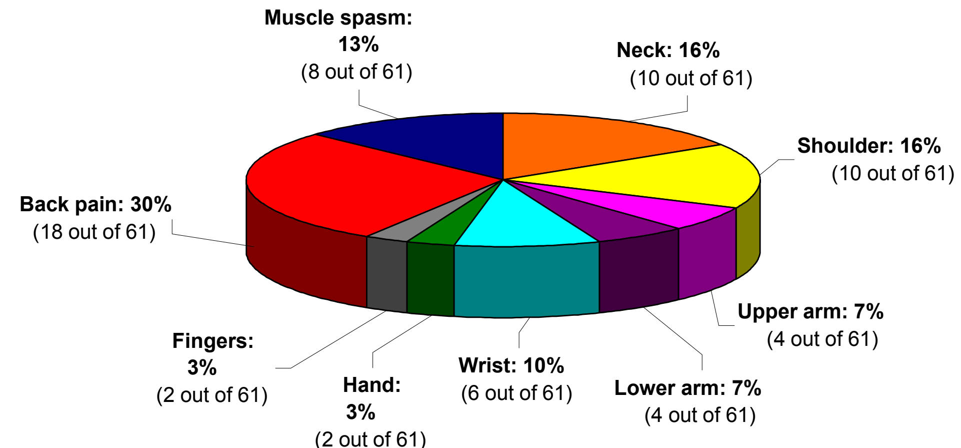
The screening highlighted the need for an ergonomics assessment on two of the assembly production lines, namely the 'Mech 1' and 'Trim 2' lines (see

description of these lines below), owing to the higher incidence of musculoskeletal complaints reported on them. These areas were confirmed and reinforced by the plant's SHEQ analysis forms and general recommendations from engineers and medical staff involved in the plant. The other lines within the assembly area had fewer occurrences and reporting of MSDs in comparison to the 'Mech 1' and 'Trim 2' lines.

The 'Mech 1' line includes mechanical parts installation, inspection and testing tasks, which are mostly completed in an overhead working posture involving the upper extremity with the arms lifted above shoulder height. The 'Trim 2' line involves installation of parts and trimmings within the chassis of the car, further inspection and testing procedures. Compared to the 'Mech 1' line, the 'Trim 2' line causes the worker to adopt an awkward working posture when completing the task as the chassis provides a restricted environment.

A summary of the musculoskeletal medical complaints taken from the medical records is illustrated in Figure 1.

(a) ‘Mech 1’ line



(b) ‘Trim 2’ line

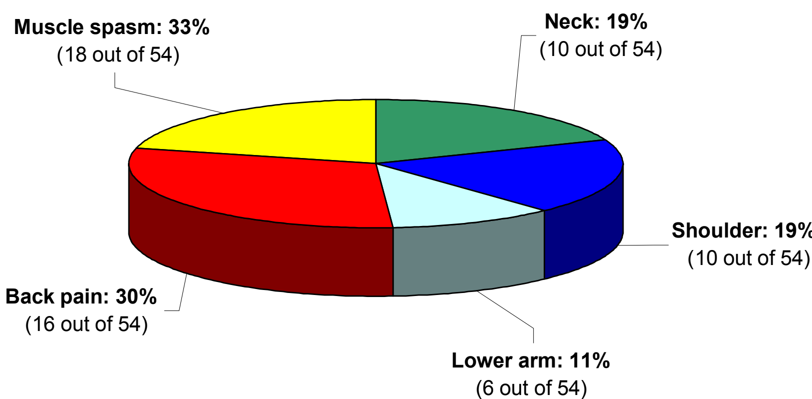


Figure 1: Musculoskeletal medical complaints for the ‘Mech 1’ (a) and ‘Trim 2’ (b) lines. The occurrence of the complaint is shown as a percentage of the total number of employees’ medical records analysed for MSDs. The number of employees out of the total number working is shown within parentheses.

Musculoskeletal complaints and injuries on the ‘Mech 1’ line were reported by 42 out of the total of 61 workers owing to a 69% incidence of musculoskeletal complaints. More detailed results indicated that back pain had the highest

precedence of musculoskeletal complaints amongst the workers on both the 'Mech 1' and 'Trim 2' lines (28% and 30% respectively). Due to the nature of the tasks, the dominant complaints among workers on the 'Mech 1' line were musculoskeletal injuries relating to the neck and shoulder region (16%), and muscle spasms indicating an occurrence of 13%. The wrist (10%), lower and upper arms (7%), the fingers and the hand (3%) indicate a relative minor ratio of complaints in comparison to the back, neck and shoulder regions, owing to the nature of the overhead work incurred during the various 'Mech 1' workstations.

Compared with the 'Mech 1' line, the 'Trim 2' line reported a 45% incidence of musculoskeletal complaints. The 'Trim 2' line also indicated that muscle spasms were more pertinent (21%) with neck and shoulder musculoskeletal complaints amounting to 19%. The focal point is therefore the back, including muscle spasms, which relate to the restrictive nature of the task and the demands placed on the worker to complete the tasks in an awkward posture.

The average number of years that a worker had remained on the 'Mech 1' line was 4 years, with those who had reported MSD complaints having worked there for an average of 4.33 years. A total of 61 workers work on the line, with half completing a morning shift (A-shift, n=30) and the other half forming part of a late afternoon shift (B-shift, n=31). With regards to the 'Trim 2' line, workers on average have worked on the line for 5.44 years, with those reporting MSDs having been there for the same amount of time. There are a total of 54 workers working on the line (27 working during the A-shift and 27 during the B-shift), with musculoskeletal complaints reported by 24 workers.

Risk assessment

To complement the medical records (which focused on the consequences of poor ergonomic conditions), a risk assessment was undertaken to explore the risk from a workstation and task perspective. This narrowed the focus even more,

with the work conditions on the 'Mech 1' and 'Trim 2' lines being assessed, including the measurement of physical risk factors. The use of risk analysis tools allowed for the overall risk categorisation of a task to be reported and an observation period of all tasks on the assembly line ensured the identification of problem areas and facilitated in the quantification and categorisation of the risks. The observation included the monitoring of 20 to 25 complete work cycles at each station. This method of analysis is supported by Li and Buckle (1999a) who state that repetitive tasks should be observed for 20 or 30 cycles before completing an analysis.

A review of literature was conducted to identify which tool would be adequate to use in obtaining a risk analysis incorporating the whole body and a prevalence of upper extremity use. Risk analysis tools, namely the Rapid Upper Limb Assessment tool (RULA) and the Rapid Entire Body Assessment tool (REBA) were chosen for risk identification. RULA is a survey method developed for use in investigations of workplaces which have an occurrence of upper limb disorders; the analysis of medical records indicated a prevalence of upper limb disorders thus its use in this study. REBA is a survey method utilised for the assessment of posture, with the means of highlighting the risk of work-related musculoskeletal disorders of the whole body. The use of the two methodologies in conjunction enabled a complete risk analysis of the whole body, and upper limbs in particular, complementing the nature of the tasks found on the 'Mech 1' and 'Trim 2' lines.

RULA and REBA are survey methods used in ergonomics investigations where postural loading is a concern. They are based on observations of working postures and joint angles and provide each task analysed with a grand score linked to an action level. A corresponding classification is also given, to be used as part of a more detailed ergonomics study. In agreement with Li and Buckle (1999b) with regard to the use of these analysis tools, areas such as the posture and movement of the back, shoulder/arm, wrist/hand and neck were observed and those categorised as having a high risk were assessed.

RULA (Rapid Upper Limb Assessment Tool)

The Rapid Upper Limb Assessment (RULA) survey method was developed by McAtamney and Corlett (1992) for use in ergonomic investigations of workplaces which had an occurrence of upper limb disorders. It is a screening tool which assesses biomechanical and postural loading on the whole body, focusing on the neck, trunk and upper limb areas. The use of this tool is efficient and the end scoring provides an action list which indicates the level of intervention required to reduce the risk of injury due to the specific task in question. A few steps are taken when using RULA to assess a working posture: observing and selecting the posture(s) to assess; scoring and recording the posture; coding the posture scores; and calculating the grand score and action level. A snapshot of the task is taken wherein the worst aspects of the job are identified, the postures are rated, and the force and movement required are also noted. The data is then entered into corresponding tables, and then captured into a final table giving a grand score that links to an action level (Table I). However, to ensure that this tool is used as an aid in efficient and effective control of any risks identified, the action level will lead to a more detailed investigation, i.e. further analysis will be required to further quantify the findings. This however is not found in all cases and is dependent on the situation and the purpose of the risk assessment tool use. The RULA tool should therefore be utilised in conjunction with a broader ergonomic study (McAtamney and Corlett, 1992). In summary, the application of RULA is for sedentary tasks where there is a risk of neck and upper limb loading and assesses the severity of postural loading. With this tool the user is able to assess a working posture and the associated level of risk efficiently.

Table I: Grand score and associated action level according to the RULA classification (adapted from McAtamney and Corlett, 1992).

RULA Score	Action level
1 - 2	(1) Posture is acceptable if not maintained or repeated for long periods
3 - 4	(2) Further investigation is needed and changes may be required
5 - 6	(3) Investigation and changes are required soon
7<	(4) Investigation and changes are required immediately

REBA (Rapid Entire Body Assessment Tool)

Hignett and McAtamney (2000) developed the Rapid Entire Body Assessment (REBA) tool for application in the health care and other service industries. REBA uses a similar approach as RULA, where posture, force, movement or action, repetition and coupling are assessed. It is thus a means to assess posture for the risk of WRMSDs.

The tool considers critical areas of a job and for each task it assesses the posture factors by assigning a score to each region. The data obtained through assessment of the task is then entered on a scoring sheet which gives a REBA score (Table II) for each task that indicates the level of risk and urgency with which action should be taken. Various criteria can also be used to select postures to analyse and the use of time sampling can also be utilised. REBA is

more for the analysis of the whole body involved in activity, animate tasks and where postures are dynamic, static or where gross changes in position take place.

Table II: REBA scoring sheet (adapted from Highnett and McAtamney, 2000).

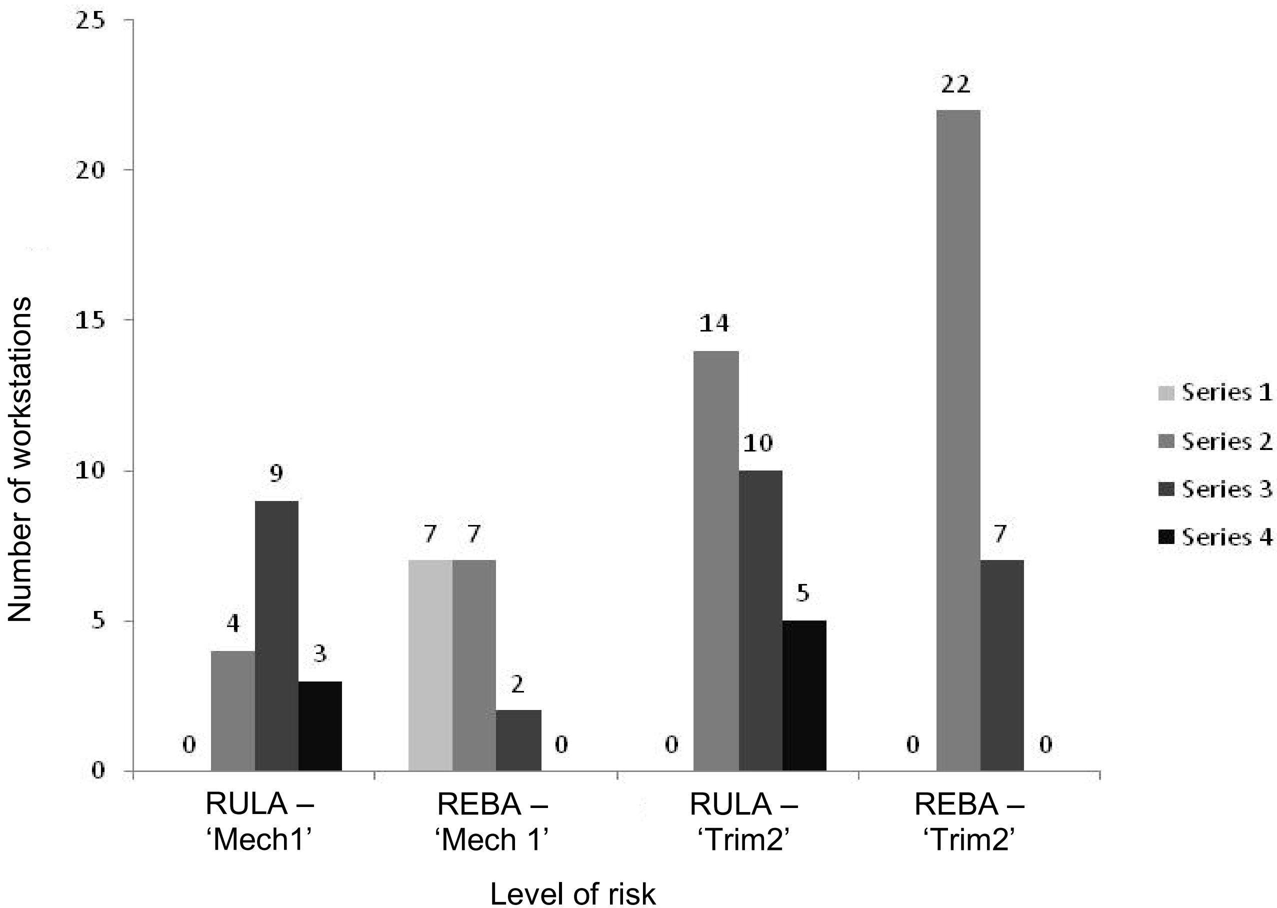
REBA Score	Risk Level
1	Negligible
2 - 3	Low
4 - 7	Medium
8 - 10	High
11 - 15	Very High

After an assessment utilising RULA and REBA, the data does however need to be analysed by a trained professional who will then categorise the postures, which may take a significant amount of time depending on the level of detail required in the analysis. Keyserling (1986) has found that it is difficult to discern between adjacent angular sectors with the areas of the upper extremity, especially the elbow and the wrist, making posture analysis difficult. Postures which include analysis of the neck and lower back have been found to be easier to evaluate.

In summary, Genaidy *et al.* (1994) found that observational methods utilising the above methods (RULA and REBA) have poorly defined posture and work activity classification, which then results in difficulty when trying to compare different studies' results. Although the aforementioned methods of observational analysis have such disadvantages and limitations, especially with regards to factors of reliability and duration, they provide a possibility for fast and effective screening.

In total, nine high risk tasks on the 'Mech 1' and 'Trim 2' lines were identified, with the majority of the tasks falling within the medium and high risk (according to

REBA classification) levels, whereby further investigation and changes may be required soon (according to RULA classification). The results are due to the circumstances found on the lines with the car suspended above the worker on the 'Mech 1' line inducing overhead working postures and the awkward postures adopted on the 'Trim 2' line imposing many risks to the individual.



Series 1: Acceptable posture (RULA)/ Low risk level (REBA);

Series 2: Further investigation and may need changes (RULA)/ Medium risk level (REBA);

Series 3: Changes required soon (RULA)/ High risk level (REBA);

Series 4: Changes required immediately (RULA)/ Very high risk level (REBA).

Figure 2: Illustrating the overall general risk estimation obtained from the assessment of all workstations on the 'Mech 1' and 'Trim 2' lines.

Figure 2 illustrates the results obtained from RULA and REBA on the ‘Mech 1’ and ‘Trim 2’ lines. Very few of the tasks analysed fell within the ‘very low risk/negligible’ risk level (REBA) and a posture that is ‘acceptable’ (RULA). The majority of the tasks fell within the ‘medium’ and ‘high risk’ (REBA) risk level, whereby further investigation and changes may be required soon (RULA). Focus was now placed on those tasks which incurred a ‘very high’ risk level (REBA) and where changes are required immediately (RULA). Results from the risk analysis therefore indicate that all the tasks induce some form of strain on the workers.

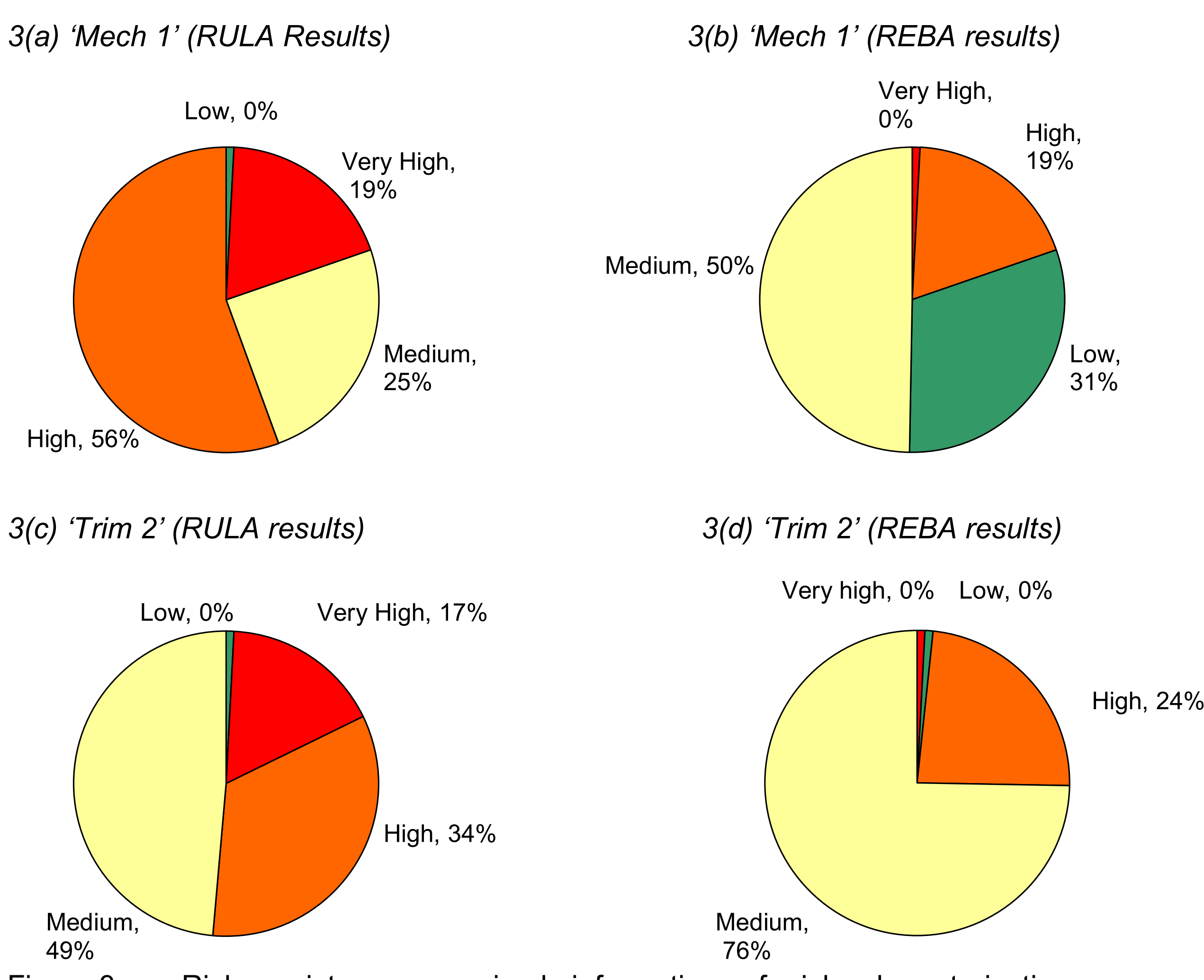


Figure 3: Risk register summarised information of risk characterisation pertaining to the ‘Mech 1’ (3a and 3b) and ‘Trim 2’ (3c and 3d) lines respectively.

Figure 3 indicates the prevalence of risks within each of the designated RULA and REBA scoring category. The information reiterates that a large proportion of the 'Mech 1' and 'Trim 2' assembly line tasks are rated within medium to very high risk classifications. Although the percentage requiring attention soon or immediately are moderate (31% and 25% on the 'Mech 1' and 'Trim 2' lines respectively), this still indicates the necessity for an ergonomics analysis and risk assessment of the respective stations identified, especially with regard to the 'Mech 1' line.

It is important to note here that these screening tools were relatively quick and easy to apply and are therefore very useful when assessing a large number of workstations. However, they do not investigate the entire complexity of the task and tend to provide very conservative risk ratings, i.e. they tend to overestimate the risk and encourage further investigations rather than claim no risk. Although the analysis of the tasks was also based on the subjective judgement, knowledge and experience of the assessor, it was only intended to give an overall 'perception' for each of the areas identified.

The assessment tools do allow for a static picture of the task to be acquired at a particular point in time. They also allow for active risks to be identified; their level and severity to be noted and easily identified. This will ultimately lead to a better understanding and acceptance of the visible risks.

However, from experience of applying risk analysis tools within the automotive manufacturing industry, it is the author's belief that, although analysis techniques such as RULA and REBA can be useful in certain phases of the identification of risks, they are incomplete when aiming to perform a full risk analysis. The tools did not represent a sufficient justification of the tasks under observation and RULA and REBA should both be used in conjunction with a broader ergonomic study. McAtamney and Corlett (1992) observed that their sensitivity, specificity

and predictive value for quantifying the actual risk for musculoskeletal injuries needs to be properly assessed.

'Mech 1' line: risk profile and task characteristics

The results obtained from the medical records and risk analysis tools were utilised to give a better idea of where to place the focus of attention and this indicated that the 'Mech 1' and 'Trim 2' lines required consideration with regards to some of the workstations and demands placed on the worker.

Although the REBA results indicate relatively low scores in terms of the postural demands placed on the workers during assembly tasks on the 'Mech 1' line, the RULA results show a considerably higher risk to the upper extremities. Results from REBA indicated that 31% of workstations were at a low risk, 50% of workstations a medium risk, and 19% were classified as a high risk that needed to be changed soon. The stresses placed on the upper extremities alone, however, as identified by RULA, indicated greater risks with 56% and 19% of workers being exposed to high and very high risks respectively, which needed urgent interventions.

Table III: RULA and REBA scores for workstations on the 'Mech 1' line.

Station	Description	RULA	REBA
1	Fit heat shields 1 (male worker)	7	5
1	Fit heat shields 2 (female worker)	7	9
2	Fit covers 1 (male worker)	5	5
2	Fit covers 2 (female worker)	5	9
3-5	Rear bumpers (male worker)	6	6
3-5	Rear bumpers (female worker)	6	6
6&7	Rear axle mounting	4	4
7	Fuel tank mounting	5	4
8	Engine & front axle 1	4	3
8	Engine & front axle 2	5	3
8	Engine & front axle 3	5	2
9	Reinforcing brackets 1	7	8
9	Reinforcing brackets 2	5	5
10&11	Fender brackets 1	5	5
10&11	Fender brackets 2	6	7
11	Absorbers	4	3
15	Front end assembly	3	3

The greatest risk on the 'Mech 1' line lies within the overhead work that the workers have to perform and this is reflected in the greater risk classifications of the RULA and REBA scores (Table III).

The following dimensions were also taken on the 'Mech 1' line where the car is suspended above the worker:

- Front of car (floor to inside rim of tyre space): 2170mm;
- Floor to base of car height: 1750mm;
- Floor to behind front wheel rim (placement of heat shields): 1850mm;
- Floor to middle of car (placement of heat shields): 1980mm.

The above indicate the dimensions of the environment within which the worker has to complete the task, creating an overhead working posture. The stature of individual workers plays a vital role in the comfortable completion of certain subtasks, such as screwing and hammering overhead. Certain instances noted on the line gave clear examples of this, whereby a tall worker had to bend and tilt his head in order to complete the task, whereas a shorter worker had to reach upwards and extend this head backwards to complete the same task.

(a)

(b) (c)

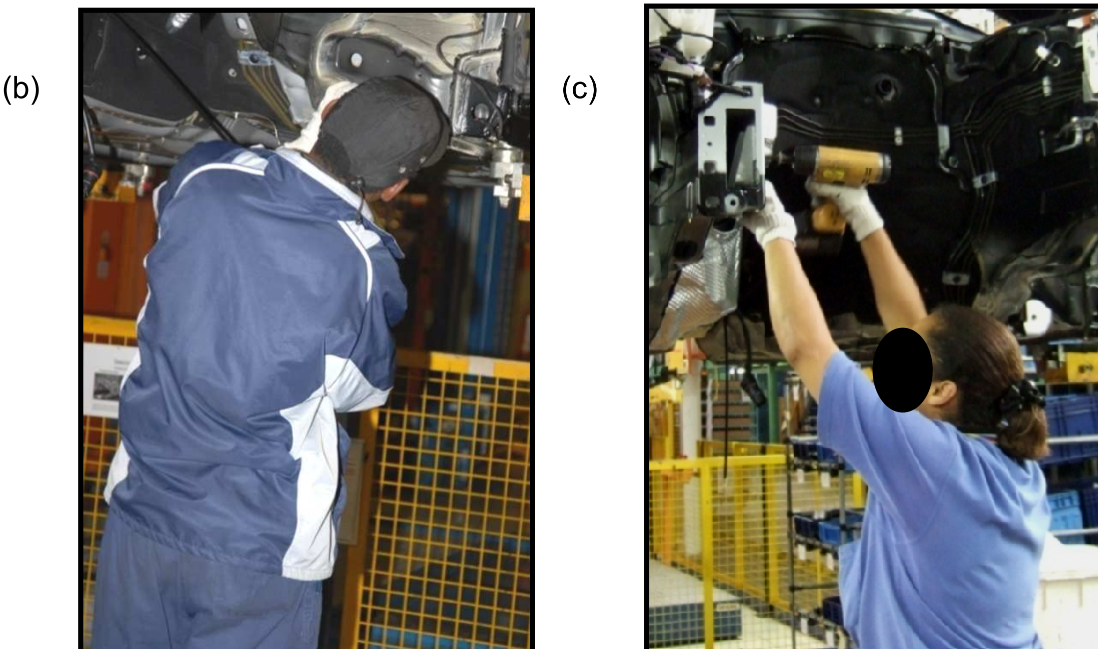


Figure 4: Effect of stature on postures adopted when working overhead (4a, b and c).

Figure 4 illustrates an aspect of overhead work, indicating how the stature of a worker plays a vital role in the posture adopted. The employee in the background (Figure 4a) is of a short stature and is working at a height that induces a posture of extension of the arms beyond shoulder level. Another aspect evident in shorter workers is the posture of the neck which is extended thereby causing strain in those muscles. The worker in the foreground of Figure 4a is however of a tall stature and has to adopt a working posture in which the head is tilted to the side or the individual has to hunch forward to allow clearance of the chassis overhead. Similar cases were observed in other stations, in which a tall male and short female worker (shown in Figure 4b and 4c) conducted the same assembly procedures on either side of the chassis but were evidently strained differently due to the kinds of body postures they had to assume. Another example of the different overhead postures which workers have to adopt is illustrated in Figure 5.

Figure 5: Mounting of the exhaust at the ‘Mech 1’ line.

‘Trim 2’ line: risk profile and task characteristics

Compared to the ‘Mech 1’ line, the ‘Trim 2’ line yielded similar results from RULA and REBA. Lower REBA scores were obtained compared to those obtained from RULA. The REBA analysis however showed that none of the stations were categorised as being low and most fell within the medium and high category. The results also indicated a greater postural demand during the ‘Trim 2’ tasks when compared to those on the ‘Mech 1’ line. The greatest risk on the ‘Trim 2’ line therefore lies with the awkward postures that the workers have to adopt and this is again reflected in the greater risk classifications of the RULA and REBA scores (Table IV).

Important dimensions relating to the ‘Trim 2’ line include:

- Height of boot (from floor of boot to top of boot): 500mm;
- Reach distance within boot: 740mm
- Floor of factory to boot level: 1240mm;
- Floor of car to steering wheel: 890mm;
- Floor of car to steering column: 350mm.

The dimensions shown above illustrate the awkward and confined spaces within which workers have to complete a task. Tasks which include clipping in the boot therefore require awkward postures such as stooping, twisting, lateral bending and a large reach distance to be able to complete the task successfully. Working under the dashboard with a maximum height measure of 350mm also requires an awkward posture within a confined space.

Table IV: RULA and REBA scores for workstations of the 'Trim 2' line.

Station	Description	RULA	REBA
1	Brake Booster 1	7	8
2	Brake Booster 2	3	5
3	Registration plate	7	9
4	Securing pedals	4	6
5	Sub-assembly- safety belt	4	6
6	Bonnet dampener	3	5
7	Insertion of dashboard	4	6
8	Fastening bolts/screws	4	6
9	Work under dash	6	8
10	Fitting air con pipes	4	4
11	Inserts ceiling	5	9
12	Attaching sun visors etc	3	4
13	Attaching sun visors etc	5	4
14	Attaching sun visors etc	3	4
15	Attaching sun visors etc	4	5
16	Connect cables in boot	7	8
17	Connect cables in boot	3	5
18	Connect cables in boot	7	8
19	Connect cables in boot	6	6
20	Secures seatbelt bolts	4	4
21	Secures seatbelt bolts	5	4
22	Front carpet & accelerator cable	4	4
23	Front carpet & accelerator cable	6	9
24	Front carpet & accelerator cable	4	4
25	Fitment of screens front and rear	6	5
26	Fitment of screens front and rear	6	7
27	Fitment of screens front and rear	7	7
28	B & C Pillar trim 1	6	7
29	B & C Pillar trim 2	5	5

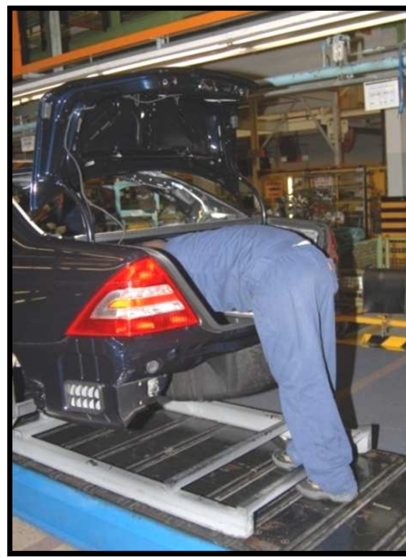


Figure 6: Examples of postures adopted on the ‘Trim 2’ line.

The images in Figure 6 indicate some of the awkward postures which workers are required to adopt when completing a range of tasks (Table IV) on the ‘Trim 2’ line. The postures vary with some requiring a seated position and others a standing and sometimes supported posture. The anthropometric characteristics of the worker again play a vital role when working on this line as the chassis is fixed and restricted thereby confining the workspace.

STATEMENT OF THE PROBLEM

The initial phase of this study, which included risk assessment, indicated the necessity for an ergonomics analysis and risk assessment on the ‘Mech 1’ and ‘Trim 2’ lines. The results did however indicate that the ‘Mech 1’ line (69%) elicited a higher incidence of musculoskeletal complaints when compared to the ‘Trim 2’ line (45%). This highlighted the ‘Mech 1’ line as the most pertinent with regards to the incidence of MSDs during work on the assembly line. Added to this the time constraints of a Masters thesis did not allow for both areas to be analysed and therefore a focus was set on the ‘Mech 1’ line.

The main aim was to gain information relating to the effects of overhead work and to identify whether an individual’s responses are dependent on changes in working height. The goal was therefore to gain information pertaining to the biomechanical, physiological and psychophysical effects of this type of work specifically. These findings can then be used *in situ* and will enable one to identify which circumstances are appropriate for the safe completion of such tasks. This may lead to a better understanding of the demands of overhead work on an individual, support appropriate design of workstations and, if indicated aid in the selection of workers, and in so doing this would limit the occurrence of MSDs within this section of the automotive industry.

RESEARCH HYPOTHESIS

It is expected that changes in working height will elicit biomechanical stress, physiological exertion and body discomfort amongst the subjects coping with the overhead conditions.

STATISTICAL HYPOTHESES

The first hypothesis (H_1) predicts that the measured biomechanical variables will not depend on working height, thus be similar for all the height conditions.

(1) H_O: $\mu_{\text{Condition 1, EMG}} = \mu_{\text{Condition 2, EMG}} = \ldots\ldots = \mu_{\text{Condition n, EMG}}$

H_A: $\mu_{\text{Condition 1, EMG}} \neq \mu_{\text{Condition 2, EMG}} \neq \ldots\ldots \neq \mu_{\text{Condition n, EMG}}$

Where: EMG = muscle activity as biomechanical variable (see details in Chapter III)

The second hypothesis (H_2) predicts that the measured physiological variables will not depend on working height, thus be similar for all the height conditions.

(2) H_O: $\mu_{\text{Condition 1, physiol}} = \mu_{\text{Condition 2, physiol}} = \ldots\ldots = \mu_{\text{Condition n, physiol}}$

H_A: $\mu_{\text{Condition 1, physiol}} \neq \mu_{\text{Condition 2, physiol}} \neq \ldots\ldots \neq \mu_{\text{Condition n, physioll}}$

Where: physiological variables (physiol)=
Breathing frequency (Rf)
Heart rate (HR)
Tidal volume (VT)
Minute ventilation (VE)
Oxygen consumption (VO_2)
Energy expenditure (EE)

(see details in Chapter III)

The third and final hypothesis (H_3) proposes that perceptions of body discomfort will not depend on working height, thus be similar for all the height conditions.

(3) H_O: $\mu_{\text{Condition 1,psychophys}} = \mu_{\text{Condition 2,psychophys}} = \ldots\ldots\ldots\ldots\ldots = \mu_{\text{Condition n,psychophys}}$

H_A: $\mu_{\text{Condition 1,psychophys}} \neq \mu_{\text{Condition 2,psychophys}} \neq \ldots\ldots\ldots\ldots\ldots \neq \mu_{\text{Condition n,psychophys}}$

Where: psychophysical variable (psychophys) = Body Discomfort (see details in Chapter III)

DELIMITATIONS

The study used a sample of 14 male and 14 female subjects who were healthy, active university students, free of musculoskeletal injury. Their ages ranged from 18 years to 28 years and their statures between 1600mm and 1850mm. Elite athletes were excluded from the selection process, to prevent distortion of data due to their greater physical and physiological capacities.

Subjects were given standardised instructions for the protocol, which lasted for 40 minutes. During this protocol subjects adopted sixteen postures including four below the stature height of the individual, two reference postures in a neutral, upright position and ten upright overhead postures. These postures were adopted whilst holding no weight for eight of the conditions and while holding two kilograms in each hand for the remaining eight postures.

Data was collected on each subject including muscle activity of eight muscles using a Mega ME6000P16 electromyography unit. Heart rate (HR) was monitored using a Polar® Heart Rate monitor, and breathing frequency (Rf), tidal volume (VT), minute ventilation (VE), energy expenditure (EE) and oxygen consumption (VO_2), using an online metabolic ergospirometer, the Quark b^2. Perceptual responses of the subject were also recorded using the Body Discomfort Map and Scale to identify any discomfort experienced during the test.

LIMITATIONS

Many impinging factors could have affected the results obtained from each subject although the researcher attempted to control and standardise as many as possible.

Heart rate especially is known to be influenced by factors such as emotional state, excitement, anxiety and environmental factors (Bales *et al*., 2001). Oxygen consumption has also been known to be affected by many factors such as environmental conditions which in turn affect a person's metabolic rate. This would impact on oxygen consumption and the accuracy of its measurement which would have limited the success of this study. These extraneous factors could therefore have affected test results, but measures were taken to avoid this by requesting each subject not to participate in any strenuous exercise prior to testing and selecting the appropriate subjects.

One limitation to the study was its reliability due to the use of a small sample size of only twenty-eight subjects, and the use of university students who were not representative of the user population, i.e. manual labourers, which may not be entirely representative of the wider population. The results of this study may not be directly applied to industrial workers as students are not work hardened. The control of all the above mentioned variables does however validate the use of these results in Industrially Developing Countires (IDCs) specifically regarding automotive labourers. Upper arm strength results were also conducted on a reference group of manual labourers in the selected automotive plant which ensured that the results obtained from the students were comparable.

Another limitation to the study is the fact that the overhead tasks completed in the automotive industry include dynamic hand and finger movements which were not part of this study protocol. Future studies should employ this activity within an

in situ setting. The laboratory experimentation was also limited to testing responses for a limited amount of time and not over an eight-hour working shift.

CHAPTER II

REVIEW OF RELATED LITERATURE

INTRODUCTION

Ergonomics defines itself as a science which aids in the designing of the task, tools and work environment to suit the capabilities of the workforce (Hager, 2003), whereby it involves matching the task to the worker, rather than attempting to fit the worker to the task/job (Owen, 2000). The same author reiterates that the goal of ergonomics is to identify aspects of the job which are hazardous and to then assess and redesign them to be safer for the individual. This will also result in a reduction in the occurrence of musculoskeletal disorders (MSDs) and contribute to the improvement of occupational health (Bernard, 1997; Buckle and Devereux, 1999; Jafry and O'Neill, 2000).

Many occupational accidents, injuries, diseases and MSDs continue to arise due to a lack of ergonomics in the workplace, and there is a need to quantitatively assess exposure of individuals to MSDs. An estimated hundred million occupational injuries are occurring annually throughout the world (Leigh *et al.*, 1999; Dzissah *et al.*, 2001), with compensation for these injuries and illnesses sustained by workers under occupational conditions imposing a large financial burden. This is occurring in industrialised and developing nations, including South Africa (Keyserling, 2000a, 2000b), with the United States for example having compensation costs estimated at 20 billion dollars (Kelsey *et al.*, 1979). Despite attempts at making the alleviation of risks more effective, MSDs continue to be the most common form of work-related ill-health in the workplace. This highlights the importance of instituting effective solutions to curb the rise in expenditure in relation to occupational illnesses, injuries and MSDs (Amell *et al.*, 2002). The World Health Organisation (WHO) (1985) report that the number of workers with some kind of impairment or disability, and who therefore have a

reduced working capacity, is ever-increasing and occupational risks are ever changing. Whysall *et al.* (2004) reiterate the importance and need for an investigation into what causes the prevalence of work-related musculoskeletal disorders (WRMSDs) and why their occurrence remains so high. There is also a growing awareness of the contributions of work conditions to industrial injuries (Wilson and Corlett, 2005) and thus it is important to identify those conditions or tasks which contribute to these injuries, to then reduce their severity and impact on an individual (Bridger, 1995; Wilson and Corlett, 2005).

The added presence of MSD risks on automotive assembly lines leads to hazardous situations which require intervention to try and minimise the likelihood of unfavorable outcomes; however, a lack of information leads to a detriment in the decision-making process (Bennett, 1996). Epidemiological studies have shown a prevalence of MSDs in various categories of workers employed in industrial assembly work, and this includes jobs which require awkward postures such as overhead work. This poses many risks to an individual such as intramuscular pressure developed in the rotator cuff muscles of the shoulder, which could impair circulation and lead to the early onset of fatigue. This study therefore aimed to obtain empirically based information concerning how the body responds to the demands of overhead work conditions.

Holistic assessment

Measuring of the exposure to risk factors for MSDs as a base for then developing programmes of risk prevention and reduction have received much interest and involvement from ergonomists, occupational health physicians, employers and regulating authorities (David, 2005). According to David (2005) it is now accepted that these aforementioned programmes should be founded upon ergonomics principles, incorporating the holistic assessment of all elements of the work system thereby ensuring optimal solutions are reached. In so doing, generic issues such as task design, worker/equipment interface, individual variation

(including motivation), training needs, work organisation and legal requirements need to be considered (Moray, 2000). The conceptual 'Center-M' model was proposed by Charteris *et al*. (1976) and has been used for many years in the assessment of human performance. These authors identified human beings as being complex creatures who need to be studied via a holistic approach incorporating biomechanical, physiological, psychophysical and conceptual domains to assess 'humans-in-motion' (Charteris *et al*., 1976; Warren, 2001). Dempsey (1998) supports the above criteria to set limits on different tasks. Tasks such as overhead work include a variety of biomechanical, physiological and psychophysical responses from workers, and a holistic assessment is thus necessary to get a complete understanding of the complex nature of the human being.

Ergonomics in Industrially Developing Countries (IDCs)

An ergonomics process is defined as a formal, systematic application of ergonomic principles integrated with management systems and in the organisational culture of the company or industry in question. This is comparable to an occupational safety and health programme which addresses health and safety hazards through a systematic method of hazard recognition, identification, evaluation and control (Torma-Krajewski *et al.*, 2007). Ergonomics has been shown to be an effective method of assessing the problem of occupational injuries, illnesses and MSDs (Bernacki *et al.*, 1999; Brisson *et al.*, 1999; Drury *et al.*, 1999; Volinn, 1999; Lincoln *et al.*, 2000). This will enhance efforts made by industry to decrease the frequency and severity of these incidents (Amell *et al.*, 2002), thereby optimising worker productivity and ensuring worker safety, which is of utmost importance from a moral, legal and economic viewpoint (Amell *et al.*, 2001).

The automotive industry in South Africa is highly competitive with those found overseas, yet it is faced with a number of challenges especially with regard to

ergonomics application and intervention strategies due to its Industrially Developing Country (IDC) status (James, 2002). The application of ergonomics also differs between IDCs and industrially advanced countries (IACs) (O'Neill, 2000) and any contribution to the Third World from the First World does need to be relevant and long lasting (Shahnavaz, 1995). O'Neill (2000) argues that the theoretical concepts of ergonomics in IDCs are not at odds with its application in IACs, but its implementation introduces a new challenge with a different starting point altogether. A possible reason for this issue could be due to attitudes of employees towards intervention, resistance to change from managers and a lack of skills with which to apply changes (Urlings *et al.*, 1990). The manner in which these interventions are implemented therefore needs to take the local atmosphere and cultural dynamics of the country, as well as the company, into account. The aforementioned plays a vital role in the successful implementation of sound ergonomic principles within industry. James (2002) also found ergonomic interventions in the South African automotive industry to be more reactive than proactive in nature.

It is however not easy to change the habits and working cultures of the indigenous people, and therefore more time is needed since it is not as straightforward when compared to a workforce that is used to mechanisation. Many of the workforces also earn poor salaries, and come from areas with inadequate housing, a prevalence of malnutrition and no safe drinking water. All these factors combined cause workers to be susceptible to disease, which they cannot address due to a lack of income. The above is one example of the many problems experienced in IDCs, and this often leads the workers into a negative spiral as described by Scott (2003).

Management do however support and conduct safety, health and environmental (SHE) programmes, which are well utilised within the South African automotive industry. Questionnaires assessing worker perceptions of the automotive industry specifically, felt safety was well instituted within various plants yet they perceived

a greater need for adherence to basic guidelines and industry specific standards (James, 2002).

Another problem faced by the workforce is that they are poorly educated and the key issue to improve existing conditions in industry is to improve the knowledge and practice of ergonomics. All of the above can only be achieved through management support, employee participation, building proper ergonomic intervention teams and by taking a holistic approach (O'Neill, 2000; Helali and Shahnavaz, 2003). Ergonomics does have the potential to create harmony between technology, technology users and the operating environment (Jafry and O'Neill, 2000; Helali and Shahnavaz, 2003); it can also improve working conditions and quality of life thereby having a greater effect, and bring about wider benefits especially in IDCs (Jafry and O'Neill, 2000).

Assembly work

There are many workplaces and tasks in existence which place constraints on a worker, such as maintenance, repair and assembly work (Haslegrave *et al.*, 1997). Assembly in the automotive industry still relies heavily on physical manpower and manual assembly despite the many advances in mechanisation; hence the need to examine all aspects of the working conditions (Goldsmith *et al.*, 1978; Nussbaum, 2001) as workers are required to adopt awkward working postures and handle loads (Hägg *et al.*, 1997; Chung *et al.*, 2001). The work involves the manufacturing of a final product through the process of subassemblies, manufactured parts and components (Dimitriadis, 2006), utilising precise and sometimes complex equipment, and the organisation of thousands of parts. The tasks are characterised as having highly repetitive demands, requiring multiple, dynamic movements which need to occur within a complex time pattern and organisational context, and these processes are thought to increase the likelihood of incurring MSDs and cumulative trauma disorders (CTDs).

The production line environment is highly regulated, whereby a worker's individual choices with regard to risk are restricted by imposed costs and benefits of operating in the industrial sector (Stanton and Glendon, 1996). Freiboth *et al.* (1997) reiterate the aforementioned where production systems often limit the possibility for change. On an assembly line the different work elements of sequential workstations also have fixed duration times, imposing restrictions on the completion and method order of each work element for the worker (Ghosh and Gagnon, 1989). The total production rate on the assembly line dictates the amount of time allocated to each workstation, called cycle time. The main objective on any assembly line is to assign work elements so as to minimise the number of workstations without violating the preset constraints and without having the work element time at any individual station exceed the cycle time. The total work element time at a specific station less the cycle time is known as the workstation's idle time, which is meant to be kept at a minimum. Even though most assembly work has been found not to be physiologically taxing (Dimitriadis, 2006), the different work elements of sequential workstations of fixed durations as mentioned, impose restrictions on the processes and completion of each task element for the worker.

As identified by Chung *et al.* (2001), automotive assembly tasks are one of the most labour intensive industries, where workers are required to perform these tasks repetitively in poor working postures due to the constrained work place, placing large amounts of strain on the musculoskeletal system. Dimitriadis (2006) states how a better understanding of the properties and performance of complex assembly systems may have significant implications when looking at the design and function of assembly lines. Although there is also the possibility of automation in many industries, including the automotive industry, manual work will continue to be important in the future (Forsman *et al.*, 2002). Forsman *et al.* (2002) emphasised that automated machines will not substitute the human being as some form of interaction will always be necessary between the two.

Working postures

Many work situations and assembly lines impose constraints on workers and force individuals to adopt awkward work postures, and to maintain these for the duration of the task, thereby increasing the risk of incurring an MSD (Carey and Gallway, 1998; Corlett, 2005). These postures may also need to be held for a certain period of time, requiring static standing and restricted postures such as those found in machine operation and assembly work (Miedema *et al.*, 1997). The effects of static and awkward postures, with the added level, duration and variation of load, may increase the risk of incurring MSDs (Westgaard and Aaras, 1984). Posture therefore needs to be taken into account when analysing a whole situation, where posture and other activities interact and where a substantial amount of effort is required in a certain position (Corlett, 2005). It has however been found that there is a lack of quantitative data and as yet ergonomic recommendations cannot be based on the long-term health effects of certain tasks or postures. With regard to this study the reference to posture includes the angular relationship of body parts and the effects of the posture on muscle activity, with emphasis on maintaining postures and the support of loads, which are examples of static work.

Most work on an assembly line is performed close to the body and involves standing positions and strenuous forced postures, with relatively low levels of forces being applied. When utilising testing tools, however, tasks are performed further from the body and higher force application is required (Winter *et al.*, 2006). Automotive assembly has also been found to include a number of tasks which involve hand impacts within the manufacturing process. When tasks require the use of these power driven tools, and therefore added weight for the completion of the task, it is known to increase the risk for MSDs and CTDs.

Standardised working postures can however lead to inaccurate predictions of the actual forces and postures which occur in everyday life, and therefore the most

suitable way of assessing human force exertion for research and design is in a free posture. A standardised posture is however considered to yield more reliable data (Daams, 1993). With specific reference to static postures, most often utilised in experimental studies, in practice they do not occur very often. In industry, static postures are broken by small movements and many work situations also allow for the body to be supported by structures in the work environment or the actual machine or device being utilised or assembled. The support offered by these structures provides support to the muscles in use during the task, allowing the muscles and joints to be relieved of strain. It has also been found by various studies that supported and dynamic postures allow for a longer endurance time to be maintained when compared to static postures (Miedema *et al.*, 1997).

It is important to consider an individual's anthropometric dimensions to reduce the possibility of developing WRMSDs. Overhead restrictions which are too low will affect the headroom available to complete a task and workers are then likely to adopt awkward postures. This was evident in the photographs documented in the identified automotive plant, shown in Figures 4 and 5 (Chapter I). A taller worker is confined to a greater degree when ceiling or working heights are lowered, forcing this individual to adopt a posture in which the trunk is excessively flexed. This posture may result in higher spinal loading due to the interaction between the worker's anthropometric dimensions and the restrictive working environment (Gallagher, 2005). Taller subjects tend to have longer trunk lengths which further elevates spinal loading (Splittstoesser *et al.*, 2007), indicating that restrictive tasks would be more ideal for shorter members of the working population. With regards to shorter individuals, studies have shown lower risk for developing lower back pain symptoms due to the reach distance being smaller, compared to taller individuals when retrieving a load (Wilson and Corlett, 1995; Mital *et al.*, 1997).

The aforementioned factors also relate to an individual's strength capability while working overhead which is reduced due to constraints of the workplace. It is

known that small constraints on a worker's posture within the workplace may have large effects on the ability of an individual to exert force (Haslegrave *et al.*, 1997), reducing it drastically (Colombini and Occhipinti, 2006). A general approach to keep in mind with regard to postures is to avoid adopting prolonged movements or positions which require the worker to adopt an awkward position. Studies have also shown that the lower the degree of muscular exertion, the longer the duration with which the exertion can be maintained (Haslegrave *et al.*, 1997). The same is found with the number of movements that can be made within a repetitive task; the lower the muscular exertion the greater the number of movements which can be made.

Overhead work

Overhead work, defined for this study as working with both hands above the head while in a standing posture, is another common occurrence in automotive manufacturing. NIOSH (1991) recommend assessments be made from a biomechanical, physiological and perceptual perspective in order to gain a holistic view of responses from the workers while they perform a series of assembly line tasks. This methodology may aid the identification of risks, although the process can be time consuming and labour intensive as laboratory research with complex equipment is required. Through a methodology which includes the aforementioned, detailed information may be provided on a task, highlighting areas which need improvement. Research on overhead work has however been varied (especially with regard to the effects of increasing arm reach) and existing guidelines in overhead work are limited (Sood *et al.*, 2007) with most recommending it be avoided, which may be impractical in many industries. According to Nussbaum (2001), an extensive review of the literature has also not provided sufficient information for the development of guidelines or information (Nussbaum, 2001) with regards to overhead tasks.

The effects of overhead work are numerous and varied. Colombini and Occhipinti (2006) suggest that potential health risks of jobs and health surveillance practices should be undertaken if one of the following risks is detected:

- Jobs which feature cyclic tasks whereby the worker is required to perform the same movement with the upper limbs every few seconds (i.e. every 15 seconds or less), for at least two consecutive hours;
- Jobs which require intermittent manual exertions (at least one every five minutes) for at least two hours per shift, e.g. holding objects which weigh more than 2.7kg; and
- Jobs which involve extreme wrist or shoulder movements; positions for one hour continuously or for a total of at least four hours per shift.

Further risk factors in overhead work specifically include the vertical distance of the overhead reach (Pepping and Li, 2000), highly repetitive work, high forces and cumulative loads. It has also been found that tasks which require the worker to perform above the body generally require greater force exertions due to the suboptimal leverage and joint angles. These tasks requiring repeated or prolonged elevation of the arms above the shoulders also result in fatigue (Hagberg, 1982).

Various other factors have been considered when looking at risk factors for overhead work including arm elevation angles during work (Sakakibara *et al.*, 1995); spinal loads (Burton *et al.*, 1994); the extent of lumbar extension incurred in this type of work and musculoskeletal symptoms in relation to working postures, particularly arm elevation and head extension (Sakakibara *et al.*, 1993).

Nussbaum (2001) studied overhead assembly tasks under a variety of conditions, and assessed subjective ratings of discomfort and objective myoelectric spectral changes. Both measures indicated consistency within and between subjects, and findings corroborated the phenomenon that fatigue is not easy to quantify or predict during complex tasks, and may have a variety of

causes and observable effects. However, when assessing overhead work, Garg *et al.* (2002) found subjective ratings of fatigue were more informative than objective measures, as perceived exertion and fatigue ratings show how the fatigue accumulates with time. Similar information is said to be difficult to obtain when utilising surface electromyography (EMG).

A field study conducted by Burton *et al.* (1994) found that motor mechanics spent 8% of their time working overhead, which included up to 10 degrees of lumbar extension in a typical work cycle. Results from their laboratory testing found that there was a greater occurrence of lumbar extension and perceived exertion in overhead work when compared to chest-height work. It was concluded that there were no substantial changes in stature from tasks which were perceived to involve moderately high levels of exertion. Therefore, some elements of a dynamic work task may have an unloading effect, together with lordotic postures which may also reduce load on the spinal discs (Burton *et al.*, 1994).

Studies conducted by Sigholm *et al.* (1984) and Jarvholm *et al.* (1989) found arm posture to be a major determinant for mechanical load on the tissues of the shoulder region. Muscle activity in this region also relates to arm elevation when measured by EMG or intramuscular pressure. Workplace studies have also been known to report high EMG levels for a selected number of muscles and these levels are also dependent on the effect of static gravitational load (Christensen, 1986).

Garg *et al.* (2002) suggest if overhead work cannot be eliminated in a work routine it would then be better to design such work whereby the hands are kept close to the body so as to reduce moments in the shoulder joint. Sood *et al.* (2007) also recommend that overhead work should be designed so that extreme reaches are avoided. Tasks also seem to be better designed higher overhead (up to 150^0 of shoulder flexion) when compared to lesser degrees of forward flexion.

Endurance time

Many tasks, such as assembly work, require certain postures which have to be maintained for a long period of time in order to complete the work appropriately. There is also a greater risk of incurring an MSD depending on the posture adopted and the duration for which it has to be held. These risks can however be avoided by improving the posture and reducing the amount time by which it has to be maintained, which will ultimately reduce static load on the muscles as well. These postures can only be maintained for a certain period of time, and this is known as endurance time. The activity will continue until such time as the individual feels maximum discomfort (Miedema and Douwes, 2001).

Reliable and valid methods to assess subjective aspects of fatigue and endurance time are therefore of importance in the context of the working environment. Together with assessments of the physical and motivational resources available to the individual, this may be important in gaining an understanding of the origin and development of MSDs (Ahsberg and Gamberale, 1998). When conducting ergonomic evaluations of static and intermittent static work it has been found that maximum endurance time is a key parameter to take into account (El ahrache *et al.*, 2006) as this type of work is known to increase the risk of developing an MSD. These authors further state how the estimation of maximum endurance time (MET) to accommodate a percentage of the population is necessary when determining work-rest ratios for *in situ* static work. The primary objective of MET is to determine the acceptable duration for maintaining a static muscular contraction (Jonsson, 1988; Miedema *et al.*, 1997). El ahrache *et al.* (2006) found MET to be most often calculated in relation to the percentage of maximum voluntary contraction (%MVC) of a muscle and it has been widely cited in the ergonomic design of jobs (Garg *et al.*, 2002).

Another aspect involved with endurance time is that of endurance limits which are the %MVC below which static muscular work or a posture can be maintained without undue fatigue (Kroemer, 1970). There are several approaches in existence pertaining to these limits and the relationship between the load on a muscle and the endurance time, including those by Rohmert (1960, 1973a and b) and Rohmert *et al.* (1986) whereby the limit is set at 15-20% of a muscle's maximum capacity, allowing an individual to sustain an exertion at this level for a longer period of time (for minutes or even hours). Figure 7 illustrates how loads which require 40% or more of a muscle's maximum, reduce the endurance time of that muscle to less than one minute. These values have been widely utilised as a guideline for assessing work tasks. However, the offset values of this function have been questioned with reference to the overestimation of the duration of exertion at low percentages of MVC. Forces as low as 7.9%MVC (Bjorksten and Jonsson, 1977) and 5%MVC in comparison (Jørgensen *et al.*, 1988; Garg *et al.*, 2002) could cause a reduction in muscular capacity of 12% after only one hour.

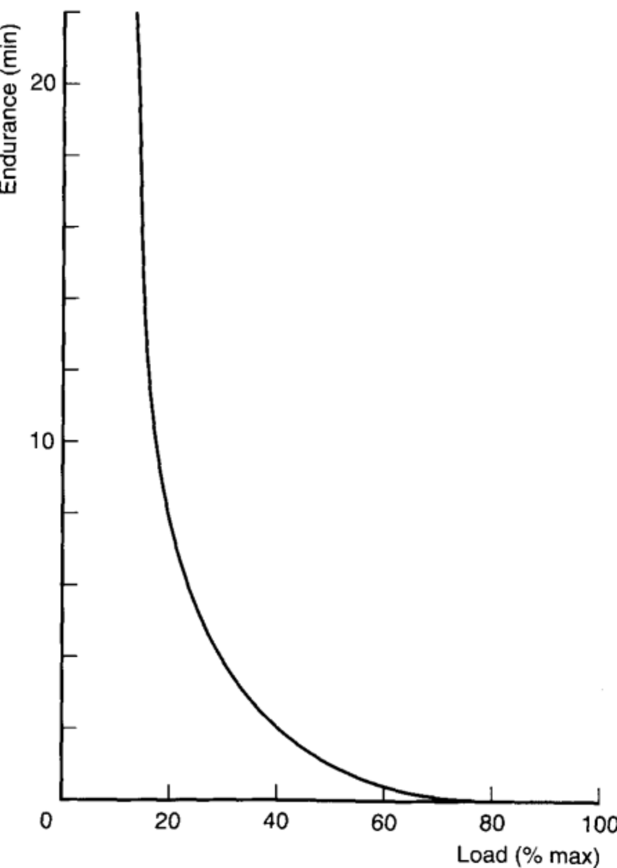


Figure 7: The relationship between the load on a muscle and the associated endurance time (adapted from Kroemer, 1970).

With reference to load on the muscle, Ahsberg and Gamberale (1998) stated that it is not possible to maintain a long endurance time if the load is higher than 20%MVC. Other studies (Rose *et al.*, 1992) have indicated endurance times of 6-12 minutes at 5%MVC and 4-7 minutes for 15%MVC. This will aid in providing some form of guidelines in industry where these tasks are performed on a daily basis. Conditions which therefore elicit a certain muscle activation level can then be allocated an endurance time and this should then be adhered to.

Postures enabling an endurance time of more than 10 minutes are said to be comfortable postures; however, it is recommended they not be maintained for longer than 2 minutes (Miedema *et al.*, 1997). Moderate postures on the other hand were found to have endurance times of 5-10 minutes and are

recommended to be maintained for less than 1 minute. Uncomfortable postures with an endurance time of less than 5 minutes are not acceptable. These values correspond with the recommended endurance time of static postures which was found by Miedema *et al.* (1997) to be 20% of the maximum holding time. Ahsberg and Gamberale (1998) conducted a study to identify a static load which could be held for a long period of time i.e. more than 10 minutes. It was, however, also found that it is not possible to maintain a longer endurance time if the muscle load is higher than 20% MVC (Ahsberg and Gamberale, 1998). It is further recommended that once the posture has been held for the recommended endurance time, either the posture, load or ideally both should be altered, enabling the loaded body part to rest.

Miedema *et al.* (1997) collated the maximum holding time of symmetric standing postures from various experimental studies in the literature, identifying a range of maximum holding times from 2 to 35 minutes. These studies were conducted without the factor of external load, and it was found that there was much variation in the endurance time of similar postures within and between the studies covered. A ranking of the postures could still be made based on the mean times from all the available data. The ranked postures are shown in Figure 8. The longest holding time is found with the posture at 75% shoulder height and 50% of arm reach. Postures with low working heights i.e. 25% of shoulder height have the lowest endurance times.

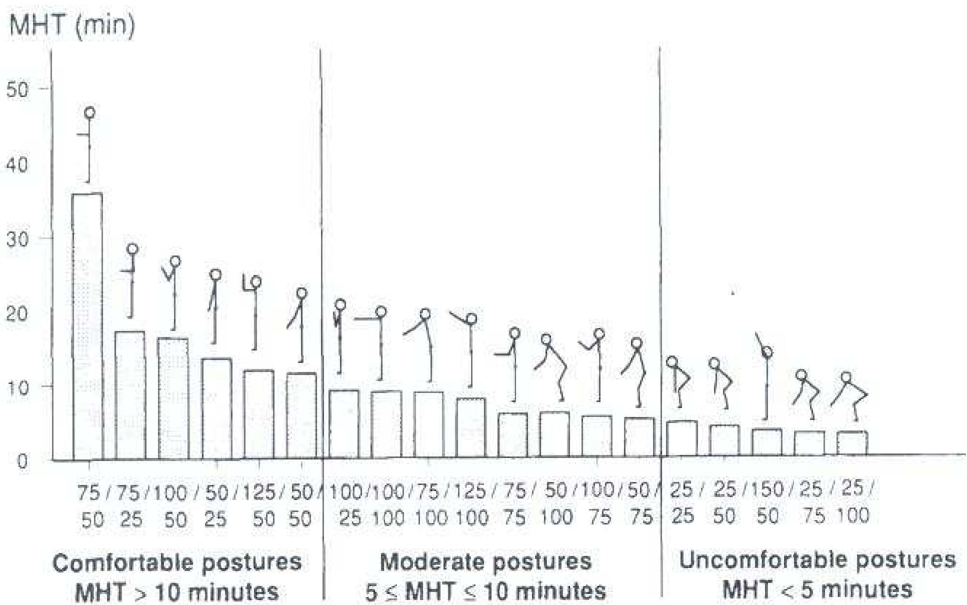


Figure 8: Ranking of postures on the basis of the mean values of Maximum Holding Time (MHT) of data from various experimental studies (adapted from Miedema *et al.*, 1997).

It was concluded that the endurance time decreases when the work distance increases and the working height decreases (Miedema *et al.*, 1997). It was also found that postures with hand positions at or below 50% of shoulder height expose an individual to discomfort in the lower back and legs, whereas postures with hand positions at or below 100% shoulder height elicit discomfort in the shoulders and arms. Other researchers have reported light workloads may cause muscle fatigue or musculoskeletal complaints, especially in the neck, shoulder and lower back regions (Jørgensen *et al.*, 1988; Sommerich *et al.*, 1993; Rose *et al.*, 1992). Examples taken from a study by Rose *et al.* (1992) reported endurance times of 6-12 minutes at 5%MVC and 3.5-6.5 minutes at 15%MVC for various work tasks. Shoulder postures (i.e. shoulder flexion angle) during overhead tasks have a significant effect on endurance time, with a decrease in time being found with an increase in shoulder flexion angles up to 120^0 and then it increases (Garg *et al.*, 2002). Garg *et al.* (2002) found overhead tasks in

particular, better designed with a greater degree of forward flexion. It has also been stated that the posture which the shoulder is in (shoulder flexion angle) has a significant effect on endurance time. This is supported by van Dieen and Vrielink (1994) who found overhead work can result in lower endurance times at the same relative load when compared to postures which are closer to the normal standing position.

The use of percentile values to describe the lowest maximum endurance time of a group of subjects is preferred when evaluating a work task (Mathiassen and Ahsberg, 1999). In this way it is possible to accommodate the majority of the population and not only the 'stronger' half.

Endurance time does however have variation of similar postures within and between different studies and this may be explained by intra- and inter-individual characteristics and differences in the experimental situation and the task which is performed. The task which is performed while maintaining the required posture is an important factor which affects endurance time. The variation in body angles within the same body posture will also have an effect on the endurance time. The highest variation in muscle effort (8%MVC to 31%MVC) is found with changes in body angles of the upper extremity area. Miedema *et al.* (1997) concluded that muscle effort increases when the working height is very low or very high, and when in a comfortable posture, the biomechanical load is relatively low. This could also be attributed to the increase in the angle of the body when working heights are lower.

Endurance time therefore remains a valuable indicator of fatigue of the most strained muscle or strain on the cardiovascular system. This then allows one to evaluate those static or intermittent static tasks which require muscular work (El ahrache *et al.*, 2006). Endurance classifications can therefore be a valid contributor as a guide in practical situations, whereby working time is matched to the working posture adopted. The recommendations in most studies are however

based on data which has large variation, from inter- and intra-individual differences and study design characteristics, and therefore these guidelines should be implemented with caution in the working environment. It is also important to note that the measure of endurance time is also dependent on motivational factors, as an individual could cease completing a task due to discomfort or it could be a factor of fatigue. Subjects therefore respond differently and these individual responses should be taken into account.

Individual variations

McArdle *et al*. (2001) point out that due to inter-individual differences certain individuals are more suited to a certain task than others depending on their stature, lean body mass and cardio-respiratory capacity for instance. Each individual has variation in their capabilities which are associated with factors such as age, sex, and the task-specific aerobic capacity of the individual (Mital *et al*., 1997). McArdle *et al*. (2001) point out that age is an important factor to consider when assessing a worker's capabilities. As age increases there is a decrease in cardiovascular and pulmonary function, a reduction in muscle mass and a decrease in concentric and eccentric strength. This all leads to a reduction in the work capability of an individual, and therefore older workers need to be assigned to tasks which require less physical demands. Another factor to acknowledge is the sex of the worker when looking at worker capabilities, as males and females have different morphologies which can affect their capabilities, particularly in physically demanding tasks. It is generally acknowledged that females have 65-75% of the strength capability of their male counterparts (Mital *et al*., 1997).

The aforementioned variables are only a few of the many concomitant variables which affect an individual's capacity to work optimally. The design of tasks and consequent assignment of employees to them should thus be dictated by the frequency, severity and cost of injuries so as to ensure that the demands of the task do not exceed the capabilities of the worker (Ayoub *et al.*, 1983).

MUSCULOSKELETAL DISORDERS (MSDs)

Overload of muscles, joints and other supporting structures of the musculoskeletal system by adopting awkward body postures may result in MSDs, also known as work-related musculoskeletal disorders (WRMSDs), CTDs, or repetitive strain injuries (RSIs). Many other pathological situations come under the term WRMSD including those which affect the various structures of the upper limbs. MSDs in the workplace may be due to cumulative damage as a result of months or years of exposure to excessive levels of psychosocial stressors caused by the work itself. MSDs of the upper extremity and low back disorders have also been found to be strongly associated with exposure to combined ergonomic stressors and the type of work performed (Andersson, 1997; NIOSH, 1997; Punnett, 1998). These stressors result in fatigue, discomfort, pain, local swelling, numbness or tingling sensations within the musculoskeletal system.

Scientific evidence has shown that physical and psychosocial factors are critical to consider when looking at the development of WRMSDs (Dempsey, 1998). Bernard (1997), Stenlund *et al*. (2002) and Cort *et al.* (2006) found repetitive industrial work associated with increased prevalence of WRMSDs, especially of the lower back, neck, shoulders, arms and hands. These body areas therefore need to be assessed and researched. The work setting, task requirements and diagnostic criteria play a vital role in the prevalence of any MSD (Werner *et al.*, 2005). Evidence exists in varying degrees regarding risk factors which are the cause for the development of MSDs, including awkward postures, poor work organisation, fast work pace, high stress, previous pain symptoms, prolonged static load on the muscles, movements, exerted forces and the combination of these factors (Kilbom, 1994; Bernard, 1997; Li and Buckle, 1999a; Hagg, 2000). Attempts have therefore been made to establish quantitative exposure-response relations to aid in the successful control of MSDs (Marras and Schoenmarklin, 1993; Hansson *et al.*, 2000).

A range of physical risk factors are evident when assessing an MSD of the lower back or upper limbs. These include a previous history of lower back pain, heavy physical work, frequent bending, twisting, lifting, pulling and pushing, repetitive and forceful actions, static posture and whole body vibration when looking at lower back disorders (NIOSH, 1997; Lavender *et al.*, 2006). When assessing upper limb disorders (Table V) it is important to take into account the awkward posture adopted due to poorly designed workstations, tools, equipment, working methods, interactions between sets of equipment and groups of people, environmental factors, repetition, high forces, hand arm vibration and static postures (NIOSH, 1997; Buckle and Devereux, 1999; Li and Buckle, 1999a; Op De Beeck and Hermans, 2000; Burton *et al.,* 2004).

It has however also been found that WRMSDs, especially of the upper extremity, occur in the absence of high force exertions and awkward body postures (Andersen *et al.*, 2003). This is supported by Aaras (1994) who found even low muscle strains in terms of load intensity i.e. 1-2% MVC, were associated with the occurrence of occupational disorders. This is the case for light assembly work (e.g. in the automotive industry) where there is a prevalence and elevated risk of neck and shoulder disorders (Hagberg and Wegman, 1987).

Table V: Some important risk factors for the back, wrist/hand, shoulder/arm and neck (adapted from Li and Buckle, 1999b).

Back	Wrist/hand
• Load weight	• Force
• Duration	• Duration
• Frequency of movement	• Frequency of movement
• Posture	• Posture
Shoulder/arm	**Neck**
• Load weight	• Duration
• Duration	• Posture
• Task height	• Visual demand
• Frequency of movement	

There have been strides in the study of risk factor exposure and the development of WRMSDs (Warren, 2001) and it is thought to be a combination of many factors. In order for an intervention to be effective one must therefore address the problem by looking at all the risk factors in a multifaceted approach. Research has identified physical (Winkel and Mathiassen, 1994), psychosocial/ organisational (Devereux *et al.*, 2002) and individual (Armstrong *et al.*, 1993) occupational 'risk factors' for the development of WRMSDs. Other factors to consider include task design, worker/equipment interface, individual variation (motivation), organisational culture, training needs, work organisation and legal requirements (Moray, 2000).

When utilising an ergonomics approach to assessing MSDs it is therefore necessary to utilise a holistic approach and assess all elements of the work system so that optimal solutions can be achieved. Punnett (1998) reiterates the importance of evaluating all ergonomic exposure factors as they occur in combination *in situ*.

Ergonomic research has made progress in the identification of physical risk factors for WRMSDs, especially with regard to biomechanical risks and the development of intervention strategies to reduce the exposures (Warren, 2001). The issues depicted in the outer levels of Figure 9 should also be assessed using the appropriate ergonomic techniques and interventions, therefore considering all levels. This points to other causal factors not solely intervention techniques which focus on biomechanical risks.

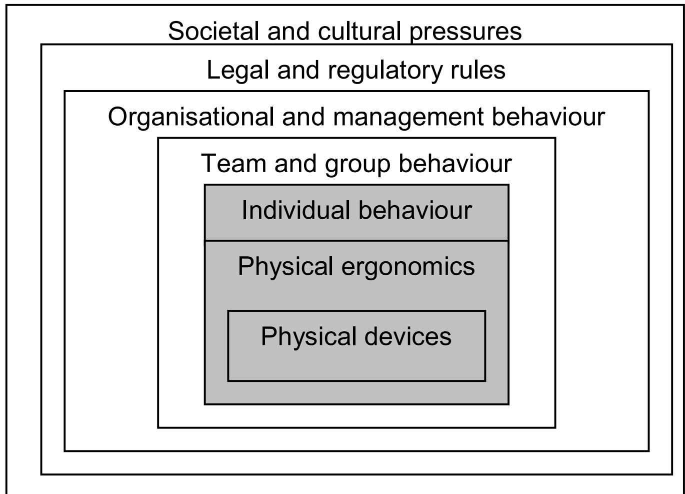


Figure 9: Holistic assessment of all elements of the work system (adapted from Moray, 2000).

Park *et al.* (1992) conducted a study within an automotive manufacturer, looking at medical insurance claims linked with work histories. A large number of cases relating to work-related diseases were identified, including many episodes of CTDs. CTD incidence rates were calculated within five plants, showing elevated risks for carpal tunnel syndrome, CTD of the upper extremities, rotator cuff syndrome, CTD of the neck and of the lower back.

Musculoskeletal disorders of the upper extremity and lower back

Most tasks observed on automotive assembly lines require the adoption of the overhead postures including arm elevation and head extension, together with the demand of short cycle times resulting in a high repetition of tasks. This may place undue stress on the body, especially the neck, shoulders and lower back (NIOSH, 1991; Sakakibara *et al.*, 1993; Sakakibara *et al.*, 1995, Lindbeck *et al.*, 1997; Stenlund *et al.*, 2002; Lavender *et al.*, 2006). Musculoskeletal diseases associated with occupational exposures of these areas include tendonitis of the shoulder, carpal tunnel syndrome, tension neck syndrome and lower back pain (Grieco *et al.*, 1998).

Occupational activities which require repetitive use of the arm above shoulder height and in confined spaces induces fatigue, and leads to the increased incidence of MSDs and injuries involving the impingement of ligaments and tendons at the shoulder level (NIOSH, 1991; Hammarskjold and Harms-Ringdahl, 1992). Various studies have found that muscle pain in the neck and shoulder region (tension neck syndrome) is strongly correlated with work. This is especially evident in tasks which require the adoption of static postures and static loads. Causes which are not yet fully clarified include local decreased blood flow, activation of pain receptors through oedema or other mechanisms, and an energy metabolism disturbance due to the long term static contraction of muscles (Grieco *et al.*, 1998).

Shoulder pain syndromes in industry are becoming increasingly common (Herberts *et al.*, 1984; Stenlund *et al.*, 2002; Sood *et al*., 2007), with existing evidence to support that overhead work specifically is an important risk factor. As stated by many authors (Anderson, 1971; Hagberg and Kvarnstrom, 1984; NIOSH, 1997; Grieco *et al.*, 1998; Sood *et al*., 2007) musculoskeletal disease has been shown to be most prevalent amongst workers involved in industrial assembly work. These diseases are most prevalent with workers exposed to high

repetition, static efforts, insufficient recovery time, significant force and tasks which require awkward non-neutral postures such as overhead work. Within overhead work specifically, arm elevation, sustained shoulder abduction and flexion, and specific postures which require a degree of upper arm flexion or abduction, have a substantial effect on the occurrence of MSDs and therefore have subsequent effects on a worker's quality of life. This is the source of large expenditure in terms of medical costs and disability payments (Anderson, 1971), yet the cause of neck and shoulder pain in the majority of the disabled is still unknown due to an incomplete understanding of its pathophysiology (Herberts and Kadefors, 1976; Herberts *et al.*, 1980).

Static work is also known to induce symptoms at an earlier age and biomechanical studies have confirmed that shoulder muscles are heavily loaded when the arm is elevated. Many studies support this claim through their epidemiological, physiological and biomechanical investigative evidence on overhead work (Kilbom *et al.*, 1986; Hagberg and Wegman 1987; Sakakibara *et al.*, 1995; Punnett and Herbert, 2000).

With regard to overhead work, the main abductors of the arms are the middle fibres of the deltoid muscle, the infraspinatus muscle and the supraspinatus muscle (De Luca and Forrest, 1973; Herberts *et al.*, 1984). Blood supply to these muscles is vital for adequate force production because the muscles need a constant supply of nutrients and removal of carbon dioxide. However, the effects of gravity on blood flow have the opposite effect together with static postures which result in an increase in intra-muscular pressure and therefore the occlusion of blood flow. Haslegrave *et al.* (1997) further reiterated that this leads to fatigue and a reduced strength producing capability, yet the degree to which the strength is affected depends on the effects of the task and layout factors such as the location of the work piece, hand tool mass, reach distance and direction of force exertion. Local muscle fatigue is also a common occurrence in overhead and shoulder level work, and in some cases waist level work (Herberts *et al.*, 1980).

These factors together may also lead to the acceleration of rotator cuff degeneration (Hagberg, 1984).

When working overhead with the arms elevated above shoulder height, incorporating head extension, two primary concerns arise: mechanical compression and impaired blood supply (Hagberg, 1984; van Dieen and Vrielink, 1994; Garg *et al.*, 2006). The work causes mechanical rubbing of two bones at the shoulder joint including soft tissues which surround the area, causing inflammation and pain in tendons and important muscles in the shoulder. A high intramuscular pressure develops in the rotator cuff muscles which could impair circulation and add to the early onset of fatigue. Overhead work also requires the arms to be raised thereby causing a reduced blood flow to tendons of muscles in this area. Impingement of the soft tissues within the shoulder girdle occurs when the humerus is elevated and pushes the tissues and muscle against the acromion of the scapula whereby mechanical pressure is highest with arm elevations of 60-120^0. This may lead to irritation and inflammation of the muscle tissue or MSDs such as tendonitis and tears to the tendon of the muscle. Load on the muscles is also significantly affected by elbow positioning in overhead work (Herberts *et al.*, 1980). Jarvholm *et al.* (1991) identified intramuscular pressure increases with arm elevation which in turn impairs local muscle blood flow with, for example, the supraspinatus muscle and its hypovascularity which is accentuated by high intramuscular pressure reducing the blood flow through the muscle. With the added effect of load in the hands this will further exacerbate the effect of intramuscular pressure effects on the shoulder.

The added factor of load which has to be lifted or held in the hands is yet another factor which is assumed to be related to shoulder symptoms. One way to measure this added load on the shoulder is through myoelectric activity of the shoulder muscles as indirect indicators of the load (Herberts *et al.*, 1980). It has also been shown that high speed contractions of muscles in the shoulder region have elicited co-contraction of muscles in the leg (Carpentier *et al.*, 1996).

With regard to the lower back, in particular the risk of muscle fatigue, muscle ruptures and damage to the spine in the lumbar region is increased due to the very high internal forces which are needed in order to exert force and to stabilise the posture of the body. This could also lead to the rupturing of the intervertebral discs from overloading which may not be felt by the individual as with muscular and cardiovascular fatigue. The aforementioned is highly dependent on the task at hand as this could induce forces which are either high or low. It is important to note that damage to the vertebral column has long-term effects which are not reversible. Tasks which require forward bending for instance create lumbar moments which are compensated by the activation of the erector spinae muscles (Potvin *et al.*, 1991). These muscles are also capable of lifting the trunk from a forward bent position to an upright one when no load is carried by the individual. However, when load is an additive factor, the erector spinae muscles are no longer capable of fulfilling this movement.

Other factors which help to reduce the incidence of MSDs include reference to medical, workplace, insurance and family systems, together with communication between all professionals in order to gain a better perspective of the complexity of the problem (Sanders and Strickoff, 2001). The treatment of MSDs can only be successful when the exposure to ergonomic risk factors is reduced or eliminated (Mani and Gerr, 2000). With MSDs of the neck, shoulder and arm being common in many occupational settings due to high precision demands and sustained static load in the neck-shoulder region (Milerad and Ericson, 1994), ergonomic assessment is therefore necessary. Many studies (Miedema *et al.*, 1997; Garg *et al.*, 2002; El ahrache *et al.*, 2006) have recently considered overhead work with a focus set on endurance time and muscle load, so there is therefore a need for numerous studies to consider the many variables.

TECHNIQUES FOR ASSESSING THE RISK OF WORK ACTIVITIES

The majority of methods utilised have been categorised within three subsections including: (1) observational methods utilising specifically designed assessment sheets allowing the observer to assess and record data and therefore establish priorities for intervention, and advanced techniques utilised for the assessment of postural variation in highly dynamic activities by recording data on either a video tape or computer dedicated software; (2) direct measurements using monitoring instruments which rely on sensors which are attached directly to the subject for measurement of exposure variables at work; and (3) self-reports from workers through diaries, interviews, subjective ratings and questionnaires (David, 2005).

Observational assessment methods

The choice between the available methods should depend on the application for which it is intended and the objectives of the study (David, 2005). Another consideration should include a well-designed hypothesis, to determine the accuracy and precision that is required (David, 2005). Hollywell (1996) stated as a general rule that risk assessments and their level of detail should be broadly proportionate to the risks involved. Many human activities or jobs are often 'designed' to alleviate the excessive physical and mental task demands on a worker. Hollywell (1996) believed that to alleviate these high task demands one should divide the task up into sub-tasks which can then be completed by more than one individual.

Most of the observational methods mentioned focus on working postures, movement, measurement of the back, neck, shoulders and arms and to a lesser degree, factors of force and task duration. This is understandable as most work-related musculoskeletal disorder problems are related to the upper extremity, with a lower frequency occurring in the lower extremity.

David (2005) however stated that the assessment of the exposure of an individual to risk factors for MSDs in the workplace is a complex and problematic area and the major challenge is selecting the appropriate method or combination of those available. General observation based assessments do however seem to provide the level of cost, capacity, versatility, generality and exactness suited to the requirements of occupational health and safety practitioners and ergonomists who need to prioritise areas for intervention within limited time constraints and available resources (David, 2005).

Direct assessment methods

A wide range of methods have been developed which utilise sensors attached directly to the subject for the measurement of exposure variables at work. Some methods include the use of electronic goniometers which measure joint motion, and more complex methods, such as electromyography (EMG), synchronously record and analyse myoelectrical activity (David, 2005). EMG has been used to estimate muscle activity (Schüldt *et al.*, 1987; Wells *et al.*, 1997) and may also be used to evaluate local muscle fatigue which interprets changes in spectral characteristics of the myoelectrical signal (De Luca, 1997; Merletti and Parker, 1999). Heart rate and oxygen consumption are often utilised to directly assess physiological response of workers to a task or situation and also require expert interpretation.

Li and Buckle (1999b) found that direct measurements provide a large quantity of highly accurate data on a wide range of exposure variables, although this capacity of generated information may be considered impractical by many due to the time required to interpret the data. Analyses may also require the attachment of sensors and masks to the subject which could cause discomfort and modification in work behaviour. The equipment tends to be expensive and requires highly trained and skilled technical staff to operate them (Li and Buckle, 1999b).

Biomechanical considerations

The biomechanical approach aims to determine the role of cumulative loading in the development of lower back, arm and shoulder injuries, establish a better understanding of the effects of shear and torsional loadings on the spine and its effect on lower back disorders, and collect more data on the dynamic capabilities of major joints (Dempsey, 1998). Biomechanical models are one such method which allow for the design of tasks without the need for experimentation. It has also been shown that biomechanical models can be utilised in many studies to determine guidelines (Jørgensen *et al.,* 1988). Force loading on the musculoskeletal system has been the main focus of biomechanical design of various tasks, especially with regards to the trunk region of the body, which has been identified as being weak (Mital, 1999). The biomechanical approach will therefore aid in the designing of tasks, where the demands will not exceed the musculoskeletal capabilities of workers and provide information on the effects certain tasks have on the musculoskeletal system.

By incorporating the morphology and posture of the individual involved in the task, so as to quantify the effects on the musculoskeletal system (Dempsey, 1998), a better understanding of the effects on the body can be obtained. A biomechanical approach is thus of utmost importance to include in the analysis of tasks in industry.

Electromyography (EMG)

Electromyography (EMG) is a technique that has been developed for the measurement of changes in electrical potential which occur during muscular contraction through the recording and processing of EMG voltage (myoelectric signals) (Chaffin, 1973). In biomechanical studies, EMG has many uses including the detection of muscle activation and the provision of an index of fatigue (De

Luca, 1997). The signal can be recorded through the use of surface electrodes or needle electrodes, which are inserted into the muscle. The latter technique is invasive and in some cases it is preferable to use the non-invasive technique of surface electrodes (Grassme *et al.*, 2005). Surface EMG has proven to be a useful tool when assessing muscle activity as it provides continuous and quantitative measures and it does not inhibit the natural execution of the task. The use of surface electrodes does however limit the amount of information which can be gained as only muscles located directly below the skin can be measured. As reiterated by Goebel (2005), EMG only provides a measure of voltage which indicates local muscle recruitment.

In addition to EMG being used to analyse relative muscle activity of working muscles, it has been widely used in the assessment and detection of local muscle fatigue in its early stages (Chaffin, 1973). This is achieved as a correlation exists between the number and intensity of spikes within an EMG signal and the force of contraction of the muscle. A researcher is then able to obtain muscle activity through recording and processing. The effects of fatigue on the active muscle cause spectral changes to occur, whereby the myoelectric signals indicate an increase in the amplitude and a decrease in the frequency. It has also been found that an increase in muscle contraction may lead to an increase in muscle fatigue and tendon tension (Grieco *et al.*, 1998).

With reference to the recording of muscle activity through surface EMG, Goebel (2005) finds bipolar electrode placement to be the most widely utilised method. This process involves the placement of two active electrodes on the belly of the muscle to be tested and one neutral electrode on an inactive region close to the muscle in question. This method allows for the difference between signals to be detected. However, when recording with surface EMG there are a few methodological aspects to consider such as the interference/crosstalk of adjacent muscles recorded as an EMG voltage (µV). A study conducted by Schüldt *et al.* (1986) found this interference to differ depending on the muscle studied, yet it

was found to be the same for all subjects tested by Milerad and Ericson (1994), as they utilised standardised electrode settings for each test subject with standard positioning of the electrodes. It is therefore imperative that the placement of the electrodes is taken into account as this is an important determinant factor with regard to the accuracy of results. The muscle to be tested should also be accurately identified and palpated in order to minimise the effect the aforementioned interference may have on the recording of muscle activity, as this may over or underestimate the activity for that specific muscle. Muscle activity may also be difficult to compare between two different postures due to movement of the placed electrodes (Mouton *et al.*, 1991). When using EMG data, the analyst therefore needs to take the placement of the electrodes, the posture and individual factors into account.

There are many factors such as muscle length, muscle-electrode distance, movement velocity (Madeleine *et al.*, 2001), amplifier input, impedance, type of electrode used, electrode contact area, and interelectrode distance (Elfving *et al.*, 2002) which may affect scaling. A study by Matthiassen and Winkel (1996) adopted a test contraction method whereby static recording of signals are likely to be produced by the same pool of motor units in every measurement. This would therefore provide information as to which group of muscles is likely to be activated during certain overhead tasks and postures.

Due to the number of aforementioned factors which may interfere with the amplitude of the signal obtained from the muscles, it has been recommended to compare an individual's recorded signal with their maximum voluntary contraction (MVC) thereby expressing EMG signal as a percentage of the maximum (Goebel, 2005). This allows one to minimise any interfering factors and provides a valid indicator of muscle recruitment. To aid the process of interpretation, measures which are obtained may be combined with measures of external load, body posture or joint movement (Goebel, 2005). EMG is a valuable tool when conducting studies assessing movement and co-ordination (Grassme *et al.*,

2005) and when making use of multi-channel EMG for instance, muscular limits may be identified (Goebel, 2005). This will provide insight into those muscles which limit their use in a certain task and may also indicate which are subject to the most fatigue.

Physiological considerations

It is known that there are a number of ways to assess automotive assembly tasks, yet most literature has focused on the biomechanical approach and postural stressors in this particular industry, leading to a gap in the literature whereby the physiological cost has not been extensively studied (Chung *et al.*, 2001).

The most applicable indirect methods of assessment are the use of heart rate recording and physiological monitoring equipment such as the Ergospirometer which allows for subsequent extrapolation of many physiological responses including respiratory responses (breathing frequency, tidal volume and minute ventilation), heart rate, oxygen consumption and energy expenditure.

As an individual takes part in more vigorous work, the body's demand for oxygen increases (McArdle *et al.*, 2001). All of the energy-releasing reactions in the body, including muscular contraction, depend on oxygen usage. The body functions as a complete system with, for example, the muscles requiring oxygen in order to function. However, if the required oxygen is not delivered at a fast enough rate to the muscles the activity will eventually cease (Bridger, 1995; McArdle *et al.*, 2001). By exploring the total cardiovascular and respiratory output, one can compare this to individuals abilities and gain a surmised index of the effects of all activities (which may not be attainable through the use of EMG). The measurement of oxygen consumption and other physiological variables is therefore of utmost importance and various methods will aid in reducing the incidence of physical stress experienced in the workplace.

Heart rate and oxygen consumption

There are several methods which are capable of directly measuring the extent to which physical activity has taxed the individual (Meijer *et al.*, 1991). The most applicable indirect method is the use of heart rate recording. Heart rate is however affected by many extraneous factors, which in turn will affect the correlation between heart rate and oxygen consumption, and has been the grounds for much debate (Dempsey, 1998; McArdle *et al.*, 2001). Heart rate is also known to be one of the most erratic physiological variables, yet it is accepted to be a reliable indicator of the amount of cardiac strain on an individual (Kapitaniak, 2001). During any activity the body reacts by increasing oxygen uptake as this is crucial for the metabolism of fats, carbohydrates and proteins. Through the aforementioned process, energy is supplied to the body enabling the optimal functioning of systems in the body required during the activity. The transportation of this oxygen and its subsequent utilisation play an important role in the onset of fatigue and the endurance capabilities of individuals (Astrand and Rodahl, 1986) and this variable is therefore an important factor to consider in any investigation.

Heart rate is affected by many factors such as those found in the natural work environment and human variability with individualised responses to tasks (Scott and Christie, 2004). Heart rate has also been shown to reach limits dependent on the interaction of frequency and load. Various factors such as emotional state, training level, body position, muscle groups exercised, continuous or discontinuous exercise, whether the muscles are acting statically or dynamically, elapsed time after the last meal and environmental temperature fluctuations all affect heart rate (Bales *et al.*, 2001). The utilisation of oxygen consumption is also known to be affected by various factors such as sex, age, morphology, genetic factors and the training level of the individual (Dempsey, 1998). An increase in oxygen consumption in the first few seconds of an activity has also

been shown to be due to cardiac and respiratory responses, and an increased demand from working muscles (Bangsbo, 2000). Bangsbo (2000) further illustrated how this initial phase of an increase in the oxygen consumption reaches a maximum after 45 seconds. All these factors need to be considered when assessing heart rate and oxygen consumption of an individual. These variables therefore reflect the aforementioned and give insight into the effects of the task in question. Their use can however be enhanced through activity which is performed aerobically, involving large muscle groups which are performing continuous intermittent dynamic contractions (Kell and Bhambani, 2003).

The cardiovascular responses to various tasks utilising the upper and lower body are known to vary substantially (Toner *et al.*, 1990). It has been established that a greater circulatory strain is reflected in measures of heart rate and blood pressure during upper body exercise at a given sub-maximal power output and oxygen uptake. This could be due to smaller muscle mass, a larger static exercise component, smaller venous return due to less muscle pump activity and an increased neural drive during upper-body exercise (Toner *et al.*, 1990). MacKinnon (1999) and Toner *et al.* (1990) found that upper body exercise elicited a greater increase in heart rate, blood pressure and total peripheral resistance when compared to lower body exercise. This difference is also attributed to the energy which is required to keep the body upright or in a certain posture. When the body is then placed under strain, i.e. during overhead work, there will be a greater increase in responses with regard to the upper body when compared to the lower body as this area is already required to keep the body upright.

Heart rate has also been shown to be 20% higher in arm activity when compared to leg activity and may therefore serves as a valid indicator of the relative strenuousness of physical activity. This is due to the smaller recruitment of musculature during arm exercise (Collins *et al.*, 1991; McArdle *et al.*, 2001; Strath *et al.*, 2001; Strath *et al.*, 2002). The use of heart rate is therefore a

satisfactory predictive power; a low cost method that is quick, easy and effective, making it suitable for many field and epidemiological applications and studies (Ceesay *et al.*, 1989).

Energy expenditure

McArdle *et al.* (2001) identified two important factors which affect the difficulty of a particular physical task, namely intensity and duration. The physical demands of the task dictate the intensity of effort required from a worker and the duration becomes important in the consideration of classifying how strenuous a physical task is. Duration plays a major role *in situ* where the analysed overhead nature of tasks in the automotive industry is performed for 8-hour shifts on a daily basis. Information pertaining to overhead work analysed in this study can therefore provide data on the physiological effects of the tasks in question.

Many classification systems are available for sustained physical activity. As a frame of reference most industrial jobs are classified as requiring more than three times resting energy expenditure (McArdle *et al.*, 2001). Occupational and, as an example, industrial overhead work usually extends longer in duration compared to exercise training, uses a large muscle mass and is performed under varying, stressful environmental conditions and physical constraints (McArdle *et al.*, 2001).

In ergonomic assessment of physically demanding tasks it is necessary to measure the intensity of activity, and the energy expenditure of the workforce required to execute these tasks to ensure that the task does not place undue strain on the individual's physiological systems (Dempsey, 1998; MacKinnon, 1999). The aim of many physiological studies is to devise recommendations based on metabolic and cardiovascular criteria, which are then used as guidelines for manual activities (Ayoub, 1992). The intensity of physical activity and its effect on the human operator is most commonly defined in terms of

percentage of maximal oxygen uptake, percentage of maximal heart rate or as a multiple of resting metabolic rate (the metabolic turnover) (Ekelund *et al*., 2001).

Physiological guidelines have originally been formulated by using cardio-respiratory responses, yet it must be remembered that these limits have been set with an 8-hour shift in mind. There is however a large variation in cardiovascular responses, and the set standards recommend a heart rate of no greater than 99bt.min^{-1} for upper body activities and 112bt.min^{-1} for lower body activities (Snook and Irvine, 1969). Wilson and Corlett (1995) argue that heart rates below 90bt.min^{-1} place a “light” strain on the cardiovascular system. It is further stated that heart rates between 90-110bt.min^{-1} indicate a “moderate” strain and those between 150-170bt.min^{-1} indicate an “extremely heavy” strain on the worker. The upper limit for continuous work has also been a contentious issue, with authors suggesting an upper limit within a range of 110bt.min^{-1} and 130bt.min^{-1} (Åstrand and Rodahl, 1986). The use of energy expenditure (EE) measures provides insight into the strain placed on an individual’s physiological system. In general the total daily EE averages are 2900kcal for men and 2200kcal for women during daily living activities between the ages of 19 to 50 years (McArdle *et al*., 2001). The physiological limit for an 8-hour work shift is 5kcal.min^{-1} for males and 3.5kcal.min^{-1} for females has also been identified (Sanders and McCormick, 1993; McArdle *et al*., 2001). The upper limit of oxygen consumption which can be sustained without undue fatigue has been considered as a criterion for setting these recommendations. This limit is specified as a percentage of the individual’s maximal aerobic capacity (VO_{2max}). McArdle *et al.* (2001) express VO_2 as an absolute measure in terms of litres per minute (l.min^{-1}) and this is more accurately expressed as VO_2 per kilogram of an individual’s mass (VO_2.kg^{-1}.min^{-1}). The physiological limit for 8-hour work shifts at 33% VO_{2max} corresponds to an EE of 5kcal.min^{-1} for males and 3.5kcal.min^{-1} for females (Sanders and McCormick, 1993; McArdle *et al*., 2001). Bridger (1995) supports the aforementioned whereby workloads which elicit 30 to 40% VO_{2max} can be sustained for an 8-hour shift. There is also a large variation in energy expenditure

with participation in varying physical activities. The caloric values mentioned above also represent averages, and these values differ for each individual depending on their skill at the task, the pace of the activity and the individual's physical condition (McArdle *et al*., 2001).

The above recommendations are the most widely utilised criterion for tasks in industry. Most of the guidelines are also set in industrially advanced countries where their appropriateness for their application in industrially developing countries may be questioned (Scott and Christie, 2004). This is due to factors which include an environment, climate, work ethic, cultural background and workforce, which is unique to a particular country such as South Africa.

Table VI: Five-level classification of physical activity based on exercise intensity (adapted from McArdle *et al.*, 2001).

Level	Energy Expenditure			
	Males			
	$kcal.min^{-1}$	$l.min^{-1}$	$ml.kg^{-1}.min^{-1}$	METs
Light	2.0-4.9	0.40-0.99	6.1-15.2	1.6-3.9
Moderate	5.0-7.4	1.00-1.49	15.3-22.9	4.0-5.9
Heavy	7.5-9.9	1.50-1.99	23.0-30.6	6.0-7.9
Very Heavy	10.0-12.4	2.00-2.49	30.7-38.3	8.9-9.9
Unduly Heavy	>12.5	>2.50	>38.4	>10.0
	Females			
Light	1.3-3.4	0.30-0.69	5.4-12.5	1.2-2.7
Moderate	3.5-5.4	0.70-1.09	12.6-19.8	2.8-4.3
Heavy	5.5-7.4	1.10-1.49	19.9-27.1	4.4-5.9
Very Heavy	7.5-9.4	1.50-1.89	27.2-34.4	6.0-7.5
Unduly Heavy	>9.5	>1.90	>34.5	>7.6
$l.min^{-1}$ based on 5 kcal per litre of oxygen; $ml.kg^{-1}.min^{-1}$ based on 65kg man and 55kg woman; one MET equals the average resting oxygen consumption.				

Table VI represents a five-level classification system based on the energy required by men and women performing varying occupational and physical activities. According to McArdle *et al.* (2001), 5kcal equal approximately 1L of oxygen consumed, and this can be converted into litres of oxygen consumed per minute ($l.min^{-1}$) or millimetres of oxygen per kilogram of body mass per minute ($ml.kg^{-1}.min^{-1}$). This can further be expressed as METS, which are defined as being multiples of the resting metabolic rates, with 1 MET being equal to resting oxygen consumption ($250ml.min^{-1}$ for an average man and $200ml.min^{-1}$ for average women). For a more accurate classification one should consider

variations in body size and therefore express the MET in terms of oxygen consumption per unit body mass (McArdle *et al*., 2001).

A system such as the one proposed by McArdle *et al.* (2001) recommends classification of work by the ratio of energy required for the task to the resting energy requirement. They surmised that 'light work' for men elicits an oxygen consumption up to three times the resting requirement, 'heavy work' elicits six to eight times resting metabolism, and 'maximal work' includes any task requiring metabolism to increase nine times or even more above the resting value (McArdle *et al*., 2001). Women tend to have lower aerobic capacities and therefore the average classifications for women are lower, as shown in Table VI. The classification system has been questioned as to what constitutes 'light' and 'heavy' activity, and therefore the above figures are generalisations for a wide range of tasks (McArdle *et al*., 2001).

Respiratory responses during manual work

During physical activity the human body requires an increased supply of oxygen (McArdle *et al.*, 2001) and a faster rate of carbon dioxide removal. This is obtained through respiratory responses including breathing frequency (Rf), and lung volumes and capacities incorporating tidal volume (VT) and minute ventilation (VE). Standards should also adhere to various other physiological criteria including respiratory variables which all may be good indicators of the level of stress on an individual's system due to their work demands. These variables are known to increase rapidly with the onset of physical activity (McArdle *et al.*, 2001). When at rest, a healthy adult is known to have a breathing frequency (Rf) of 12 breaths per minute. A complete breathing cycle of inhalation and expiration requires the movement of approximately 500ml of air into and out of the lungs. The volume of one breath is known as tidal volume (VT), and minute ventilation (VE) refers to the total volume of air inhaled and exhaled during a

minute. Minute ventilation in a healthy adult equates to 6 litres.min^{-1}, calculated from the respiratory rate multiplied by the tidal volume (McArdle *et al.*, 2001).

Table VII: Respiratory responses during physical exertion (adapted from McArdle *et al.*, 2001).

Condition	**Breathing frequency (Rf) (br.min^{-1})**	**Tidal volume (VT) (L)**	**Minute ventilation (VE) (L.min^{-1})**
At rest	12	0.5	6
Moderate physical exertion	30	2.5	75
Vigorous physical exertion	50	3.0	150

When light to moderate work demands are placed on an individual, the ventilatory responses react quickly resulting in an increase in breathing frequency and tidal volume, due to the body's attempt to minimise the oxygen deficit thereby providing the working muscles with the oxygen required for aerobic metabolism (McArdle *et al.*, 2001). The increase in Rf and VT is in varying proportions depending on the intensity of the exertion required. This will ultimately result in an increase in VE. This increase reduces the effects of carbon dioxide production and lactic acid build-up affecting the blood pH. It has also been found that an increase in Rf and VT causes an increase in energy expenditure due to the energy required to move air into the lungs against the resistance of the forces which are produced by the tissues. Other factors which are known to increase energy expenditure and breathing responses are

restrictive working postures and use of the arms during a task, as these further increase the forces in the tissues.

The ventilatory responses of an individual react in a manner which ensures that the oxygen and carbon dioxide levels remain close to aforementioned normative values recorded at rest. When involved in physical exertion which requires light to moderate exertion the ventilatory response increases linearly until such time as a steady state is reached, whereby the demand for oxygen is equivalent to the amount taken in. During vigorous work (Table VII), Rf can increase to 30-50br.min^{-1}, with VT increasing to 3.0L. These increases in Rf and VT cause a subsequent increase in VE as great as 150L.min^{-1}.

Respiration is also known to employ the least amount of muscles to ensure the energy cost remains low; however, when involved in activities which require the use of the upper arm musculature, respiration increases (Cerny and Ucer, 2004). Higher values have also been recorded during upper arm activation when compared to leg muscle usage.

These physiological demands are therefore quantified so they can be used to ensure task demands remain within the physiological limits proposed to protect the labourers (Dempsey, 1998). The same author stated that oxygen consumption and energy expenditure were the most commonly used criteria in setting these tolerable task limits.

Self-report (psychophysical considerations)

The assessment of physical work load, tasks, body discomfort and pain may also take the form of self-report methods. Many methods are available, with arguably the most popular being the Rating of Perceived Exertion Scale (RPE) by Borg (1985) and the Body Discomfort Map and Scale by Corlett and Bishop (1976). The assessment of tasks should include a psychophysical approach as

subjective reactions to physical work have been found to correlate with the intensity and performance of a task (Gamberale, 1985) and discomfort has been found to be useful in independent evaluation criterion, especially of static postures (Dul *et al.*, 1994). It has also been found that subjective measures of fatigue through the use of one-dimensional scales, also give measures of the general perception of fatigue (Ahsberg and Gamberale, 1998).

Wilson and Corlett (1995) commented on the use of subjective forms of task assessment of body discomfort and found that it was the most frequently utilised form of analysis as it is easy to use and it has face validity. The observer does however have to be careful when using these methods as they are subjective ratings which are prone to many external influences, emotions and pain for example, which are difficult to assess (Borg, 1971). This is due to the fact that subjective ratings are difficult to define and measure as they are obtained indirectly through the subject's self report on their perception of the task (Olivier and Scott, 1994). Overall the self-report approach may have a low validity and reliability and should be used in conjunction with other methods of assessment. Use of self-report methods and the need for subjective scoring will always be useful as an additive descriptive form of analysis in any task assessment and they also provide insight into the demands of the task from the perceptions of the workers themselves. This may prove highly important as workers often make a task seem easy to an observer, yet they have had much experience in the task itself, which may mask the 'real' work demands (Wilson and Corlett, 1995).

CONCLUSION

Although the human body is adaptable and capable of performance in a wide range of environments and conditions, for example, when required to perform tasks in an awkward posture or under high biomechanical demands, the musculoskeletal system faces performance limitations (Bjorgvinsson and Wilde, 1996; Jafry and O'Neill, 2000; Gallagher, 2005). This is evident when a worker

has to adopt an unusual or restricted posture, and therefore in recent years there has been an increase in the study of adaptations, limitations and trade-offs associated with working in non-traditional working postures. The reduced performance capabilities of an individual are due to a combination of many factors including biomechanical loads, high physiological costs, reduced strength, decreased stability or balance, limiting the use of substitute motion patterns to relieve fatigued muscles and motivational factors (Gallagher, 2005).

By conducting ergonomic studies related to and within industry, overexertion of the workers can be significantly reduced. This in turn would decrease health problems and injuries while improving worker general well-being, and ultimately increase productivity to the benefit of the company. Basing the study on these premises it may be possible to analyse jobs and tasks to suit the worker. The discipline of ergonomics is very much needed worldwide to ensure worker safety while at the same time improving the quality and quantity of the company's output, and hence it is important to instil sound ergonomic principles within industries.

CHAPTER III

METHODS

INTRODUCTION

The risk assessment conducted within the selected automotive plant highlighted an area incorporating overhead work, which needed ergonomic investigation. Research on overhead work has been varied to date and guidelines have been noted to be limited (Sood *et al.*, 2007). A review of related literature on varying tasks in the automotive industry, which require overhead work, found a need for increased data on the effects of different working heights. A lack of information was especially noted with regard to restricted overhead work tasks and some upright overhead situations.

EXPERIMENTAL DESIGN

As many industries rely on overhead work for the successful completion of a task, it is impractical to recommend that it be wholly eliminated from a work process. This work does however require the adoption of awkward postures which increase the likelihood that workers are exposed to a large amount of physical strain (Mathiassen *et al.*, 2003). Bearing this in mind, it is imperative that information and data be obtained in order to highlight the most appropriate manner in which to complete these tasks, whereby the least amount of strain is placed on an individual. The focus of this project was therefore the identification of the effect of varying working height, during overhead tasks, on the biomechanical, physiological and psychophysical responses of an individual. This approach was taken to gain a holistic understanding and it was expected that changes in working height would elicit biomechanical stress, physiological exertion and body discomfort amongst the subjects coping with the overhead conditions. A holistic conceptual approach such as the one adopted for this study

has been recommended and supported by other authors (Charteris *et al*., 1976; Warren, 2001).

With regard to the use of these methods in this study, although the biomechanical approach was considered as the primary parameter, there is a limited amount of information which has utilised objective measures of physiological variables to determine acceptable standards within a work environment (Bridger, 1995). Added to this, few studies have been conducted measuring the physiological cost of work on assembly lines in the automotive industry specifically (Turner, 1955; Durnin *et al.*, 1961), yet it has been found that workers classify the work as medium to light in terms of physiological cost (Goldsmith *et al.*, 1978). Literature has also suggested physiological responses to assembly tasks are not physiologically taxing (Dimitriadis, 2006). Physiological methods can however be applied in industry and aid in evaluating the physical demands of jobs and therefore it is necessary to take physiological capacities into consideration. The psychophysical responses were also utilised as a supplementary addition to the study to provide insight into the perception of the requirements of overhead work situations.

Due to the numerous problems associated with measuring *in situ*, tasks were conducted in the laboratory for further scrutiny. The study incorporated restricted and upright overhead conditions, which started at 200mm below and up to 400mm above the subject’s stature. The conditions were then chosen in steps of 100mm within this range and the study therefore consisted of seven different conditions (Figure 10). These conditions corresponded to some of the areas which were found to be lacking in the literature and were similar to those situations found *in situ*. This also allowed for a spectrum of heights to be studied and provided data which would prove to be useful to the industry in question. A reference condition was also included, which was utilised as a comparative posture which resembled no similarity to the aforementioned restricted or upright overhead postures. This therefore allowed the reference condition to act as a

‘neutral’ posture with which to compare the conditions which required overhead work in some form. During the reference posture subjects were required to stand upright with the arms at the sides of body and bent at 90 degrees at the elbow (see Figure 10). Each condition that the subject completed was adjusted to their stature, within a range from -200mm below to +400mm above their stature. This eliminated any effect stature would have on the responses. Weight was added as another factor to consider as most tasks in the overhead assembly area require the use of tools. A weight of four kilograms (2×2kg weights) was decided upon as this was found to be the maximum weight of a tool observed in industry and subjects would also be able to complete the condition with this amount of additive weight in the hands. No weight was also considered as factor as many tasks require the movement of the hands alone without the use of tools. This would give insight into the effect weight would have under varying height conditions. The various height conditions in this study were therefore adopted while holding two kilograms of weight in each hand and these conditions were repeated without any weight i.e. holding arms overhead. Subjects were therefore required to perform sixteen conditions in total.

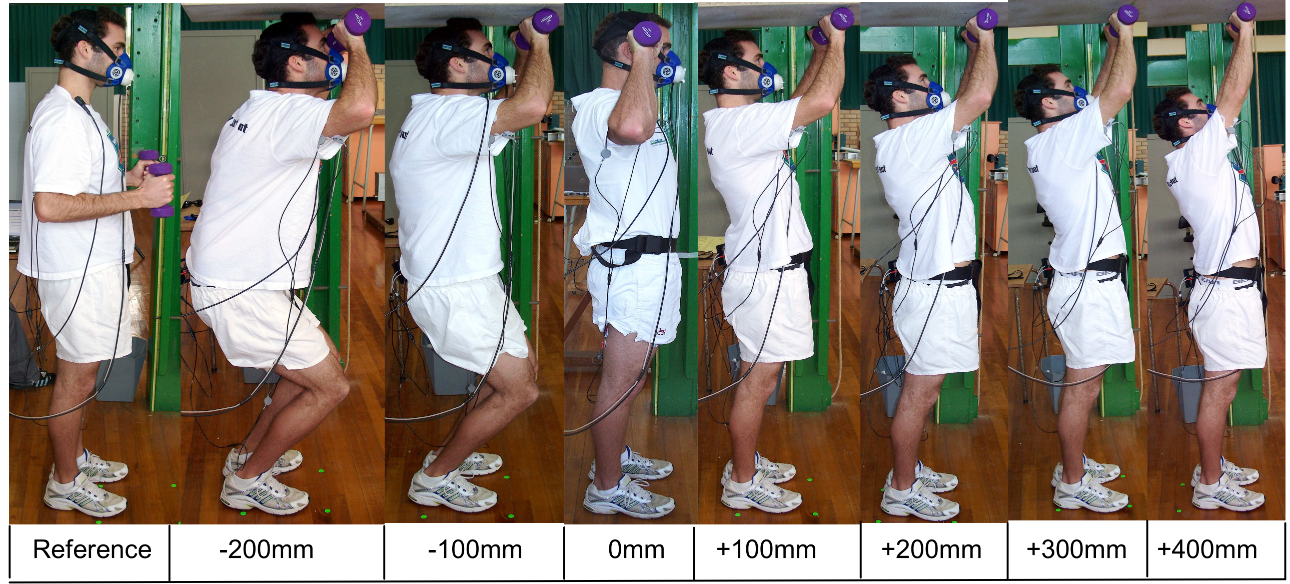


Figure 10: A subject completing the overhead and restricted postures both above and below his stature – only the "with weight" conditions are represented as the same postures were adopted without weight (refer to Table X for the condition details; note that scaling was changed for the different photos).

Assembly tasks require workers to dynamically move their hands and manipulate tools and objects while in an overhead working posture. Although the hands are moving when completing the aforementioned tasks the arms remain static (ranging from a duration of ten seconds to one minute) in order to maintain the correct positioning of the body. Static working postures are also responsible for a high number of MSDs and are known to cause elevated and unfavourable levels of muscle activity (Mathiassen *et al.*, 2003). The conditions adopted in this study were therefore static to gain results on the effect this requirement of the task would have on an individual. Each of the conditions was maintained for one minute as static postures maintained in industry are seldom held for longer periods of time. The duration of one minute was also found to be sufficient in terms of gaining muscle responses and changes in heart rate and other physiological responses. Duration of longer than a minute of activity was impractical in terms of subjects being able to maintain the postures with weight.

Added to this, a longer duration would have increased the likelihood of fatiguing the subjects together with the overall cumulative effect of all the postures. A two-minute rest break was afforded between each condition to allow sufficient recovery time for the subject and to minimise the effect of fatigue. The study aimed at gaining an understanding of which muscles were activated in these conditions and what physiological and psychophysical effects they may have on the body. This provided insight into the amount of strain the work required during the differing height conditions and the presence or lack of weight had on the aforementioned variables.

Electromyography (EMG) was used in this study to detect muscle activation during differing overhead work heights and the additive effect of load. EMG data was only assessed on the right hand side for each subject as the task was symmetrical and it was therefore expected that the same relative effort would be required by both sides of the body throughout the task. Muscles in many of the differing areas of musculature were chosen as this would provide information to what extent these muscles were utilised during these conditions and therefore would indicate those muscles which limited the adoption of these postures. This would provide insight into the 'optimal' condition to adopt and which height condition would elicit the least amount of strain in relation to muscles situated all over the human body. The muscles which were selected for EMG analysis indicated the most recruitment throughout the pilot testing and their use during overhead work was reiterated by Gerdle *et al.* (1988) and Nussbaum (2001). The muscles were also known to be accessible through the use of surface electrodes. A total of eight muscles were analysed, including the biceps brachii muscle, middle deltoid muscle, trapezius muscle, latissimus dorsi muscle, erector spinae muscle (both the upper: thoracic region and lower: lumbar region), quadriceps muscle and the semitendinosus muscle.

The assessment of the worker responses to overhead work tasks included direct methods of assessment looking at physiological variables through the use of an

ergospirometer and heart rate monitor. The biomechanical variable of muscle activity was assessed through the use of electromyography and the psychophysical variable of body discomfort used the Body Discomfort Map and Scale. The physiological variables which were studied included respiratory responses (breathing frequency, tidal volume and minute ventilation), heart rate, oxygen consumption and energy expenditure. These variables were chosen as they are most indicative of the strain placed on an individual during any physical exertion and they have been researched and validated therefore providing guidelines with which to compare results. The choice of body discomfort as a psychophysical measure was due to its ability to aid in quantifying muscular discomfort felt during activity, thereby giving an indication of where a subject perceived discomfort.

SUBJECTS

Subject characteristics

The sample comprised 28 subjects (14 male and 14 female). Both males and females were included, as workers in the South African automotive industry comprise both sexes and this would therefore be representative of the population. The number of subjects in the sample was chosen as it was divisible by the number of original conditions which were tested (seven conditions; see page 86 for further details). All the subjects were Rhodes University student volunteers who were physically active and healthy, and between the ages of 18 to 28 years. The mass of each individual was obtained and subjects were required to be moderately active and free of health complications or injuries. The sample was restricted, however, to exclude individuals who possessed unusually high upper-body strength, and those who were extreme in terms of their body mass index (BMI) (i.e. >25) and training status. This was identified during the habituation session whereby the subject was questioned and therefore it was possible to gain insight into the level of fitness and type of activity they partook in.

Table VIII: Descriptive statistics of subject characteristics (where SD = standard deviation; CV = coefficient of variation).

VARIABLE	Males			Females		
	MEAN	SD	CV (%)	MEAN	SD	CV (%)
AGE (yr)	20	2	10	22	1	6
STATURE (mm)	1767	45	3	1684	47	3
MASS (kg)	73	10	13	63	9	15
Reference heart rate ($bt.min^{-1}$)	67	9	14	69	8	12
Body Mass Index (BMI) ($kg.m^{-2}$)	23	3	11	23	3	11

The male subjects' mean age was 20 years with a standard deviation of ±2 years. The mean stature found amongst the male subjects was 1767mm (±45mm) and their body mass was 73kg (±10kg). Female descriptive statistics indicated a mean age of 22 years with a standard deviation of ±1 year. Stature was found to be 1684mm (±47mm) and the mean body mass 63kg (±9kg).

EQUIPMENT AND INSTRUMENTATION

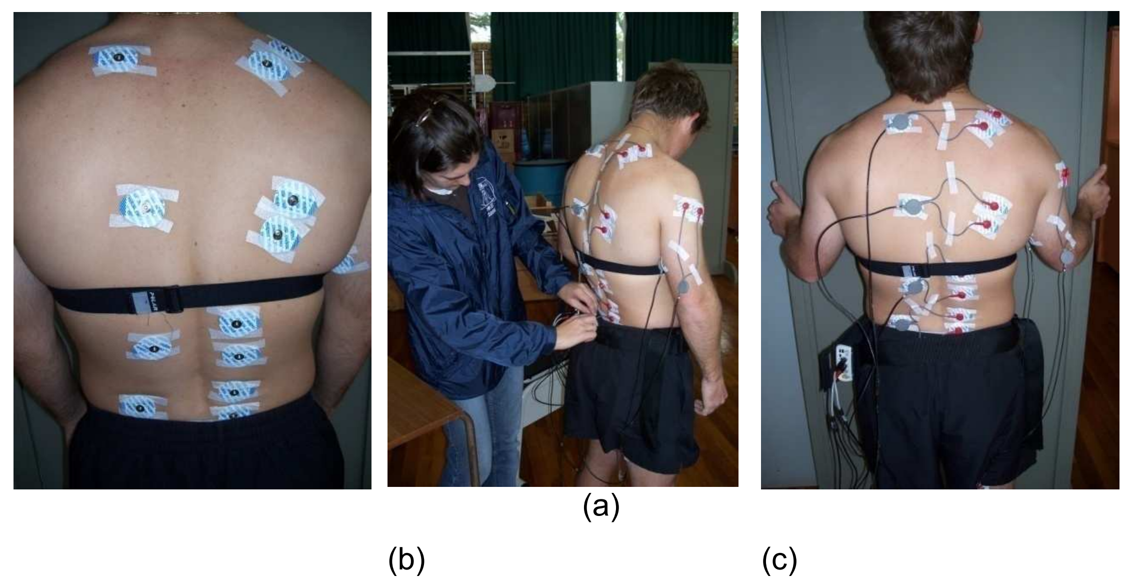
Anthropometric measures

Stature was recorded in millimetres, and was measured in the mid-sagittal plane from the floor to the vertex with a Harpenden Stadiometer. Subjects were instructed to stand erect with their heels against the base and their head against the back of the stadiometer. The subject was also required to look forward in the Frankfurt horizontal plane.

The body mass of each subject was measured in kilograms using an electronic Toledo scale. All subjects were required to remove heavy clothing and objects such as watches, shoes, wallets and jackets before being weighed.

Biomechanical devices

The Muscle Tester “Mega ME6000P16” (Mega Electronics Ltd, Finland) device was utilised in order to gain information pertaining to the electrical activity in various muscles. This was achieved through two cables each of which had four measurement preamplifiers, each of which were attached to two pre-filled silver-silver chloride ECG conductive adhesive surface electrodes (Kendall, Meditrace 200) placed on the skin overlaying the muscle of interest. The electrodes were placed with the predominant fibre direction closer to the motor point and parallel to the muscle fibres above the centre of the belly of the investigated muscle and no further than 50mm apart (Figure 11). The subject was grounded through the placement of a neutral electrode on passive tissue. All the electrodes were placed on the right hand side of the body due to the symmetrical nature of the tasks studied; similar results can be expected for the left hand side. The signals received were directly recorded to a laptop via telemetry, which allowed for the instant availability of the information and provided for ease of various types of processing thereafter. The EMG device runs on a MegaWin© software programme, and the raw data of an EMG response and a data sheet displaying the values is shown in Appendix E. The MegaWin© software also illustrated the location of the placement of the electrodes on the muscle in question.



(a)

(b) (c)

Figure 11: (a) Placement of the electrodes; (b) Attachment of cables to electrodes; (c) Subject with all EMG equipment attached to the upper body.

Physiological devices

A portable Polar® Heart Rate Monitor used for the measurement of heart rate consisted of a heart rate transmitter attached to the chest, which utilised telemetry to send signals to the heart monitor receiver, which had to be held within 1.5 metres of the subject at all times. The connection between the transmitter and the skin of the subject was fundamental for the accurate recording of heart rate, thus the strap had to be positioned carefully in the centre of the subject's chest below the inferior border of the sternum and pectoralis major. Signal transmission was amplified by placing water on the electrodes of the chest strap, thereby increasing the conductive properties of the monitor. The ergospirometer also monitored heart rate throughout the testing, with a heart rate probe attached to the collar of the subject's shirt.

This study also chose to utilise indirect calorimetry as a means for assessing the effects of overhead work. The online metabolic ergospirometer used in this study, the Quark b^2, uses a computer software package to continually analyse an individual's physiological responses during a task. Firstly, this is achieved through the use of a respiratory mask which checks volume flow, followed by a gas analysis which deduces the gas composition of each breath. The subject inhales ambient air with a known composition of 20.93% oxygen, 0.03% carbon dioxide and 79.04% nitrogen. Energy metabolism is then indirectly reflected in the changes in oxygen and carbon dioxide percentages in expired air, which are compared with percentages in inspired ambient air. Two factors are therefore analysed, the volume of air breathed during a specific time period and the composition of exhaled air together provide a way of measuring oxygen consumption, and to infer energy expenditure.

Prior to the testing of any subject the ergospirometer system had to be calibrated. The three stages of calibration included: calibrating to the environmental air within the laboratory, then with known concentrations of gas from a gas cylinder and finally calibration of the volume of air passing through the mask using a three-litre calibration syringe.

The ergospirometer recorded a range of physiological variables, yet for the purposes of this study the variables included breathing frequency, tidal volume, minute ventilation, heart rate, oxygen consumption and energy expenditure. The subject was able to breathe easily and without any restrictions as there was a low resistance bidirectional turbine located in the mouthpiece attached to the mask (Figure 12). The mouthpiece was attached to the mask and the amount of oxygen inhaled and carbon dioxide exhaled were monitored via gas analysers.

The subject was required to keep the mask on at all times throughout the duration of the two protocols. The subject was also asked not to talk, laugh or

cough during experimentation so as not to interfere with the gas volume and composition. Any indication to stop or questions were done via hand signals.

Figure 12: Illustrating the attachment of the face mask to a subject.

Psychophysical measures

The Body Discomfort Map and Scale developed by Corlett and Bishop (1976) allows one to obtain a subjective rating whereby the subject indicates the areas of most discomfort incurred during the specific task, thereby highlighting areas subject to the greatest stresses.

The map consists of an illustrated anterior and posterior view of the human body which is divided into 29 regions (Figure 13). A Likert scale ranging from 1 (very slight discomfort) to 10 (very uncomfortable) is present at the bottom of the diagram reflecting the level of discomfort. The Likert scale assists in quantifying muscular discomfort felt during activity, by having the subjects indicate where they feel the most discomfort on the map and rate the intensity of discomfort indicated using the scale. The subject was asked to indicate these areas at the end of each minute relating to the posture and condition they had just performed.

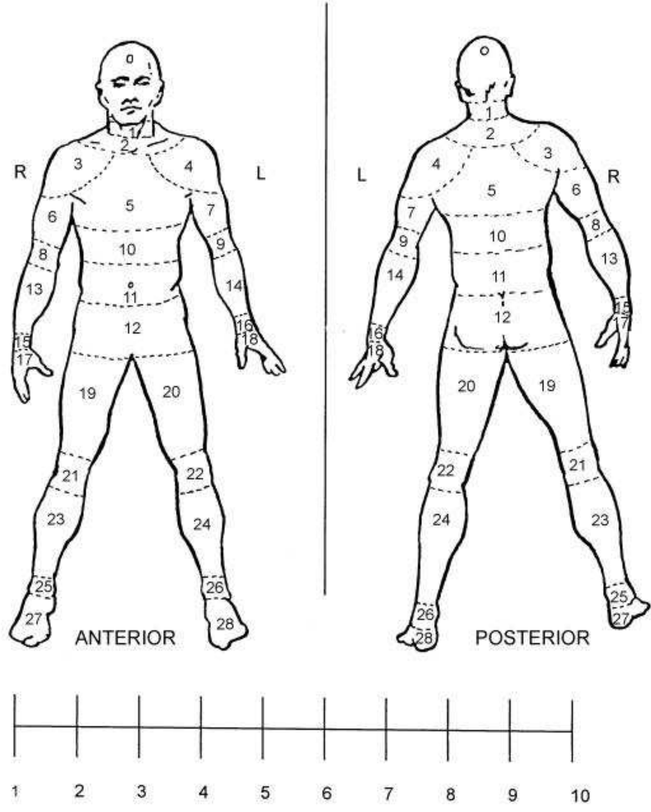


Figure 13: The Body Discomfort Map and Scale (adapted from Corlett and Bishop, 1976).

Body discomfort is a key factor to take into account when assessing the complex human being (Charteris *et al.*, 1976) and is essential in order to obtain a holistic overview. The information obtained in this study pertained to the awkward nature of the postures adopted and the resultant musculoskeletal strain imposed by these conditions. As reported by Kroemer and Grandjean (1997) the origin of MSDs lies with body discomfort and ratings will therefore assist with the determination of the risk of MSDs as a result of the conditions. The findings also aided in gathering information on the different conditions in the study.

PILOT TESTING

The aim of pilot testing was to assess the validity of the chosen overhead protocols, and to determine the reliability of the equipment to be used. Conducting preliminary tests on subjects allowed the researcher to become acquainted with the procedures involved, and to develop a suitable test sequence, which in turn enabled the tester to assess the applicability of the overhead work protocol for the prediction of musculoskeletal risk.

Two male and two female subjects were tested in the pilot study, following the methods described in the experimental design and procedure. The duration of the protocol was adjusted and monitored during the pilot testing. The weight held by the individuals was also altered during the pilot testing with weights of two to six kilograms being tested initially. A weight of four kilograms (2×2kg) was decided upon as this was found to be the maximum observed weight of a tool in industry.

Varying schedules were tested with reference to the evaluation of the ergospirometer and EMG data including intervals which assessed the last 15 seconds, 30 seconds and 45 seconds of each working minute. It was found that evaluating after 30 seconds, i.e. the remaining 30 seconds of the protocol, eliminated inconsistent measurements produced by the subject while adopting and becoming accustomed to the appropriate posture required in the beginning of each condition.

EXPERIMENTAL PROCEDURE

Subjects were recruited from the Rhodes University campus on a voluntary basis. They were assigned to a habituation session which lasted for 20 minutes with a maximum of six individuals per group. Subjects were welcomed and thanked for their voluntary participation. The concept of the heart rate monitor

was explained to the group before attaching a strap and wristwatch to each individual. As the researcher explained the protocol, ‘reference’ heart rate measures were obtained from the subjects. Recording of this value was not indicated to the subject as this would increase their anticipatory response. A true resting heart rate was highly unlikely to be attained as the subject would never be at complete rest due to the experimental environment and the anticipation of the testing to follow. As a resting value was unlikely to be obtained, a ‘reference’ heart rate value was recorded and used as a baseline value to compare heart rate responses during the protocol. This value would be lower than that achieved during any activity and effect of the conditions and would therefore be useful in order to make comparisons.

A background to the study and the biomechanical, physiological and psychophysical equipment to be used in the study were then explained ensuring that the subjects had a clear understanding of what was expected of them. Throughout the habituation session individuals were encouraged to ask questions and ask for clarity on any points or situations about which they were unsure. A letter of information (Appendix C) pertaining to the protocol was then handed to each subject to read what was required of them. Once subjects were fully informed and content with the procedures and requirements of the study they were required to sign a letter of informed consent (Appendix C) for ethical reasons.

During the habituation session various anthropometric data were also obtained including the subject’s stature and mass. This enabled the researcher to determine the individual’s body mass index in order to exclude extreme outliers. The age of the sample was also obtained so as to avoid any ages beyond the pre-assigned selection criteria. Age is known to affect physiological responses and this was therefore screened for. Additionally, all conditions were individualised to the subject’s stature.

An opportunity was then afforded to the participants to practise the conditions of the study. If no further queries had arisen, subjects identified a suitable date for testing. Before the end of the session subjects were asked to comply with a few restrictions, including not to consume alcohol, participate in strenuous exercise, or take any medication unless absolutely necessary 24 hours prior to testing. They were required to inform the tester if they had done so and lastly to get a good night's rest before the test. On the day of testing subjects were required to eat sufficient meals throughout the day and not deviate from their normal behavior.

For the testing session subjects were required to come to the Ergonomics laboratory in the Human Kinetics and Ergonomics Department at Rhodes University. The preparation for each test was standardised and involved setting up the testing area according to a specific layout decided upon by the researcher, and following pre-established procedures for equipment calibration. The area for testing required the removal of any unnecessary equipment, the preparation of the varying heights according to the subject's stature and the placement of equipment in allotted areas in the laboratory. Although the habituation session included six subjects, the testing session was conducted on one subject at a time. Upon arrival of the subject, the researcher attached the heart rate monitor and the subject was again familiarised with the test, which involved the subject adopting some of the conditions and a demonstration of the protocol. The researcher then oriented the participant in terms of exact procedures, including descriptions of the perceptual rating scales and other equipment used, and reassured the subject in order to minimise possible anticipatory responses. It was emphasised that subjects were not under any obligation to participate in the test and they could terminate the session at any time.

The electromyography unit (see details of unit within equipment and instrumentation section) was attached to the subject; the areas where the

muscles to be tested were located were cleaned with alcohol and where required, excess hair was shaved off to ensure electrodes remained in place. Three surface electrodes per muscle were attached (two placed over the active muscle area and one placed over an inactive area as a neutral electrode), and the cables were then attached to each electrode. The cables led to the EMG unit which was placed in a pouch and attached via a ‘belt’ around the subject’s waist. The cables were then taped to the subject to limit the amount of interference with movement which they may have caused. The electromyography unit was then turned on and the signal was detected by a laptop receiving the information via telemetry.

Maximum voluntary contractions (MVCs) for each muscle were then performed in order to obtain the maximum possible activation represented in an EMG. The MVCs were utilised as a normalisation protocol and were interpreted as the maximum value that a subject could voluntarily generate during an isometric contraction. This method of comparing an individual’s recorded signal with their MVC, thereby expressing the EMG signal as a percentage of the maximum has been supported by various authors (Goebel, 2005). The validity of MVCs is however questioned due to their moderate reliability (~0.8μV), but no other options are available. This research also does not affect the relationship between measures as it is used as a general multiple for each subject. Subjects were required to perform two successive MVCs for each muscle, with each lasting five seconds, with a minimum of 30 seconds rest between trials. The EMG data was then calibrated using the MVC dataset with an evaluated MVC duration of four seconds and the largest MVC for each muscle was determined by the programming and defined to be maximum. The MVC data was analysed over a period of four seconds and not the total duration of five seconds so as to eliminate any irregularity which may have been found at the start or end of the contraction due to the subject’s behaviour. The testing involved the placement of the subject in a position that offered the best fixation of the body as a whole (usually supine or prone) and each muscle required subjects to adopt different

body positions and limb movements which are shown in Table IX. These images were shown to each subject and the action was described in detail. The limb/body area proximal to the area being tested was then stabilised as this was necessary for specificity in testing. Pressure was then applied directly opposite the line of contraction of the muscle being tested as the direction of the pressure aided in eliciting the desired muscle action. The pressure was also applied uniformly avoiding any localised pressure which could cause the subject discomfort. The individual produced the MVC against the resistance of the assistant and motivation was given throughout the MVC to elicit the individual's maximal response. If subjects felt any discomfort or pain during the MVC they were instructed to stop immediately and notify the researcher.

Table IX: The positions adopted by the subject and researcher during MVC testing (adapted from Kendall *et al.*, 1993).

Muscle	Subject	Researcher	Image
Biceps brachii	sitting upright, abducts arm slightly, pulls forearm towards ceiling	supports elbow and pulls down on wrist resisting force exerted by subject	
Middle deltoid	sitting upright, abducts arm at 90 degrees to body, pushes upwards towards ceiling	places hand at elbow and resists elbow abduction	
Quadriceps	sitting upright, pushes shin upwards towards ceiling extending knee, leg slightly inwardly rotated	places one hand under thigh and resists knee extension by pushing down at shin	
Semitendinosus	lying on stomach, lifts lower leg and pulls it towards the body	holds ankle area and resists force by pushing leg down towards bench	
Upper and lower erector spinae	lying on stomach, hands at ears, lifts trunk and head up as high as possible, extending the back	holds legs down	
Trapezius	lying on stomach, abducts arm at 45 degree angle to body, pushes arm upwards towards ceiling	holds arm at wrist/mid-forearm and resists force of subject pushing upwards	
Latissimus dorsi	lying on stomach, arm parallel to body, slightly hyper extended across and behind the back, lifting arm towards ceiling	supports arm underneath	

The subject was then required to rest for a few minutes until heart rate decreased close to the ‘reference’ value again. The mask of the ergospirometer (see details of unit within equipment and instrumentation section) was placed over the subject’s nose and mouth, and secured with velcro straps and a head cap. The ancillary cords and hoses were fastened in place with Fixomull stretch tape. Two minutes of ‘resting’ data were then obtained while the subject sat in a chair before commencement of the protocol.

The subject was then asked to stand upright within a demarcated area on the floor. A further minute was required whereby the subject’s heart rate could return to ‘reference’, as the anticipation of the task and standing up would have elevated heart rate above the baseline value. The protocol started and the subject adopted one of the sixteen permutated conditions, eight with two by two kilograms of weight and eight without any weight i.e. holding of arms overhead, as shown in Table X. Two dumbbell weights weighing two kilograms each, making up a total of four kilograms, were held by the subject, one in each hand. The subject was required to position their hands below two markers which were placed on the restrictive ceiling. The adjustment of this beam was done by the assistant during the subject’s rest period. Permutation of the sixteen different postures was conducted for each subject allowing varied and equal combinations of the postures to be adopted (Appendix D). Each individual therefore adopted a different order of the postures. The researcher and assistant started the test by simultaneously starting the clock, ergospirometer and EMG unit.

During the experimentation muscle activity was continuously measured using the electromyography unit attached to the subject. Breathing frequency (Rf), tidal volume (VT), minute ventilation (VE), heart rate (HR), energy expenditure (EE), and oxygen consumption (VO_2) were also continuously recorded using the ergospirometer and heart rate monitor.

Table X: Postures adopted during the protocol (see also Figure 10).

Condition number	Height at which posture was restricted		Condition number	Height at which posture was restricted	
1	Reference	NO WEIGHT	**9**	Reference	WITH WEIGHT (2×2kg)
2	- 200mm		**10**	- 200mm	
3	- 100mm		**11**	- 100mm	
4	0mm		**12**	0mm	
5	+ 100mm		**13**	+ 100mm	
6	+200mm		**14**	+200mm	
7	+300mm		**15**	+300mm	
8	+ 400mm		**16**	+ 400mm	

The conditions in Table X required the subject to adopt different postures with or without load under varying height restrictions. These included a reference position to be used as a comparative posture with which to compare all the conditions, as this condition was dissimilar to the test conditions in nature. The reference condition required the subject to adopt an upright standing posture with the arms held at the sides of the body and the elbows bent at 90 degrees of flexion. With reference to the restricted overhead conditions (-200mm and -100mm), subjects were required to adopt a freestyle crouching posture below their stature, due to the restrictive ceiling height, with the arms held above the head as with any overhead work task. The remaining conditions were completed in an upright standing posture with the arms held up either at head height (0mm) or at various heights above the individual's stature up to +400mm.

An error occurred in the acquisition of the data and the initial assessment within the laboratory. Initial assessment was conducted without considering a 0mm

posture (at head height) with which to compare the overhead conditions. A separate protocol therefore had to be re-calibrated and assessed after completion of the initial testing. The measures obtained for the 0mm position were then calibrated against new -100mm and +100mm data, and inserted into the existing dataset. This may explain some of the variation observed in the 0mm position. The number of subjects (n = 28) initially agreed upon for the study was in relation to 14 conditions and not 16, hence the mismatch in the number of conditions and the subject number.

An upper arm strength test was conducted during the second round of testing. The aim of this test was to gain a strength measure of the upper arm and shoulder musculature as they are often activated during overhead tasks. Strength measures were also obtained *in situ* from the automotive plant identified, so as to compare the strength measures of the student population with those of the workers (n=15) in industry who perform overhead work on a daily basis. This would therefore give an indication of the applicability of values, obtained in the study, *in situ*.

Figure 14: Illustrating a subject completing the upper arm strength test.

The subject was required to stand upright on a fixed base where a dynamometer, which measures an individual's strength in kilograms, was attached between the feet (see Figure 14). Handle bars were attached to a length of chain which could easily be adjusted to each individual's height. The subject raised their arms to head height and the test required them to perform one repetition to the maximum of their strength capabilities by pushing upwards for a duration of five seconds. Although this measure is not wholly accurate and does not incorporate all the muscles involved during overhead work, it provided an assessment of the strength capabilities of the student test sample which could be comparatively used to those values obtained from the workers in industry. Standard procedures were employed during testing of both the student and worker samples to ensure that results were equivalent.

ETHICAL CONSIDERATIONS

Due to the use of human subjects in this study, the Rhodes University Ethics Committee was informed about this study. The study was explained both verbally and in written form (refer to Appendix C) to the subjects prior to testing so as to ensure that all details were clarified, as well as being within the capabilities of the individuals. The requirements of the study were demonstrated by the researcher, and participants were given time to familiarise themselves as well. Subjects were informed that they could discontinue the protocol if at any stage they felt excessively strained, or unable to complete the tests. Each participant was also required to sign an informed consent form (refer to Appendix C) outlining the aims and expectations of the procedures, as well as the possible risks and benefits involved.

STATISTICAL PROCEDURES

A quantitative analysis of the EMG signals during the entire experimentation was done via PC. A data reduction tool was developed by the researcher's supervisor which gave the mean EMG amplitude of a specified working period. The mean EMG amplitude was normalised by utilising the standardised maximal reference contractions conducted earlier in the study. The values were therefore presented as a percentage of the maximum voluntary contraction. This EMG normalisation procedure allows for comparison of the intra- as well as inter-individual muscular load levels. Similar methods were utilised when reducing physiological data, whereby mean amplitudes of the variables were obtained through the use of the data reduction tool.

All experimental data was downloaded and analysed using the STATISTICA (Version 7.0) statistical package and basic descriptive statistics were run on all the data obtained, thus providing general information relative to the variables assessed and the sample in question (see Appendix E). An alpha level (level of significance) was set at $p<0.05$ and providing a corresponding confidence level of 95% so as to minimise the chance of making a Type I error (there was still a 5% chance that a Type I error could however occur, therefore rejecting a true hypothesis). The setting of the significance level was maintained throughout the statistical treatment of the results. Any variation within the intervals and different heights can be considered to be normal variability within the chosen 95% confidence level.

Two factorial analyses of covariance were computed for both dependent variables including: (1) the different height levels and (2) the two levels of weight. Further analysis considered gender as a categorical covariate. Statistical tables were processed for each muscle and for each physiological variable, although each had the same basic structure.

CHAPTER IV

RESULTS AND DISCUSSION

INTRODUCTION

Overhead work was studied in a laboratory setting, aiming at highlighting the effect of different heights and varying load on an individual's responses. This was achieved through the assessment of biomechanical, physiological and psychophysical responses of subjects during the study protocol.

ELECTROMYOGRAPHY (EMG) FINDINGS

Statistical findings

Data were processed by a Two-way ANOVA. Factors included in the testing were the effects of height and weight on the biomechanical responses of the individual.

Table XI: Results of the analysis of variance testing the effects of height and weight on the muscles analysed.

Muscles	Height	Weight (2×2kg)	Weight*Height
Biceps brachii	p<0.05 f(6,156)=17.99	p<0.05 f(1,26)=19.96	p<0.05 f(6,156)=3.69
Middle deltoid	p<0.05 f(6,156)=58.66	p<0.05 f(1,26)=34.09	p<0.05 f(6,156)=6.08
Trapezius	p<0.05 f(6,156)=15.70	p<0.05 f(1,26)=71.54	p<0.05 f(6,156)=4.77
Latissimus dorsi	p<0.05 f(5,156)=25.92	p<0.05 f(1.26)=24.71	p<0.05 f(6,156)=5.82
Upper erector spinae	p<0.05 f(6,156)=115.47	p<0.05 f(1,26)=42.59	p<0.05 f(6,156)=15.78
Lower erector spinae	p<0.05 f(6,156)=79.92	p<0.05 f(1,26)=15.52	p<0.05 f(6,156)=7.86
Quadriceps	p<0.05 f(6,156)=64.53	p<0.05 f(1,26)=32.84	p<0.05 f(6,156)=13.49
Semitendinosus	p<0.05 f(6,156)=21.15	p<0.05 f(1,26)=16.98	p=0.34 f(6,156)=1.14

Table XI shows that all of the biomechanical variables were dependent on the change in height ($p<0.05$). The factor of weight elicited significant results ($p<0.05$). Similar findings (except for the semitendinosus muscle) were identified when statistics were computed for the interaction effect of height and weight ("Weight*Height"), thus the effect of weight varies with a change in height.

Statistics were also run on the restrictive (-200mm and -100mm) and upright conditions (0mm, +100mm, +200mm, +300mm and +400mm) to identify whether there was a significant difference within these two categorisations (Table XII and XIII).

Table XII: Results of the analysis of variance testing the effects of height and weight on the muscles analysed and the differences which occurred during the upright overhead conditions (0mm, +100mm, +200mm, +300mm and +400mm) only.

Muscles	Height	Weight (2×2kg)	Weight*Height
Biceps brachii	p<0.05 f(4,104)=23.93	p<0.05 f(1,26)=20.49	p<0.05 f(4,104)=6.39
Middle deltoid	p<0.05 f(4,104)=86.07	p<0.05 f(1,26)=31.04	p<0.05 f(4,104)=9.20
Trapezius	p<0.05 f(4,104)=9.30	p<0.05 f(1,26)=56.23	p=0.96 f(4,104)=0.16
Latissimus dorsi	p<0.05 f(4,104)=9.42	p<0.05 f(1.26)=24.90	p<0.05 f(4,104)=6.88
Upper erector spinae	p=0.28 f(4,104)=1.30	p<0.05 f(1,26)=25.04	p=0.07 f(4,104)=2.28
Lower erector spinae	p=0.06 (f(4,104)=2.32	p=0.16 f(1,26)=2.09	p=0.44 f(4,104)=0.94
Quadriceps	p=0.55 f(4,104)=0.76	p=0.58 f(1,26)=0.31	p=0.25 f(4,104)=1.36
Semitendinosus	p=0.15 f(4,104)=1.73	p<0.05 f(1,26)=12.82	p=0.24 f(4,104)=1.39

Results obtained from the statistics computed in reference to the aforementioned, identified significant differences ($p<0.05$) due to the change in height during the upright overhead conditions (Table XII) for the biceps brachii, middle deltoid, trapezius and latissimus dorsi muscles. The upper and lower erector spinae, quadriceps and

semitendinosus muscles were however not significantly affected by the change in height with no significant effect identified. Weight had a significant effect ($p<0.05$) on all the muscles except the lower erector spinae and quadriceps muscles. Statistics on the interactive effects of height and weight ("Weight*Height") only exposed significant differences ($p<0.05$) for the biceps brachii, middle deltoid and latissimus dorsi muscles.

Table XIII: Results of the analysis of variance testing the effects of height and weight on the muscles analysed and the differences which occurred during the restricted overhead conditions (-200mm and -100mm) only.

Muscles	Height	Weight (2×2kg)	Weight*Height
Biceps brachii	p=0.51 f(1,26)=0.45	p<0.05 f(1,26)=7.53	p=0.42 f(1,26)=0.65
Middle deltoid	p<0.05 f(1,26)=4.86	p<0.05 f(1,26)=10.91	P=0.90 f(1,26)=0.02
Trapezius	p<0.05 f(1,26)=36.01	p<0.05 f(1,26)=96.27	p=0.08 f(1,26)=3.39
Latissimus dorsi	p<0.05 f(1,26)=13.07	p<0.05 f(1.26)=20.51	p=0.66 f(1,26)=0.19
Upper erector spinae	p<0.05 f(1,26)=69.06	p<0.05 f(1,26)=57.89	p=0.05 f(1,26)=4.13
Lower erector spinae	p<0.05 (f(1,26)=55.20	p<0.05 f(1,26)=68.35	p<0.05 f(1,26)=8.82
Quadriceps	p<0.05 f(1,26)=24.97	p<0.05 f(1,26)=33.34	p=0.09 f(1,26)=3.21
Semitendinosus	p<0.05 f(1,26)=6.99	p<0.05 f(1,26)=7.06	p=0.17 f(1,26)=2.04

With regard to the restrictive overhead conditions (Table XIII) significant effects ($p<0.05$) were noted for all the muscles tested with the exception of the biceps brachii muscle. The factor of weight had a significant effect on the muscles ($p<0.05$). The height and weight ("Weight*Height") interactive effect only provided a significant effect ($p<0.05$) for the lower erector spinae muscle.

The muscle activity results were also analysed to identify whether a stable activity level was reached by conducting a related t-test between two analysis periods within the one minute duration of each condition of the study. The analysis periods which were compared were from 30 seconds into the condition to the 45 second mark, and this was

compared to the last 15 seconds, i.e. from 45 seconds to 1 minute. The majority of the muscles and conditions (103 out of 112) did not show a significant difference for both periods of time (refer to Appendix E), with a few (7 out of 112) indicating a decrease in activation of the duration of the condition and two conditions showing an increase. Considering the normal fluctuation of muscular activity, no general trend is to be observed.

Effect of height

Biceps brachii and middle deltoid muscles

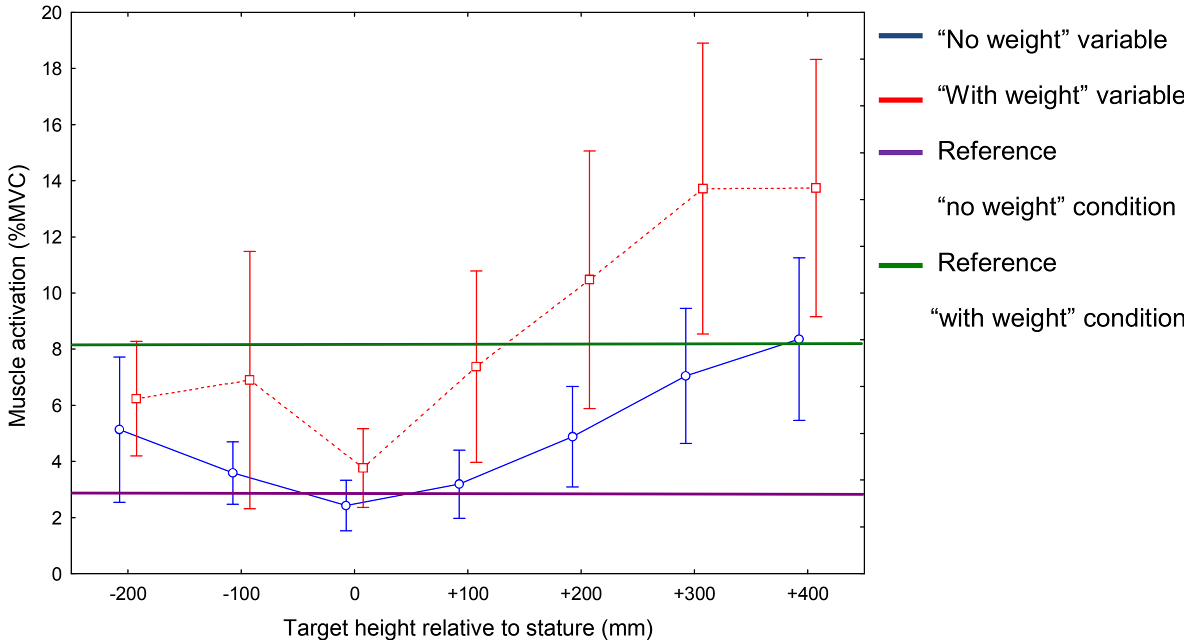


Figure 15: Activation level of the biceps brachii muscle for different target heights and two different weight conditions (no weight and 2×2kg), represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

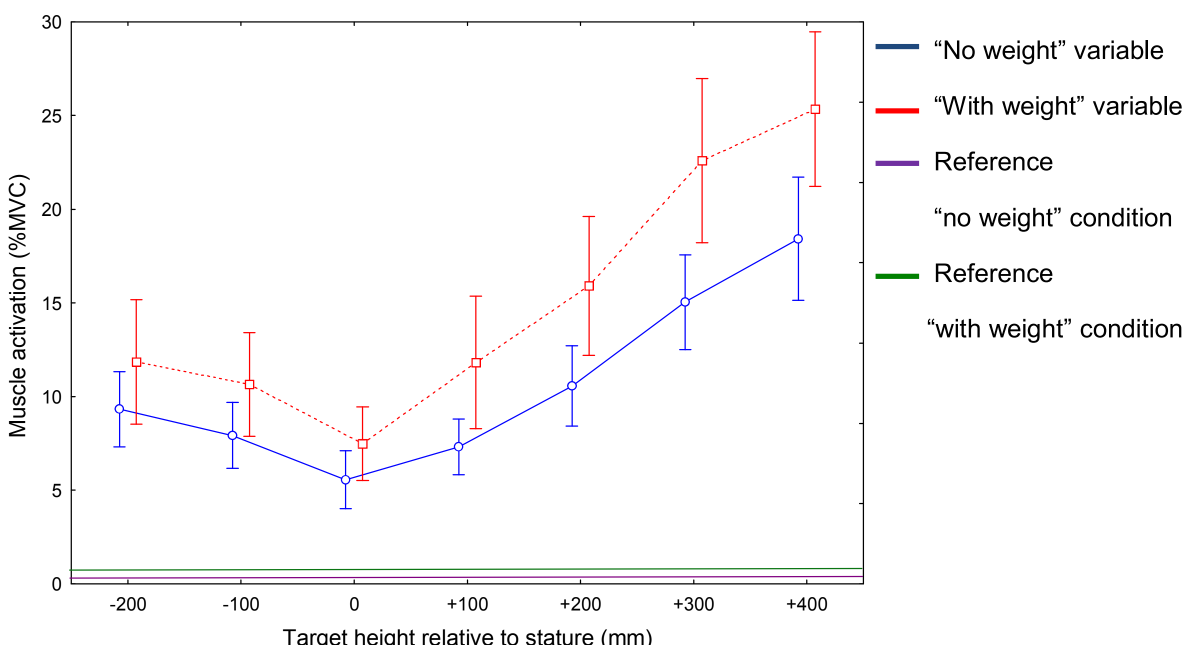


Figure 16: Activation level of the middle deltoid muscle for different target heights and two different weight conditions (no weight and 2×2kg), represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

The biceps brachii and middle deltoid muscles displayed a similar pattern whereby activity was higher when completing the upright overhead tasks compared to the restrictive overhead tasks (Figures 15 and 16 respectively). The activation for both muscles decreased from the -200mm to 0mm conditions and then increased from the 0mm to +400mm conditions above the subjects' stature. When in an upright standing position, muscle usage in the upper arms is affected, especially when static holding is required. Figures 14 and 15 illustrate how the upright conditions cause an increased activation of the biceps brachii and middle deltoid muscles as opposed to the back or lower extremities, as the arms are raised and flexed at the elbow. The biceps brachii and middle deltoid are two of the muscle groups which support the weight of the upper arms during overhead work (De Luca and Forrest, 1973) hence the increase in their use as the height level increased from 0mm to +400mm.

The muscle activation level significantly depends on the working height of all the upright overhead conditions (0mm, +100mm, +200mm, +300mm and +400mm) for the muscles ($p<0.05$). With regard to the restrictive conditions (-200mm and -100mm, see Table XIII), a significant effect was only found for the middle deltoid muscle. This indicated how use of the biceps brachii muscle is not affected when involved in restricted overhead tasks.

The highest activation values were recorded for the +400mm condition, indicating the greatest recruitment of these muscles. The maximal values obtained for the biceps brachii and middle deltoid muscle were 14%MVC and 25%MVC respectively. These values indicated that the biceps brachii muscle was within a reasonable range during testing and not taxed beyond the recommended 15-20%MVC (Rohmert, 1960) when involved in intermittent static muscular work or postures. The middle deltoid muscle however, fell beyond the recommended range and therefore postures of this nature should be avoided. The lowest values of activation were found during the 0mm condition for both muscles with the biceps brachii eliciting 2%MVC (“No weight”) and 4%MVC (“with weight”) and the middle deltoid 6%MVC (“No weight”) and 8%MVC (“with weight”).

Activation levels of the biceps brachii muscle during the -200mm, -100mm, 0mm and +100mm “with weight” conditions were below those obtained for the reference position. The biceps brachii muscle was therefore utilised more actively when the elbows were bent at 90 degrees while standing upright compared to the restrictive and upright overhead conditions up to +100mm. However, as soon as the arms were positioned higher in the +200mm to +400mm conditions, the biceps brachii muscle activation increased.

Trapezius muscle

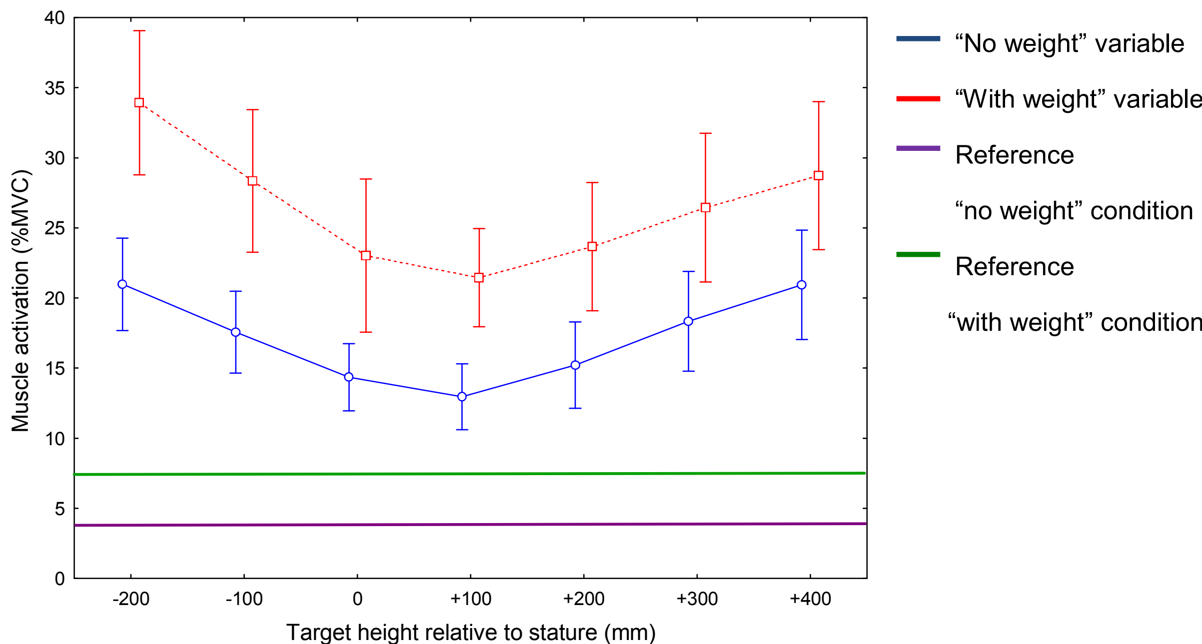


Figure 17: Activation level of the trapezius muscle for different target heights and two different weight conditions (no weight and 2×2kg), represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

The trapezius muscle had a high level of activation when working in the restricted overhead conditions (-200mm and -100mm), activation levels then decreased to the +100mm condition, and slowly increased once again when required to work higher overhead (+200mm to +400mm conditions). This pattern was similar to the one observed for the biceps brachii and middle deltoid muscles, yet a difference was found within the +100mm condition, which elicited the lowest activation level in the trapezius muscle. Significant effects (see Table XI) of working height on the activation of the muscle were found for the upright and for the restricted overhead conditions ($p<0.05$).

Latissimus dorsi muscle

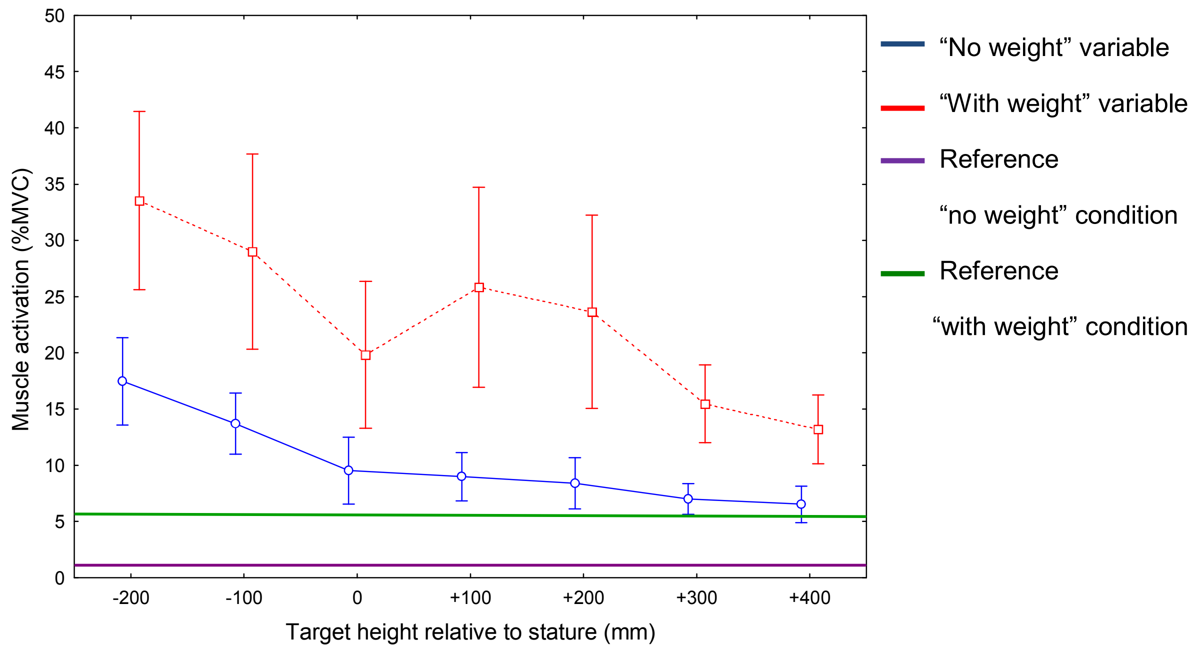


Figure 18: Activation level of the latissimus dorsi muscle for different target heights and two different weight conditions (no weight and 2×2kg), represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

With regard to the latissimus dorsi muscle, the activation levels were more variable, with high %MVC values recorded for the restricted overhead postures. Activation then decreased to 0mm from the restrictive conditions, increased during the +100mm condition and decreased thereafter for the remaining overhead postures during the "with weight" condition. The "no weight" conditions elicited high activation during the restricted overhead postures, decreased to the 0mm condition, and then exhibited a continuous decrease in muscle activation with increased target height. Similar to the trapezius muscle, the conditions overall and in isolation were dependent on the change in height (Table XI).

Upper and lower erector spinae, quadriceps and semitendinosus muscles

Although the conditions required different use of all the muscles tested, there was a similarity in the activation of the upper and lower erector spinae, quadriceps and semitendinosus muscles (see Figures 19 to 22). In general, these muscles showed a high activation level for the restricted overhead postures with the -200mm and -100mm conditions. The muscles then exhibited a decrease to the 0mm condition. Significant effects were however only found between the restricted overhead conditions, with no significant muscle activation level variations due to the working height over the upright overhead conditions (see Table XII and XIII). Therefore, when working in an upright and overhead posture, this does not affect the load on the leg and back muscles. However, once an awkward or a restrictive posture is adopted, the muscle activity increases dramatically.

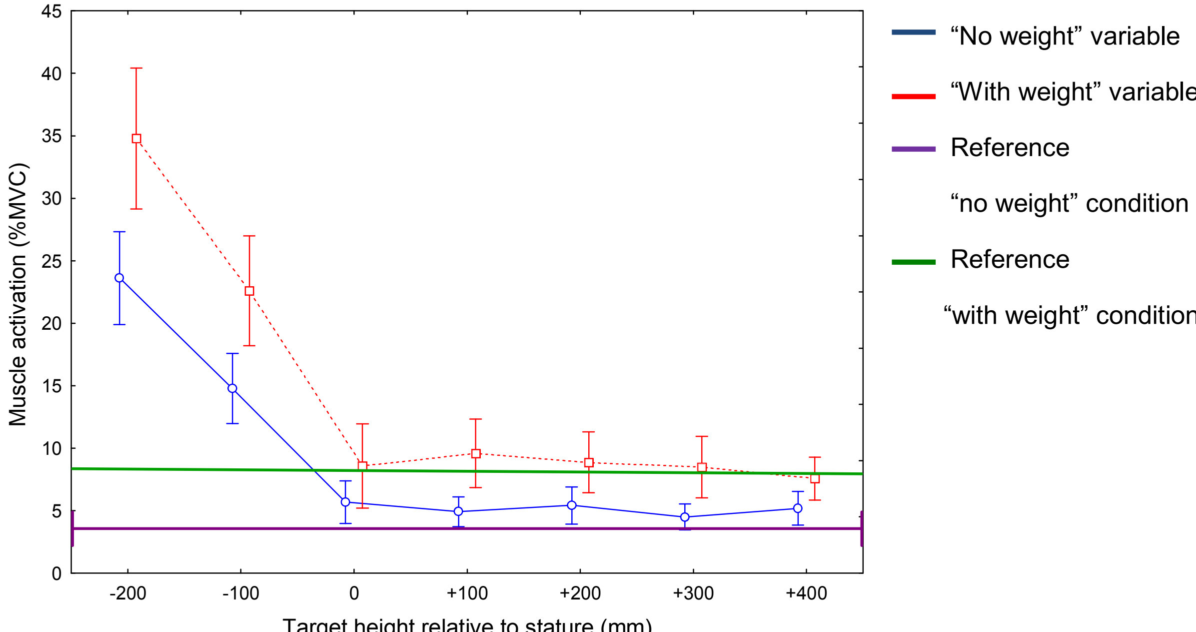


Figure 19: Activation level of the upper erector spinae muscle for different target heights and two different weight conditions (no weight and 2×2kg), represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

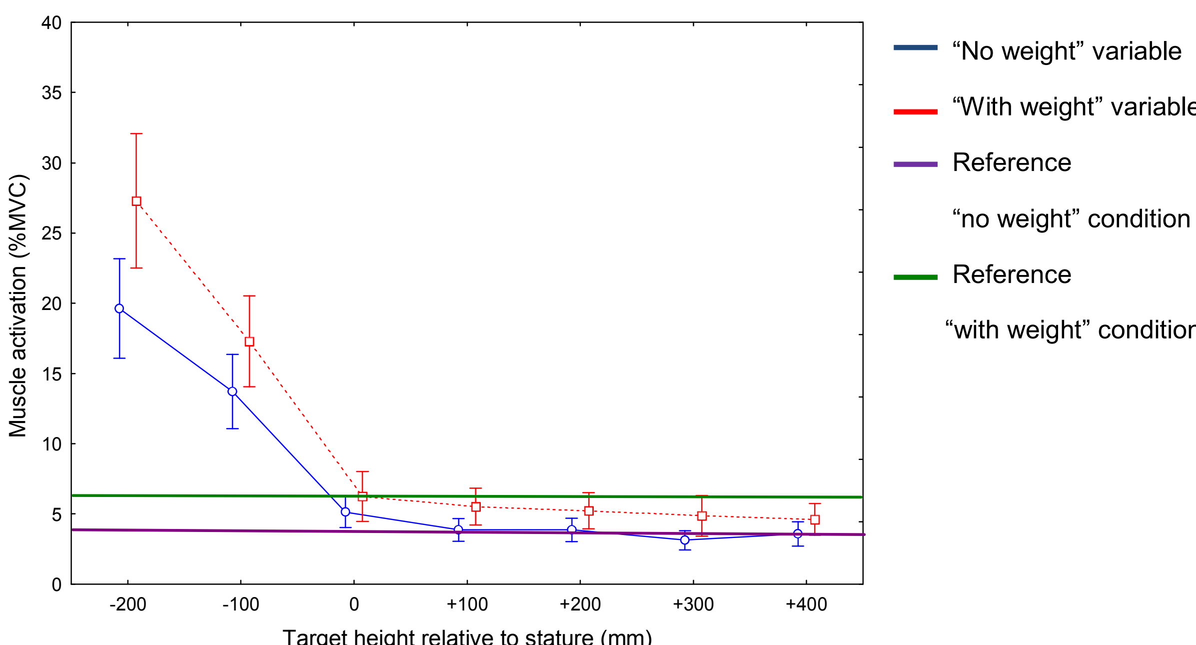


Figure 20: Activation level of the lower erector spinae muscle for different target heights and two different weight conditions (no weight and 2×2kg), represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

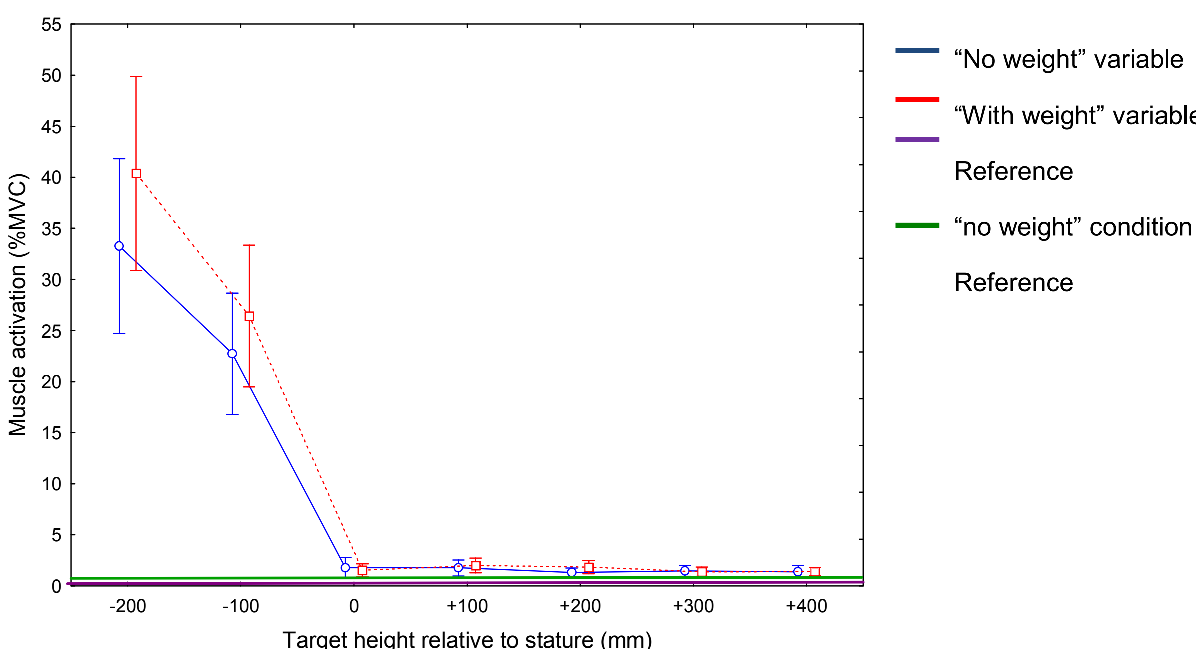


Figure 21: Activation level of the quadriceps muscle for different target heights and two different weight conditions (no weight and 2×2kg), represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

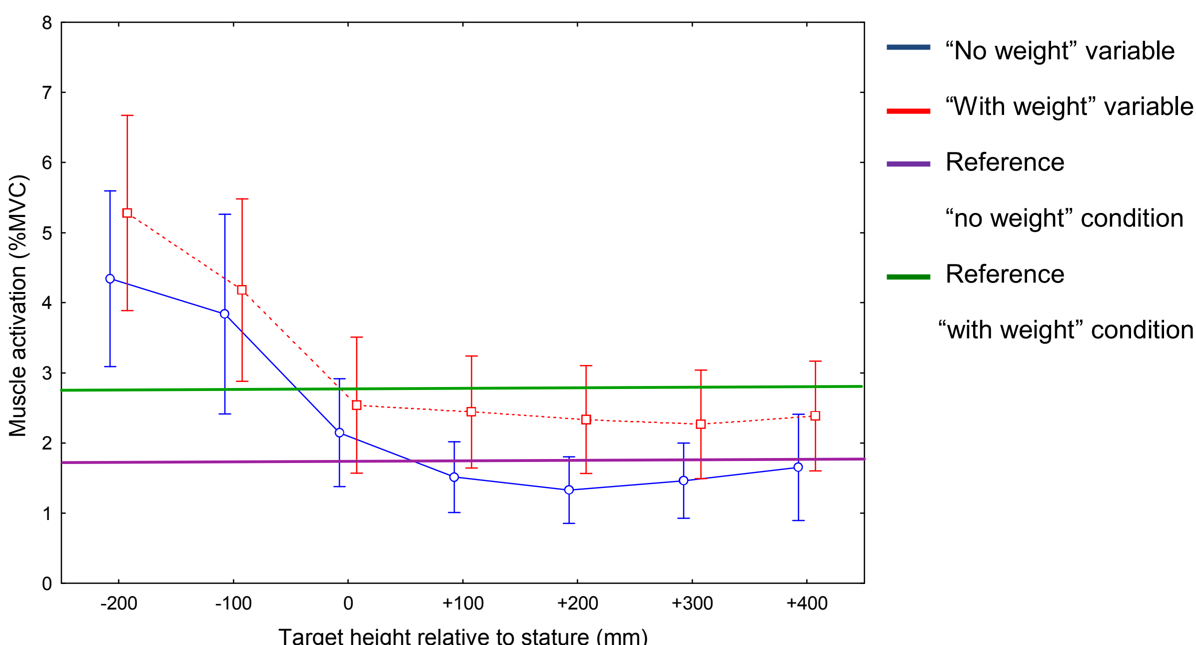


Figure 22: Activation level of the semitendinosus muscle for different target heights and two different weight conditions (no weight and 2×2kg), represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

With regard to the erector spinae muscle in detail, the upper erector spinae (Figure 19) had greater muscle activity during the -200mm and -100mm conditions, which indicated a greater strain during these conditions in comparison to the lower erector spinae muscle. The activation for this muscle group then decreased at the 0mm condition and responses thereafter for the upright overhead conditions slightly decreased. The lower erector spinae (Figure 20) elicited a similar pattern to that observed with the upper erector spinae although the activation levels were lower for most of the conditions. Higher activity was noted in the -200mm and -100mm conditions when compared to the other target heights within this study.

With regard to the lower back in general (upper and lower erector spinae), great internal forces are required to maintain and stabilise body positions causing many risks for this area in particular. The aforementioned increase in the use of the erector spinae during

the restrictive overhead conditions can be explained by the posture adopted whereby subjects were required to bend slightly forward in order to maintain the posture, compared to the upright overhead postures whereby subjects did not adopt a forward bending posture. This is supported by Potvin *et al.* (1991) who found tasks which require forward bending induce lumbar moments, which are then supported by the activation of the erector spinae muscles which try to compensate the demands from this posture (see Figure 10, Chapter III).

The quadriceps (Figure 21) had the largest degree of muscle activation of all muscles tested during the restricted overhead conditions with values reaching a maximum of 40%MVC during the -200mm “with weight” condition. The values then displayed a decrease towards the 0mm condition; thereafter the activation remained low within a range of 1%MVC to 2%MVC over all the remaining upright overhead conditions. The low activation of the quadriceps muscle during the upright overhead conditions could be due to the knee and hip joints being “close-packed”. This refers to a situation where an upright posture requires minimal muscle activation due to the ligaments in the hip and knee which maintain the upright stance; with the hips and knees extended the muscle can relax thereby decreasing activation within the muscle to a minimum (McGinty *et al.*, 2000).

The semitendinosus muscle (Figure 22) followed a similar pattern to the erector spinae and quadriceps muscles; however, the activation level was much lower. The level of activation remained below an average of 5%MVC (-200mm “with weight” condition) and decreased to a minimum of 1%MVC (+200mm “no weight” condition). The range was therefore smaller than any of the other muscles tested, indicating that this muscle group was used to a lesser extent during overhead work tasks. The posture required during the conditions in this study therefore does not elicit activation from this muscle group. Activation was again highest for the restricted overhead conditions and decreased to the 0mm condition. A possible explanation for the activation of these muscles during the restricted conditions could be due to the posture which the subjects adopted. The restricted conditions required a squat stance due to the inhibitory height level of the

conditions. A squat results in simultaneous ankle dorsiflexion, knee flexion and hip flexion with co-contraction of the quadriceps and semitendinosus muscles (McGinty *et al.*, 2000). Findings in a study by Ohkoshi *et al.* (1991) and Palmitier *et al.* (1991) support the aforementioned co-contraction of these muscles when squatting on both legs. The variation within this small range is however negligible and should be tentatively assessed as the muscles were not fully utilised during these conditions and the values could be due to inter-individual differences and not as a consequence of the study conditions themselves.

The results obtained for the quadriceps and semitendinosus muscles in this study are supported by Jerome *et al.* (1997). Their study revealed minimal hamstring activity of 4-12%MVC when compared with activity in the quadriceps muscle of 21-63%MVC, during a squat posture with no load.

Effect of weight

With regard to the effect of weight on these muscles, the activation levels were generally greater for the "with weight" conditions when compared to the "no weight" conditions ($p<0.05$), which illustrated how the weight affected muscle activation.

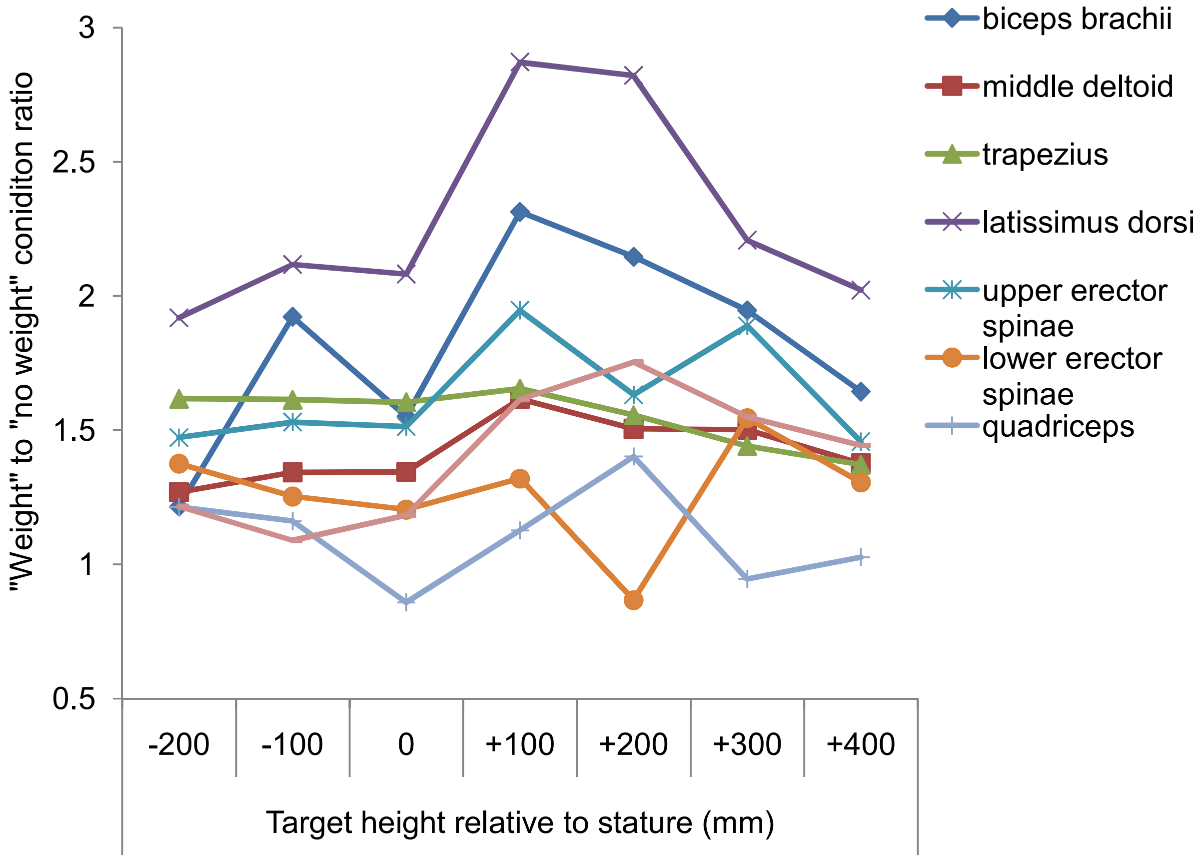


Figure 23: Ratio of muscle activity of the "with weight" (2×2kg) conditions to the "no weight" conditions.

Figure 23 illustrates the relative increase in activation of the muscles due to the two by two kilogram weights compared to the same conditions but without any weight. The ratio is above one for most of the muscles illustrating the added strain caused by the addition of weight. The latissimus dorsi muscle has the greatest increase in activation when weight was an additive factor in the conditions of the study. This supports findings by

Herberts *et al.* (1980) whereby the additive factor of load can be identified by an increase in muscle activity in the shoulder region.

Muscle activation in comparison to the reference conditions

In order to obtain a comprehensive overview of the implications of overhead work when compared to an upright standing posture, Figures 24 and 25 summarise the activation levels of the muscles in relation to the reference conditions. Conditions were analysed in relation to this neutral condition as this would give an indication to what extent they were activated and how much more strained the muscles were. The values illustrated in Figures 24 and 25 were obtained by dividing the muscle activation value attained during each condition, for each muscle, with the associated reference condition. This resulted in a value which indicated the factor by which the value obtained in each condition was different to those of the reference condition. Values close to one therefore indicate that the strain on the muscles is similar to that of the reference position.

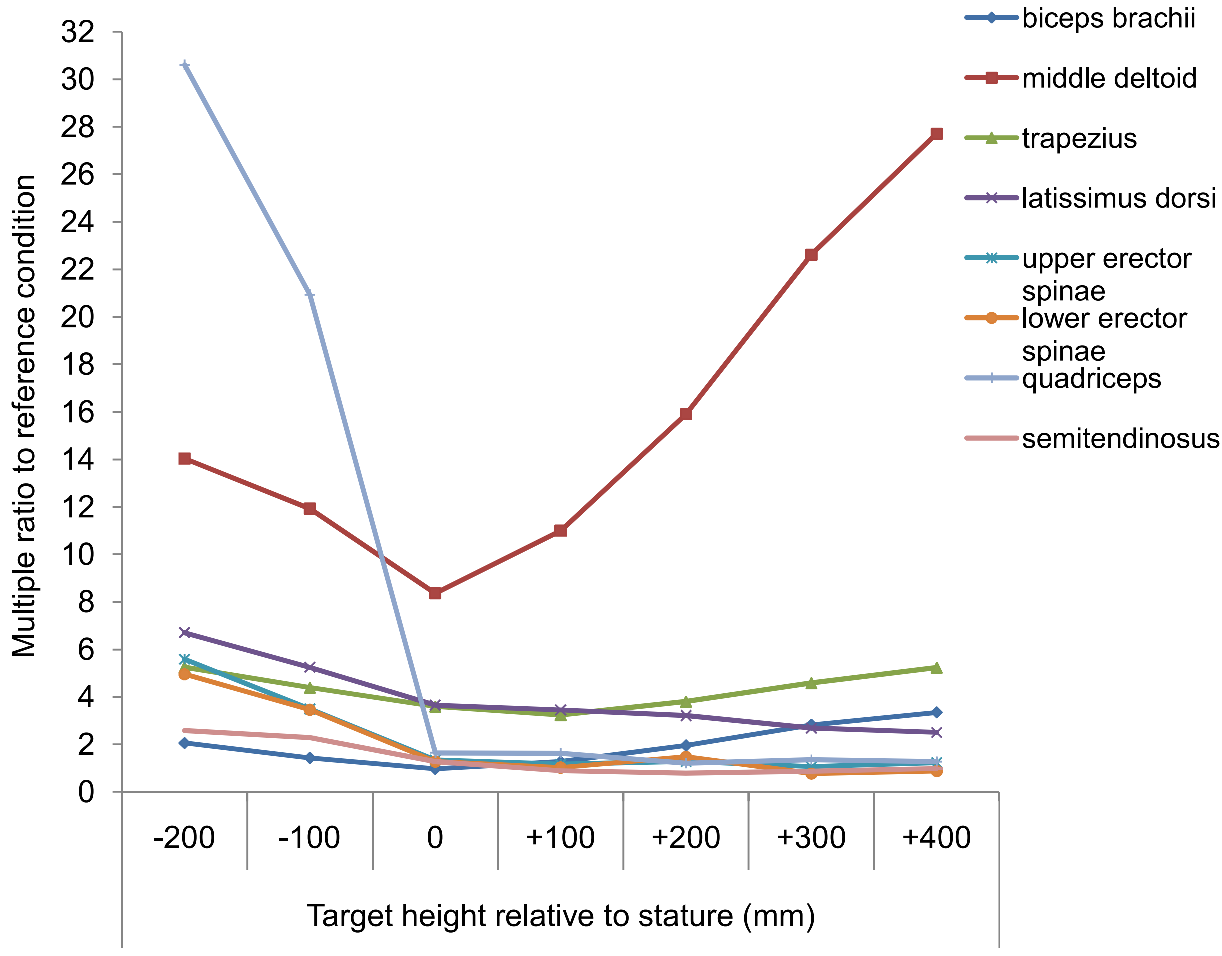


Figure 24: Ratio of muscle activity of the different working heights to the upright reference position (without weight).

The extent to which most of the muscles differed in relation to the reference condition with no weight (Figure 24), indicated that that they fell within a factor of 0.79 (semitendinosus muscle during the +200mm condition) to 6.71 (latissimus dorsi muscle during the -200mm condition). The highest multiple ratio was found with the quadriceps muscle (30.61) during the restrictive overhead condition of -200mm indicating an increased level of strain on this muscle during this target height. The middle deltoid muscle had the highest level of strain throughout all of the “no weight” conditions, indicating that its use during all postures was elevated in comparison to the other muscles tested. The middle deltoid muscle was activated within a factor of 8.36 (0mm condition) to 27.71 (+400mm condition). Overall, this showed how the middle deltoid

had the highest factor relationship to the reference position. The quadriceps were however utilised during the restricted conditions and elicited the highest activation overall, yet this was due to the specific posture adopted in order to allow the condition to be successfully completed.

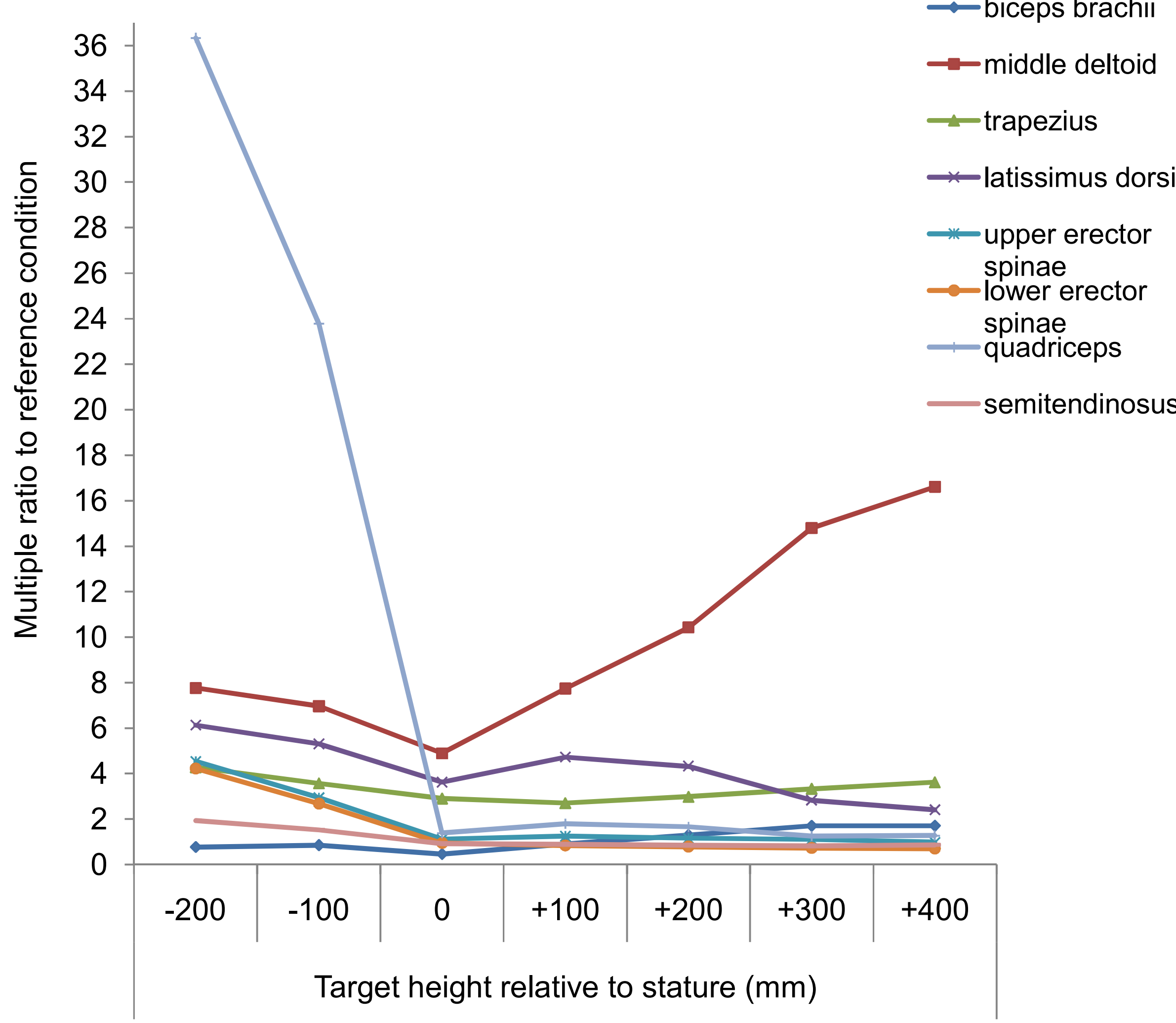


Figure 25: Ratio of muscle activity of the different working heights to the upright reference position (with weight of 2×2kg).

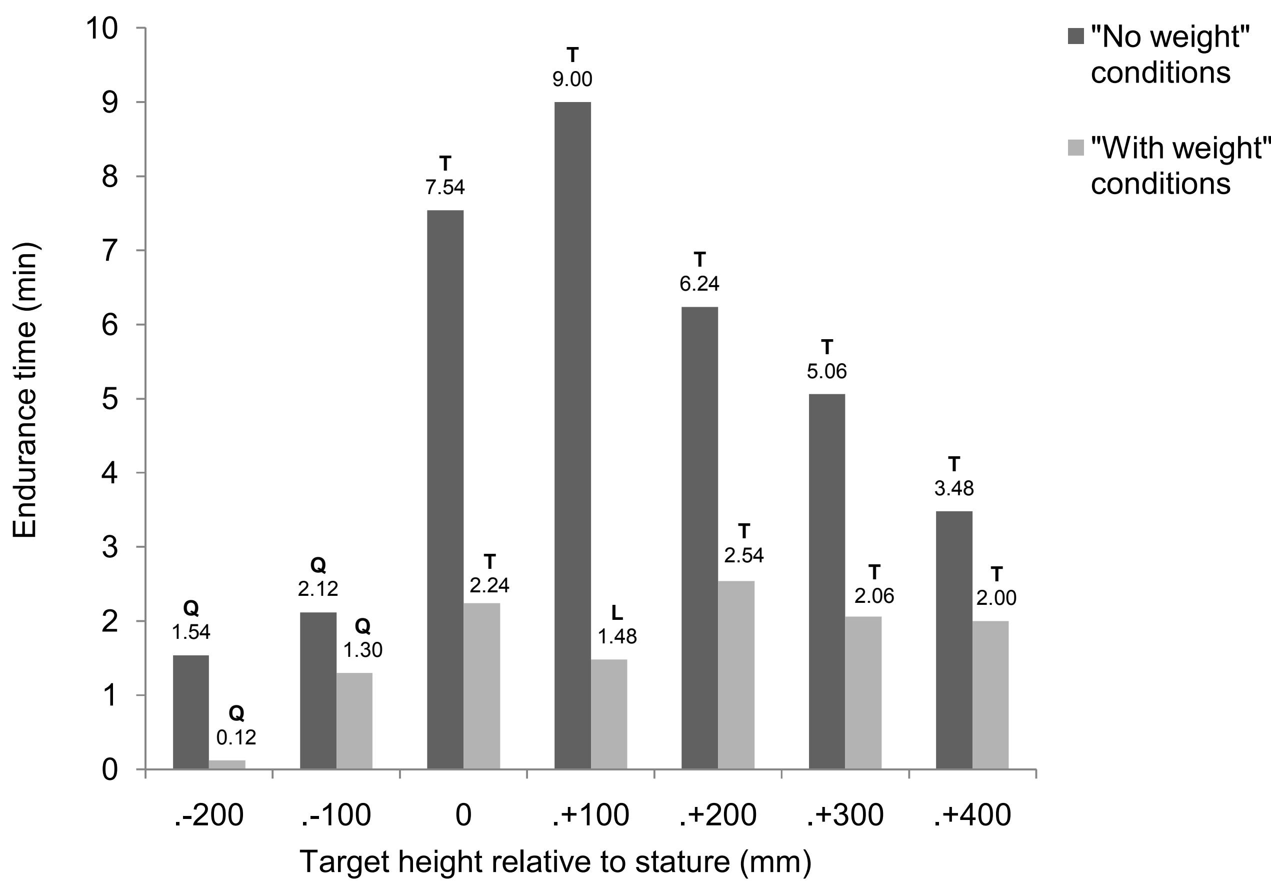
Figure 25 illustrates the muscle activity in relation to the reference posture with the added factor of load, which, for this study, was a weight of two kilograms in each hand. The factor range by which the target heights were greater than the reference condition were found to be 0.47 (biceps brachii muscle during the 0mm condition) to 6.14

(latissimus dorsi muscle during the -200mm condition). Similar results to the “no weight” conditions were again found with regard to the highest activation being the quadriceps muscle group during the restrictive overhead condition of -200mm (a factor of 36.34 greater than the reference position). The middle deltoid muscles reiterate the aforementioned by being identified overall as the highest muscle use ratio throughout all of the “with weight” conditions. The muscle’s use fell within a range of 4.90 (0mm condition) to 16.61 (+400mm condition). The influence of weight does not seem to play a role when the muscle activation is displayed in this format, although higher activation levels were noted for the quadriceps muscle.

In most cases, the muscles exhibited greater activation levels when compared to the reference conditions, thereby indicating the effect of both the restricted and upright overhead conditions on an individual’s muscle responses. This reinforces the idea that any posture compared to the reference position in this study caused an increased muscle strain. The findings also suggest that conditions which require extreme restricted or upright overhead postures should be avoided and work should be completed within a range of 0mm to +100mm.

Estimation of endurance time

Tasks require the adoption of certain postures which may increase the risk of incurring an MSD. The risk may be aggravated further by the duration with which these postures need to be maintained. It is important to therefore identify the amount of time which a given posture may be safely maintained as it has also been found that muscles fatigue especially under conditions of static loading even at low workloads (Kroemer, 1970). The static muscle activation values obtained during this study were therefore used to infer the maximum endurance time, utilising the load endurance curve developed by Kroemer (1970) (see Chapter II). Activation levels were taken from the 5th percentile of the subject population, therefore allowing 95% of the population to adopt the postures for the endurance time identified. The values were computed for 80% of the recorded MVC values as only two maximum contractions were performed for a duration of five seconds (see Ch III). By setting an 80%MVC criterion this would consider submaximal contractions produced by the subject due to the limited reliability and the required duration of the MVC.



Where: Q = quadriceps muscle; L = latissimus dorsi muscle; T = trapezius muscle (i.e. these represent the limiting muscles in each condition).

Figure 26: Estimated maximum endurance time for 95% of population for the "no weight" and "with weight" (2×2kg) conditions.

The muscles indicated in Figure 26 were those which attained the highest activation level for each condition thereby highlighting the limiting muscle. These muscles had the highest activation levels and the remaining seven muscles tested would therefore have had activation levels which were lower than the identified limiting muscle. This would suggest that those muscles were not as strained as the muscle which indicated the highest activation level. The endurance time for each condition is therefore based on the muscle which was most activated, and therefore all the other muscles which were tested in this study would be capable of maintaining the posture within the allocated endurance time. This again would accommodate the weakest member of the sample

group. The limiting muscles, as shown in Figure 26, for the “no weight” conditions were the quadriceps for the restricted overhead postures and the trapezius muscle for the upright overhead postures. The “with weight’ conditions varied slightly with the limiting muscle for the -200mm and -100mm condition being the quadriceps, the latissimus dorsi for the +100mm condition, and the trapezius for the remaining 0mm, +200mm, +300mm and +400mm conditions. The aforementioned muscles being identified as limiting were due to the confines of the conditions which required the adoption of the awkward postures; the quadriceps during the restricted conditions and the trapezius and latissimus dorsi muscles during the upright overhead conditions. This is supported by Jerome *et al.* (1997) and McGinty *et al.* (2000) who found an increased activation of these muscles during the similar adoption of such postures and conditions.

Overall, the restricted overhead postures (-200mm and -100mm) had the lowest endurance times and therefore indicate that these postures can be maintained only for very short periods of time. This is supported by Miedema *et al.* (1997) who found that low working heights have the lowest endurance times. The highest endurance time was found with the +100mm condition with no weight, followed by the 0mm “no weight” condition which both had long endurance times. It should be noted that as soon as weight was added, the endurance time for the +100mm condition decreased from 9 minutes to 1 minute and 48 seconds. The limiting muscle without weight was the trapezius; however, as soon as weight was added the latissimus dorsi muscle became the limiting factor. This supports findings in this study whereby weight generally had a greater impact on the latissimus dorsi muscle when compared to all the other muscles tested (see Figure 23). High %MVC values make the extrapolation of endurance time from the Kroemer (1970) curve difficult and therefore allow for a limited amount of accuracy. This is due to the function developed by Kroemer (1970 (see Chapter II).

When looking at the “no weight’ conditions there is a large variation in the endurance times when looking at the upright overhead conditions (+100mm, +200mm, +300mm and +400mm), which is supported by Miedema *et al.* (1997). These authors also found shoulder postures were important to consider when assessing endurance time as an

increase in shoulder flexion angles up to 120^0 caused a decrease in endurance time. This was evident with the upright overhead conditions of +100mm, +200mm, +300mm and +400mm, whereby the +100mm condition had the highest endurance time and thereafter it decreased to the +400mm condition which had the lowest endurance time. This finding is further explained by van Dieen and Vrielink (1994) who state that variables such as certain postures can result in a lower endurance time at the same relative load, if the posture impedes blood circulation within the musculature, as those tasks found in overhead work.

According to Miedema *et al.* (1997) postures which enable an endurance time of longer than 10minutes are categorised as "comfortable". None of the conditions in this study had endurance times greater than 9minutes and therefore none would be categorised as "comfortable". The same authors categorise "moderate" postures allowing an endurance time of 5-10 minutes. This would include the 0mm, +100mm, +200mm, and +300mm "no weight" conditions. The last category refers to uncomfortable postures with an endurance time of 5 minutes or less. The conditions which would be included in this category are the restricted overhead "no weight" conditions (-200mm and -100mm) and all of the "with weight" conditions. The effect of the additional factor of weight in these tasks is again exposed and indicates how none of these postures should be maintained for any length of time.

It is therefore favourable to complete overhead tasks with a minimal amount of load in the hands as results show how the addition of two by two kilograms of weight causes a dramatic decrease in the endurance time. According to the endurance times the 0mm and +100mm postures are best to adopt if overhead work cannot be eliminated completely.

Comparison of subject population with industrial workforce

The tests conducted within the framework of this study were carried out on students and it is therefore questionable whether the results are applicable to industrial workers as well. A comparative strength test was therefore performed on the student sample and a group of industrial workers in the automotive plant utilised for this study (see Chapter III). All individuals were required to perform one repetition to the maximum of their abilities by pushing upwards, against the dynamometer, utilising their upper arm musculature. The length of the chain was adjusted to each individual’s stature to allow similar body postures for all those tested (see Figure 11). The weight of the chain and handlebars attached to the strength dynamometer were also taken into account to allow a more precise force measure. By comparing the strength measures of the student population with those of the workers in industry who perform this work on a daily basis, an indication of the applicability of the study *in situ* could be determined. This would therefore allow for the most relevant and correct estimation of endurance time for industrial workers to be applied.

Table XIV: Comparative strength measures obtained from the student sample and from employees within the automotive industry (in brackets: standard deviation; CV = coefficient of variation).

	Student sample	Automotive industry employees
Males	393.97 (±63.32)N CV=16.07% n=14	381.87(±82.53)N CV=21.61% n=12
Females	218.92 (±36.06)N CV=16.47% n=14	190.63 (±20.44)N CV=10.72% n=3

Due to constraints within the industry, strength assessment could only be made during one work shift and the sample was not comprised of even or large numbers of males and females comparatively to those of the student sample (see Table XIV). The results were therefore only statistically analysed for the male group as a statistical comparison could not be made with so few female automotive employees.

A related t-test was conducted on the male strength measures which indicated no significant difference between the student sample and the industrial employees ($p=0.68$). Mean values for the student sample and the industrial workforce were 393.97N and 381.87N respectively, thus the numerical difference was 3%. This indicates the findings in this study are applicable *in situ* within overhead work tasks found on assembly lines for males specifically.

ERGOSPIROMETER FINDINGS

Statistical findings

Table XV shows that all of the physiological variables were dependent on the height during the conditions in this study (“Height”, $p<0.05$). The factor of weight (“Weight”) elicited significant results ($p<0.05$) for all physiological variables except tidal volume. Similar significant findings were found when statistics were computed for the interactive effect of height and weight (“Weight*Height”).

Table XV: Results of the analysis of variance testing the effects of height and weight on the physiological variables tested.

Physiological variables	Height	Weight (2×2kg)	Weight*Height
Breathing frequency (Rf)	$p<0.05$ $f(6,156)=6.12$	$p<0.05$ $f(1,26)=15.31$	$p<0.05$ $f(6,156)=3.88$
Tidal volume (VT)	$p<0.05$ $f(6,156)=33.58$	$p=0.47$ $f(1,26)=0.55$	$p=0.58$ $f(6,156)=0.79$
Minute ventilation (VE)	$p<0.05$ $f(6,156)=75.06$	$p<0.05$ $f(1,26)=42.12$	$p<0.05$ $f(6,156)=3.50$
Heart rate (HR)	$p<0.05$ $f(6,156)=131.60$	$p<0.05$ $f(1,26)=63.16$	$p<0.05$ $f(6,156)=3.14$
Oxygen consumption (VO_2)	$p<0.05$ $f(6,156)=167.47$	$p<0.05$ $f(1,26)=49.25$	$p<0.05$ $f(6,156)=2.71$
Energy expenditure (EE)	$p<0.05$ $f(6,156)=155.05$	$p<0.05$ $f(1,26)=50.38$	$p<0.05$ $f(6,156)=2.72$

Table XVI: Results of the analysis of variance testing the effects of height and weight on the physiological variables tested for the upright overhead conditions (0mm, +100mm, +200mm, +300mm and +400mm) only.

Physiological variables	**Height**	**Weight (2×2kg)**	**Weight*Height**
Breathing frequency (Rf)	$p<0.05$ $f(4,104)=2.51$	$p<0.05$ $f(1,26)=8.41$	$p<0.05$ $f(4,104)=3.29$
Tidal volume (VT)	$p=0.17$ $f(4,104)=1.65$	$p=0.43$ $f(1,26)=0.65$	$p=0.57$ $f(4,104)=0.74$
Minute ventilation (VE)	$p=0.18$ $f(4,104)=1.61$	$p<0.05$ $f(1,26)=21.37$	$p<0.05$ $f(4,104)=3.30$
Heart rate (HR)	$p=0.55$ $f(4,104)=0.76$	$p<0.05$ $f(1,26)=35.40$	$p<0.05$ $(f(4,104)=3.96$
Oxygen consumption (VO_2)	$p=0.09$ $f(4,104)=167.47$	$p<0.05$ $f(1,26)=22.39$	$p<0.05$ $f(4,104)=3.25$
Energy expenditure (EE)	$p=0.08$ $f(4,104)=2.18$	$p<0.05$ $f(1,26)=24.28$	$p<0.05$ $f(4,104)=3.23$

With regard to the statistics run on the upright conditions (0mm, +100mm, +200mm, +300mm and +400mm; Table XVI), results identified that only breathing frequency was dependent on the change in height during the upright overhead conditions ($p<0.05$). The remaining physiological variables were however not significantly affected by height. Weight had a significant effect ($p<0.05$) on all the physiological variables except tidal volume. Similarly, statistics conducted on the interactive effects of height and weight ("Weight*Height") exposed significant differences ($p<0.05$) for all the variables apart from tidal volume. There is therefore no general effect of height (except for breathing frequency), yet there is a weight dependent effect of height (Weight*Height). This infers that different reactions for the two different weights occur.

Table XVII: Results of the analysis of variance testing the effects of height and weight on the physiological variables tested for the restricted overhead conditions (-200mm and -100mm) only.

Physiological variables	Height	Weight (2×2kg)	Weight*Height
Breathing frequency (Rf)	$p<0.05$ $f(1,26)=10.40$	$p<0.05$ $f(1,26)=9.87$	$p<0.05$ $f(1,26)=14.88$
Tidal volume (VT)	$p<0.05$ $f(1,26)=12.58$	$p=0.62$ $f(1,26)=0.25$	$p=0.18$ $f(1,26)=1.91$
Minute ventilation (VE)	$p<0.05$ $f(1,26)=58.44$	$p<0.05$ $f(1,26)=39.17$	$p<0.05$ $f(1,26)=4.83$
Heart rate (HR)	$p<0.05$ $f(1,26)=60.36$	$p<0.05$ $f(1,26)=65.00$	$p=0.90$ $f(1,26)=0.02$
Oxygen consumption (VO_2)	$p<0.05$ $f(1,26)=54.18$	$p<0.05$ $f(1,26)=39.66$	$p=0.74$ $f(1,26)=0.11$
Energy expenditure (EE)	$p<0.05$ $f(1,26)=55.56$	$p<0.05$ $f(1,26)=41.32$	$p=0.66$ $f(1,26)=0.20$

With regard to the restrictive overhead conditions (Table XVII) significant differences ($p<0.05$) were noted for all the physiological variables tested. Overall, the factor of weight had a significant effect on the variables (except tidal volume). The height and weight ("Weight*Height") interactive effect only provided a significant effect ($p<0.05$) for the breathing frequency and minute ventilation responses.

The physiological variables were also analysed to identify whether steady state was reached by conducting a related t-test between two analysis periods within the duration of each condition of the study. The analysis periods were the same as those for the muscle activity results, i.e. two 15second analysis periods after the 30 second mark of data collection. The majority of the physiological responses reached steady state (64 out of 84 over all physiological variables and study conditions; refer to Appendix E), with a few indicating a decrease and some conditions showing an increase. It should be noted that heart rate was found to be the most erratic, either increasing or decreasing during the last 30 seconds of each condition. This was however found not to be critical as the conditions were categorised as being 'light' to 'moderate', and in order for heart rate to have reached steady state, the duration of the protocol should have been longer.

The duration of the conditions was however reduced to avoid muscle fatigue and therefore the heart rate responses in this study could be underestimated.

Effect of height

Respiratory responses

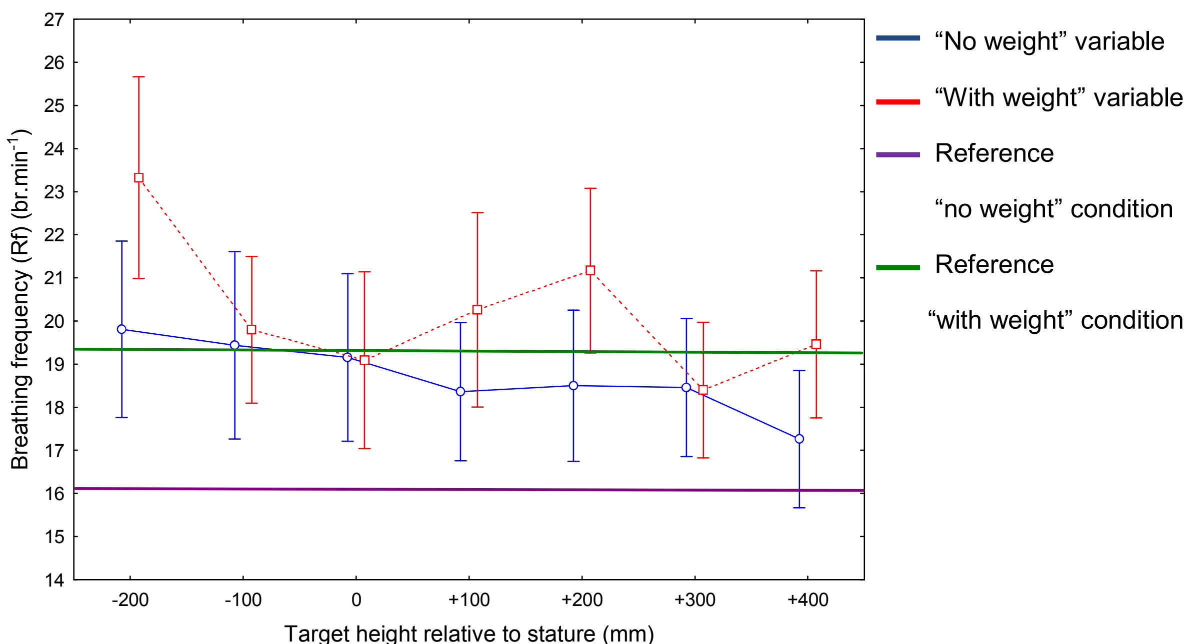


Figure 27: Breathing frequency responses (br.min^{-1}) for different target heights and two different weight conditions (no weight and 2×2kg). Vertical bars denote 95% confidence intervals.

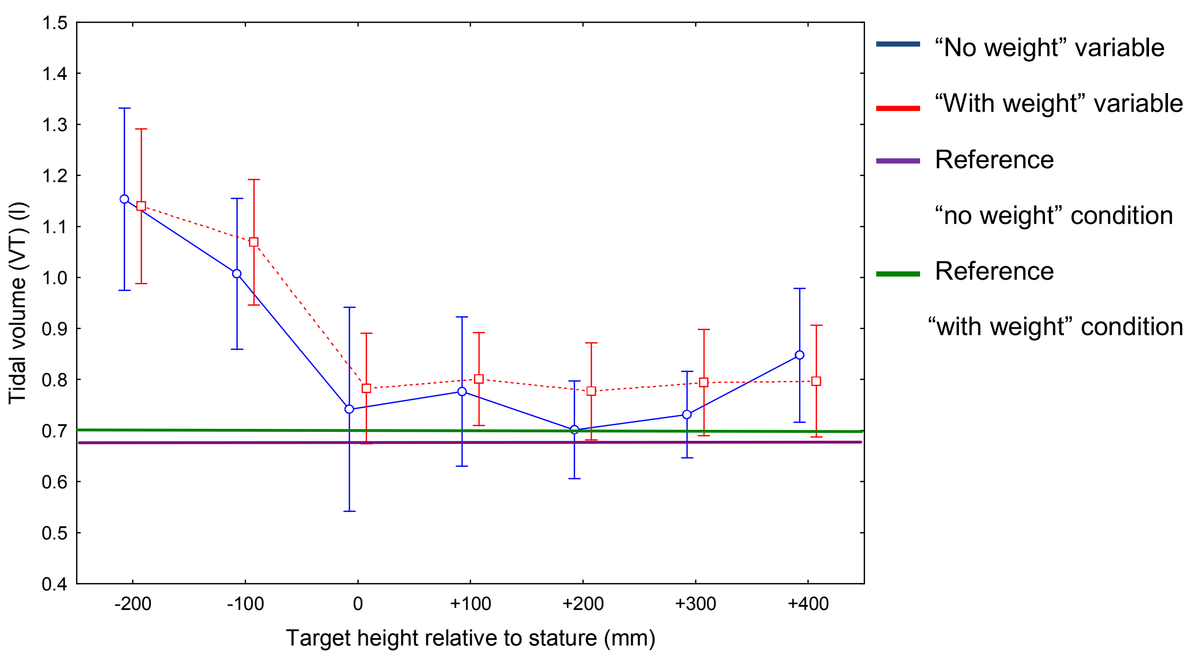


Figure 28: Tidal volume responses (l) for different target heights and two different weight conditions (no weight and 2×2kg). Vertical bars denote 95% confidence intervals.

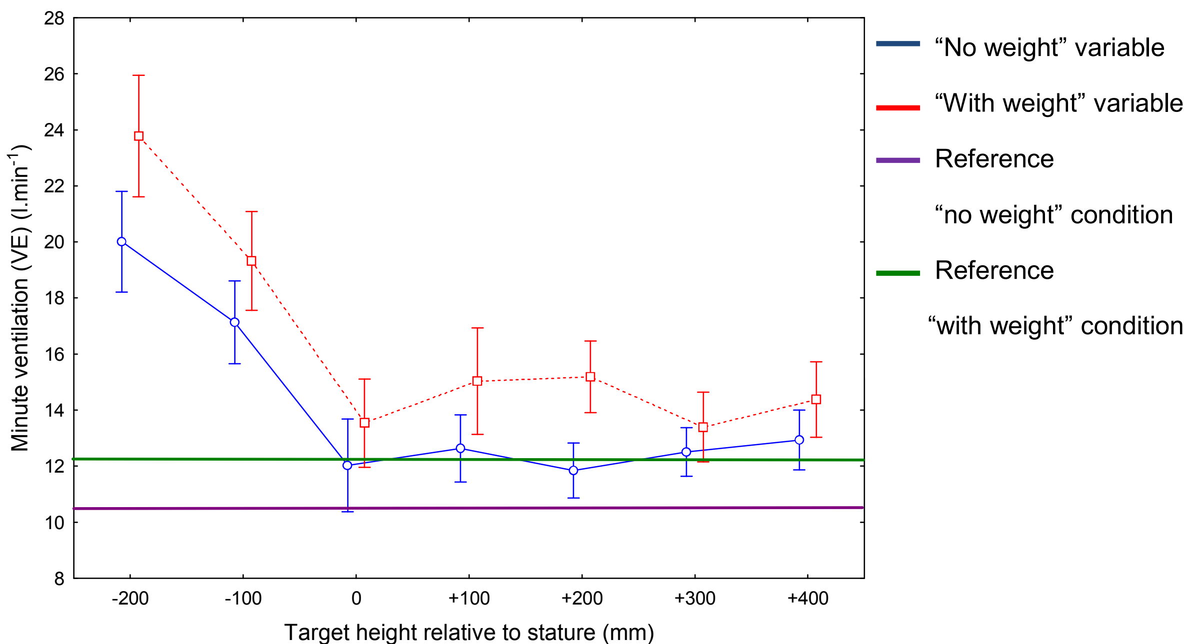


Figure 29: Minute ventilation responses (l.min^{-1}) for different target heights and two different weight conditions (no weight and 2×2kg). Vertical bars denote 95% confidence intervals.

The respiratory responses found in this study depend on the working height (see Table XV) and results were elevated above normative values during the differing working heights. Breathing frequencies were elevated above the normative 12br.min^{-1} (at rest) with a minimum of 16.72br.min^{-1} and a maximum of 23.32br.min^{-1} being recorded. Tidal volumes were 0.68L to 1.15L higher than the recommended average of 0.5L recorded at rest (McArdle *et al.*, 2001). As a result of the breathing and tidal volume responses, minute ventilation was elevated by between 10.52L.min^{-1} and 23.78L.min^{-1} above the normative value of 6L.min^{-1} also recorded at rest. The aforementioned maximum responses were reached during the -200mm conditions and the lower values during the upright overhead conditions. These responses therefore fall within the low to moderate physical exertion categories proposed by McArdle *et al.* (2001) (see Table VII, Chapter II).

Breathing frequency indicated the highest value during the -200mm “with weight” condition and the lowest for the +400mm “no weight” condition. During the restrictive conditions, both the leg and arm muscles were utilised and this would have increased the respiratory responses. Similar responses were noted for the tidal volume and minute ventilation with the highest being found for the -200mm “with weight” condition and the lowest with the +200mm “no weight” condition. This indicated that the restrictive overhead postures were the most strenuous in terms of the respiratory responses. The significantly lower values obtained for the reference positions ($p<0.05$) indicate the effects which the overhead conditions had on the respiratory responses.

When presented as percentages compared to the normative values mentioned, average values over all conditions for breathing frequencies increased by 161%, whereas tidal volumes on the other hand increased by 168%. Minute ventilation indicated an increase of 247%. The larger tidal volumes and an increased breathing frequency compared to resting values indicate that a more effective breathing pattern was adopted by the subjects (McArdle *et al.*, 2001) as more air was inspired. With regard to the “no weight” and “with weight” conditions increases in breathing frequency, tidal volume and minute ventilation indicated a 158%, 166%, 228% and 167%, 172%, 265% increase respectively. The larger increases in the respiratory responses during the “with weight” conditions indicate that they were more strenuous. The overall progression of the respiratory functions indicated an increase as a result of the cardiovascular and muscular fatigue. The respiratory responses obtained were all elevated, however they were not excessive. The respiratory responses in this study may therefore be classified as requiring a low to moderate demand as the conditions did not place excessive respiratory demands on the subjects.

Heart rate responses

Reference and working heart rates were recorded to ascertain the degree of physical exertion which subjects experienced during the conditions of this study.

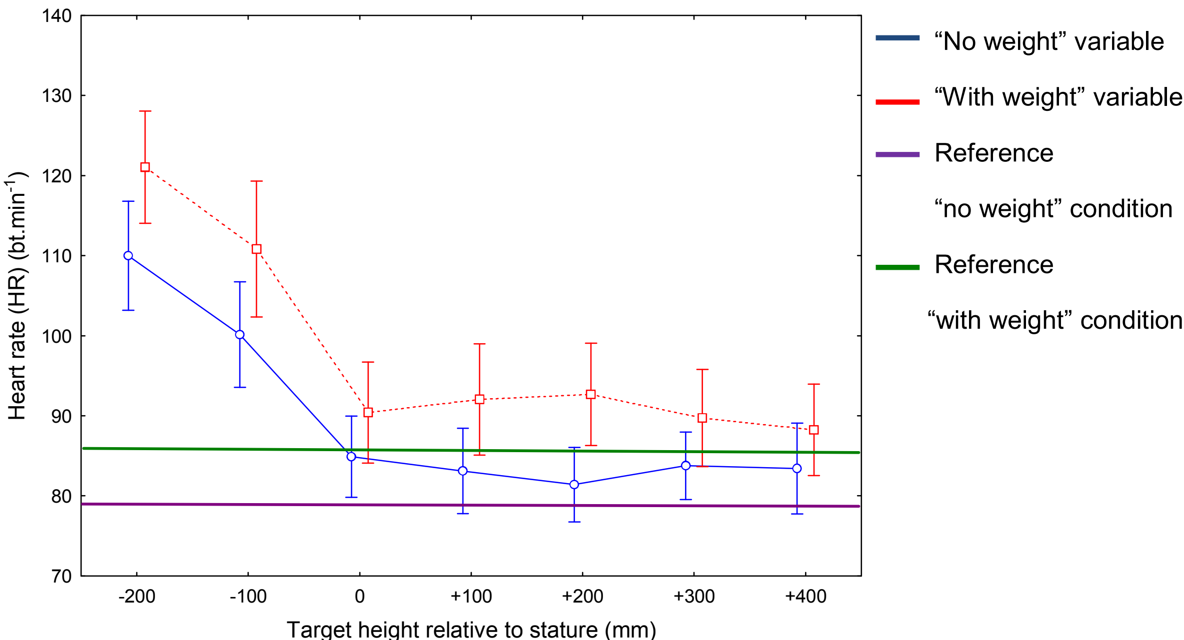


Figure 30: Heart rate (bt.min^{-1}) for different target heights and two different weight conditions (no weight and 2×2kg). Vertical bars denote 95% confidence intervals.

The responses over all the conditions (Figure 30) ranged from 79bt.min^{-1} to 121bt.min^{-1} and heart rate was highest for the restrictive conditions. The increased heart rate observed during the restricted overhead tasks indicated the increased activation of working muscles and the demand for blood to them. The heart rate in relation to the reference condition varied within a range of 1-18bt.min^{-1}. All the values for the "no weight" conditions (90bt.min^{-1}) also indicated heart rates which were lower than those obtained for the "with weight" conditions (98bt.min^{-1}) with a difference of 8bt.min^{-1}.

The average responses between the upright overhead conditions were not significant (see Table XVI) and remained within 12bt.min^{-1} (ranging from 81bt.min^{-1} to 93bt.min^{-1}), however the restrictive conditions indicated heart rate was dependant on the change in height (see Table XVII). Overall the values recorded for all conditions were however dependent on the change in height (see Table XV).

According to Sanders and McCormick (1993) the aforementioned range (79bt.min^{-1} to 121bt.min^{-1}), including all the target heights within the study, are classified as "moderate" in terms of the demands placed on the individual. No values amounted to being classified as "heavy", where individuals' heart rates reached 180bt.min^{-1} or higher which would indicate excessive demand and strain on the cardiovascular system. With reference to other physiological guidelines set by cardio-respiratory responses, a heart rate of no greater than 99bt.min^{-1} for upper body activities, and 112bt.min^{-1} for lower body activities (Snook and Irvine, 1969) is recommended. These limits have been suggested by many authors and remain valid today (Ayoub and Mital, 1989; McArdle *et al.*, 2001). Heart rates in this study, except for the aforementioned -200mm condition, did not exceed the recommended level for upper and lower body activity. All the conditions below the stature range of the subjects did however elicit heart rates which were all above 100bt.min^{-1}. The most restrictive condition (-200mm) with weight elicited a heart rate above the recommended level of 112bt.min^{-1}, indicating this condition is unfavourable to maintain for extended periods of time and should be avoided. Wilson and Corlett (1995) argued that heart rates below 90bt.min^{-1} place a "light" strain on the cardiovascular system, between 90-110bt.min^{-1} a "moderate" strain, and those between 150-170bt.min^{-1} indicate an "extremely heavy" strain on a worker. The majority of conditions within the frame of this study therefore fall within the "light" strain category. The restrictive postures without the added factor of weight are deemed "moderate", however those with weight fall outside of this range, yet they are not deemed to be "extremely heavy".

Heart rate has also been shown to be higher when an individual takes part in work which requires a greater degree of arm activity when compared to that which requires

activation of the legs. Collins *et al*. (1991) maintain that heart rates are 20% higher for arm activity compared to leg activity. In this study the restrictive conditions (-200mm and -100mm) caused subjects' heart rates to reach 105bt.min^{-1} with no weight and 116bt.min^{-1} with weight, and these were found to be 21% and 22% higher respectively than those heart rates obtained for the upright overhead postures. This is in contradiction to the findings by Collins *et al.* (1991) as the legs were mostly utilised during the restrictive overhead conditions which elicited higher heart rates when compared to the upright overhead conditions which had a higher activation in the arm muscles. The results do however support the EMG findings in this study which indicate a higher activation of leg muscles during the restrictive postures when compared to the upright postures. Heart rate during the restrictive conditions was however a representation of the combined activity of the arm and leg muscles and the conditions required the activation of a few of the large muscle groups and not sole use of one or the other.

According to the age-predicted maximal heart rate responses represented as a percentage, subjects worked at an average of 44% and 48% during the "no weight" and "with weight" conditions. The subjects were working within a range of 40-60% of the mean age-predicted maximal heart rate which translates to a 26% difference between the mean maximal heart rate and the mean reference heart rates. The general consensus within the literature according to Zhu and Zhang (1990), is that healthy workers should be able to tolerate an upper heart rate limit of 115bt.min^{-1} over an eight-hour work day. This converts to 58% of the sample's mean age-predicted maximal heart rate. A variation of 2-18% was therefore exhibited between the actual working heart rates and the recommended values.

In spite of the majority of the work being classified as 'light' to 'moderate' in terms of strain on the cardiovascular system, which is acceptable, a few subjects during the "with weight" restricted conditions worked above 70% of their predicted maximum, with one subject's heart rate reaching 159bt.min^{-1}, which is 79% of his age-predicted maximum. This is unacceptable to maintain for long periods of time over an eight-hour work shift.

In comparison to the respiratory responses, heart rate was similar with the most cardiovascular strain evident during the restrictive conditions and less strain during the higher height levels. Overall, it can be surmised that heart rate was within a reasonable range for the majority of the conditions, with most being classified as ‘light’ to ‘moderate’ in terms of the demand on the cardiovascular system. The restrictive overhead conditions should however be avoided within industry over eight-hour work shifts as heart rate would be elevated. The results do however need to be considered cautiously as the protocol conditions only lasted for one minute each. Heart rate should therefore be monitored over a longer time period as overhead tasks may be maintained for a duration of 1 to 21 minutes, as identified from the muscle activity levels reached during the study conditions and their associated estimated endurance time.

Oxygen consumption (VO_2) responses

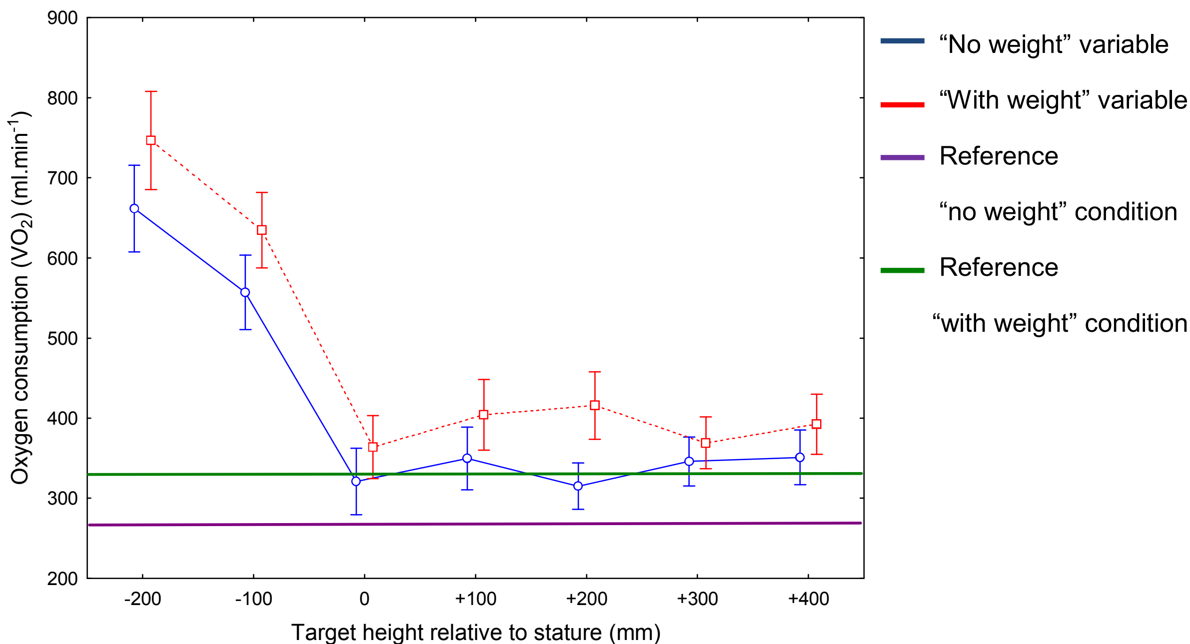


Figure 31: Oxygen consumption ($ml.min^{-1}$) for different target heights and two different weight conditions (no weight and 2×2kg). Vertical bars denote 95% confidence intervals.

Universally accepted classification tables of physical activity, including energy expenditure and oxygen consumption, are widely utilised. Yet they must be used with caution as many are based on exercise and not industrial applications, and an individual's physiological capacity is affected by factors including age, sex and body size (Mital *et al*., 1997). One such classification table was proposed by McArdle *et al*. (2001) where oxygen consumption values which fell within the range of 0.44-0.99$L.min^{-1}$ were categorised as placing a 'light' strain on an individual. The values reached in this study fell within this range (0.28$L.min^{-1}$ to 0.75$L.min^{-1}$) and the conditions were therefore not taxing in terms of the level of oxygen consumption utilised. Figure 31 illustrates that the greatest increase in oxygen consumption, similar to those findings for the other physiological variables, occurred during the restrictive conditions. In contrast, the lowest value was found with the +200mm condition (315.12$ml.min^{-1}$) without weight. The

reduced oxygen consumption throughout the upright overhead conditions indicates oxygen consumption did not depend on the working height and resulted in a reduced muscular strain. The oxygen consumption responses were also found to be significantly dependent on height and weight over all of the conditions tested in the study (see Table XV). It is also shown how the “with weight” conditions elicited a higher physiological strain compared to the “no weight” conditions with values reaching 746.45ml.min^{-1}, indicating the effect of weight (see Table XV). The values obtained for oxygen consumption reiterates the effect of the overhead conditions having little effect on the physiological responses of an individual.

Energy Expenditure (EE)

The energy expenditure values obtained in this study would have to be tested with workers *in situ*, as manual labourers in IDCs generally have lower working capacities. The EE results have been expressed in terms of absolute terms, relative to an individual's body mass, as well as in terms of multiples of the resting metabolic rate (MET). It has been found that there is a large variation in EE with participation in varying physical activities, and these values differ for each individual depending on their skill at the task, the pace of the activity and the individual's physical condition (McArdle *et al*., 2001).

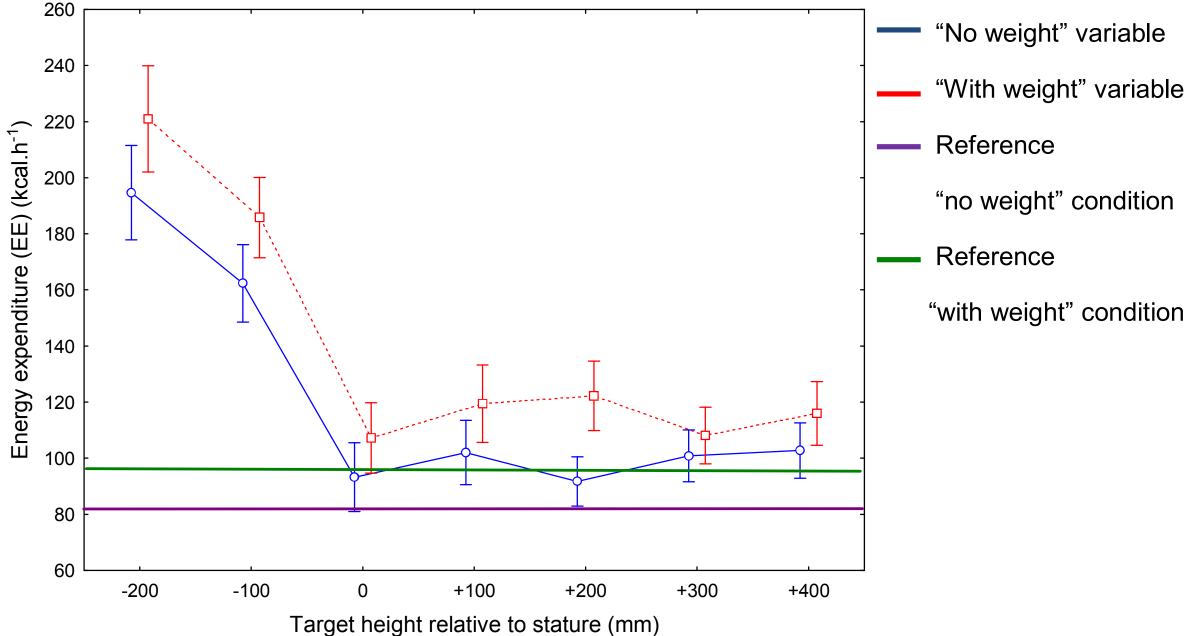


Figure 32: Energy expenditure (kcal.h^{-1}) for different target heights and two different weight conditions (no weight and 2×2kg). Vertical bars denote 95% confidence intervals.

Energy expenditure was affected similarly to the oxygen consumption whereby the weight and interactive effect of weight and height influenced energy expenditure (see Table XV). The height caused significant effects in energy expenditure when comparing all the conditions; however, when conditions were analysed apart, the upright conditions

(see Table XVI) did not have a significant effect, yet the restrictive conditions (see Table XVII) did. This reiterated those findings for the oxygen consumption, which therefore suggest a change in height when standing upright does not effect the energy cost and oxygen consumed by an individual.

In accordance with all other physiological variables analysed, the restrictive conditions elicited the highest energy demand and the upright overhead tasks within the lower reaches, i.e. 0mm and +100mm, were more favourable to adopt. The energy expenditure displayed in Figure 32 is the sum of the energy cost which is required for each condition. This energy was utilised to maintain the whole body in the required position and was found to depend on the working height ($p<0.05$).

According to the five-level classification system proposed by McArdle *et al*. (2001), work is classified according to the ratio of energy required for the task when compared to resting values. The energy expenditure in terms of $kcal.min^{-1}$ and METS for this study fell within ranges of 1.36 to $3.68kcal.min^{-1}$ and 1.17 to 3.12METS, which are deemed 'light' to 'moderate' in terms of the energy expenditure level. The highest value in this range was elicited during the -200mm "with weight" condition, and therefore should be avoided. These values were however obtained over a short duration and the responses may be significantly higher over an eight-hour work shift.

The results indicate that the "no weight" tasks ($1.94\ kcal.min^{-1}$) were again significantly lower than those obtained for the "with weight" conditions ($2.24\ kcal.min^{-1}$), indicating an effect due to the weight, as energy is said to be utilised most when weight-bearing activities are included in a task (McArdle *et al.*, 2001). It has also been noted by De Looze *et al.* (1994) that significantly lower energy costs are required during isometric muscular contractions when compared to concentric contractions. Maintaining postures in a static manner requires isometric contractions of the muscles, which in all likelihood would have caused a decrease in the energy cost responses obtained in the study, and therefore would underestimate those values which would be found in industry.

Effect of weight

With regard to the effect of weight on the physiological variables, levels were generally greater for the "with weight" conditions when compared to the "no weight" conditions, which illustrated how the weight affected physiological responses similarly to muscle activation responses. Comparison of all the conditions within the protocol found that physiological responses varied significantly (see Table XV) between the two weight conditions (except tidal volume).

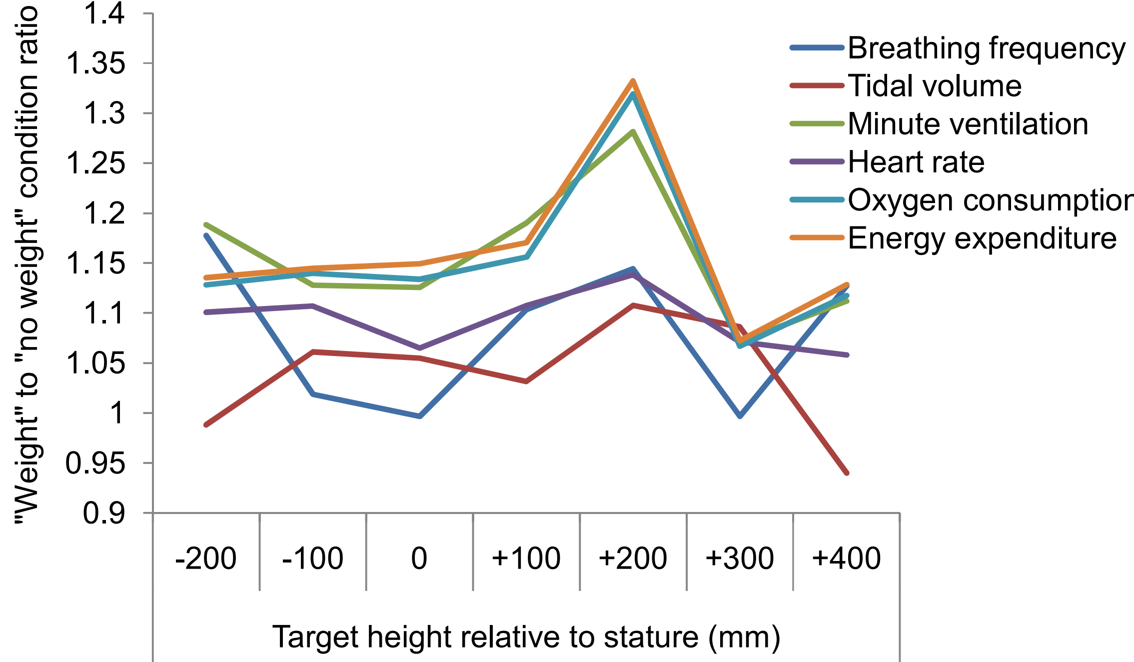


Figure 33: Ratio of physiological responses of the "with weight" (2×2kg) conditions to the "no weight" conditions.

Figure 33 illustrates the relative increase of physiological responses during the conditions with the two by two kilogram weights when compared to those adopted without any weight in the hands. All the variables were strained to a greater extent during the "with weight" conditions. It was also found that all the functions behaved roughly in a similar manner (except with regard to the +200mm condition). The increase within the results in comparison to those conditions without weight is also quite

moderate with all of the responses generally below 35%, and most falling within a 5% to 15% range.

Overall, the physiological results show similar characteristics to those found with the muscle activity. The highest strain was observed during the most restrictive overhead condition of -200mm. The least amount of strain was found within the majority of the upright conditions (excluding the +200mm condition).

BODY DISCOMFORT FINDINGS

In addition to the direct biomechanical and physiological measures obtained, subjective measures were recorded through the use of perceptual rating scales. On completion of each posture during the protocol, subjects were required to identify which area of the body they experienced the most discomfort, together with indicating the intensity with which they felt this discomfort. The two-dimensional nature of the map and scale in terms of the localisation and intensity rating did however make the results difficult to interpret. This was overcome by summing the intensity ratings pointed out by the subject on the Likert scale which then provided information on the overall effect of the condition in relation to the perception of the subjects. Similarly to the biomechanical and physiological data, a two-factorial analyses was conducted on the overall body discomfort ratings which yielded the following results.

Table XVIII: Results of the analysis of variance testing the effects of height and weight on the body discomfort intensity ratings.

	Height	**Weight (2×2kg)**	**Weight*Height**
Body discomfort	$p<0.05$ $f(6,162)=31.18$	$p<0.05$ $f(1,27)=135.57$	$p=0.054$ $f(6,162)=2.12$

As Table XVIII shows, the body discomfort intensity ratings were significantly dependent on the height and on weight during the conditions in this study ($p<0.05$). Statistics computed for the interaction effect of height and weight (“Weight*Height”) indicated no

significant difference. However, for the computed p=0.054, a significant effect for a large sample size might not be excluded.

Table XIX: Results of the analysis of variance testing the effects of height and weight on the body discomfort intensity ratings for the upright overhead conditions (0mm, +100mm, +200mm, +300mm and +400mm) only.

	Height	**Weight (2×2kg)**	**Weight*Height**
Body discomfort	$p<0.05$ $f(4,104)=3.31$	$p<0.05$ $f(1,26)=130.74$	$p<0.05$ $f(4,104)=3.93$

With regard to the statistics run on the upright conditions (0mm, +100mm, +200mm, +300mm and +400mm; Table XIX), results identified that body discomfort was dependent on the change in height, weight and the interactive effects of height and weight ($p<0.05$).

Table XX: Results of the analysis of variance testing the effects of height and weight on the body discomfort intensity ratings for the restricted overhead conditions (-200mm and -100mm) only.

	Height	**Weight (2×2kg)**	**Weight*Height**
Body discomfort	$p<0.05$ $f(1,26)=14.99$	$p<0.05$ $f(1,26)=46.80$	$p=0.43$ $f(1,26)=0.65$

The restrictive overhead conditions (Table XX) showed results were dependent on the factors of height and weight ($p<0.05$), yet the height and weight ("Weight*Height") interaction effect was not significant ($p=0.43$).

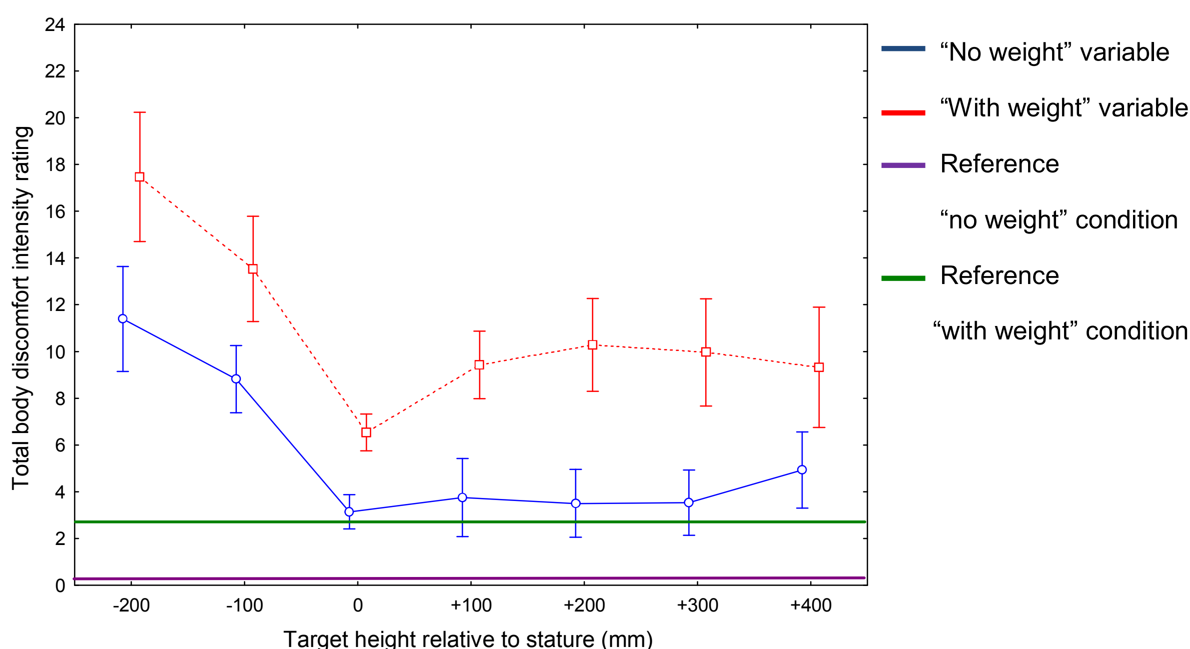


Figure 34: The body discomfort intensity ratings for different target heights and two different weight conditions (no weight and 2×2kg). Vertical bars denote 95% confidence intervals.

Figure 34 represents the total intensity ratings for each condition within the study protocol. The reference and 0mm conditions, when compared to the other conditions, elicited a limited amount of discomfort as rated by the subjects. The restrictive overhead conditions (-200mm and -100mm) both with and without load had the highest discomfort ratings overall. An increase in working height also resulted in an increase in the perceived discomfort, with ratings increasing from the +100mm condition to the +400mm condition. This supports findings by Ulin *et al.* (1990) and Sood *et al.* (2007), who found that working height has significant effects on the rate at which perceived discomfort increases.

Those conditions with the weight of two by two kilograms did however result in higher discomfort ratings being assigned by the subjects. This suggests that subjects perceived those conditions conducted with weight to cause more discomfort when compared to those completed without weight. This holds true for those findings during

the reference conditions, as subjects perceived all the conditions to be more uncomfortable when compared to the reference condition.

The body part in which discomfort is felt depends largely on the posture adopted (Miedema *et al.*, 1997). All subjects who rated discomfort perceived it in similar areas of the body. As none of the subjects reached their endurance limits during the testing session, no maximum ratings of 10 (very uncomfortable) were recorded from the Body Discomfort Map and Scale. When applied *in situ*, the body discomfort findings may be different due to the prolonged nature of the task and the cumulative effect of working on this assembly line on a daily basis. Ratings may therefore go beyond the threshold limit on the scale proposed by Corlett and Bishop (1976). In this case productivity would be affected and there would be an increased risk of accidents and injuries.

The fact that the subjective interpretation was over a short time needs to be taken into account as discomfort may be perceived differently over longer a working period. Added to this, discomfort also encompasses other sensory experiences such as pain and pressure as well as discomfort in tissues other than the muscles or physiological variables looked at, and therefore body discomfort ratings should be taken with caution.

DIFFERENCES IN THE MALE AND FEMALE RESPONSES

The majority of the workforce in industry has traditionally been comprised of males but female participation in the labour force is increasing. In South Africa for example, the number of women in the workforce has risen from 47% in 2004 to 51% in 2006 (Statistics South Africa, 2007). These numbers are also set to increase due to the Employment Equity Act of 1993 whereby workers cannot be discriminated against according to their sex (Department of Labour, 2007). With the increase of females working in industry it is important to consider the effect of tasks and the subsequent responses, indicating whether there were sex related differences to the same task. Women are also being assigned to previously male dominated areas of work where awkward postures and manual handling jobs are prevalent. It has also been found that WRMSDs are more common amongst women and this needs to be assessed (WHO, 1985).

Table XXI: Results of the analysis of variance testing the gender effects of height and weight on muscle activity, physiological responses and body discomfort ratings.

Muscles	Gender	Height*gender	Weight (2×2kg)*gender	Weight*Height *gender
Biceps brachii	p=0.09 f(1,26)=3.07	p<0.05 f(6,156)=4.13	p=0.07 f(1,26)=3.59	
Middle deltoid	p<0.05 f(1,26)=14.61	p<0.05 f(6,156)=8.07	p<0.05 f(1,26)=6.32	p<0.05 f(6,156)=2.36
Trapezius	p<0.05 f(1,26)=5.32		p<0.05 f(1,26)=10.63	
Latissimus dorsi		p=0.09 f(6,156)=1.85		
Upper erector spinae		p<0.05 f(6,156)=6.02		
Lower erector spinae		p<0.05 f(6,156)=2.98		
Quadriceps		p<0.05 f(6,156)=2.57	p<0.05 f(1,26)=4.58	p=0.08 f(6,156)=1.94
Semitendinosus		p<0.05 f(6,156)=2.19		
Physiological variables				
Breathing frequency (Rf)	p<0.05 f(1,26)=5.37	p=0.07 f(6,156)=1.97		p<0.05 f(6,156)=2.72
Tidal volume (VT)	p<0.05 f(1,26)=8.77	p<0.05 f(6,156)=2.50		
Minute ventilation (VE)			p=0.06 f(1,26)=3.90	
Heart rate (HR)	p<0.05 f(1,26)=5.70		p<0.05 f(1.26)=12.62	
Oxygen consumption (VO_2)	p<0.05 f(1,26)=13.93			
Energy expenditure (EE)	p<0.05 f(1,26)=13.36			
Body discomfort ratings				
Body discomfort	p=0.07 f(1,26)=3.53	p<0.05 f(6,156)=2.55		

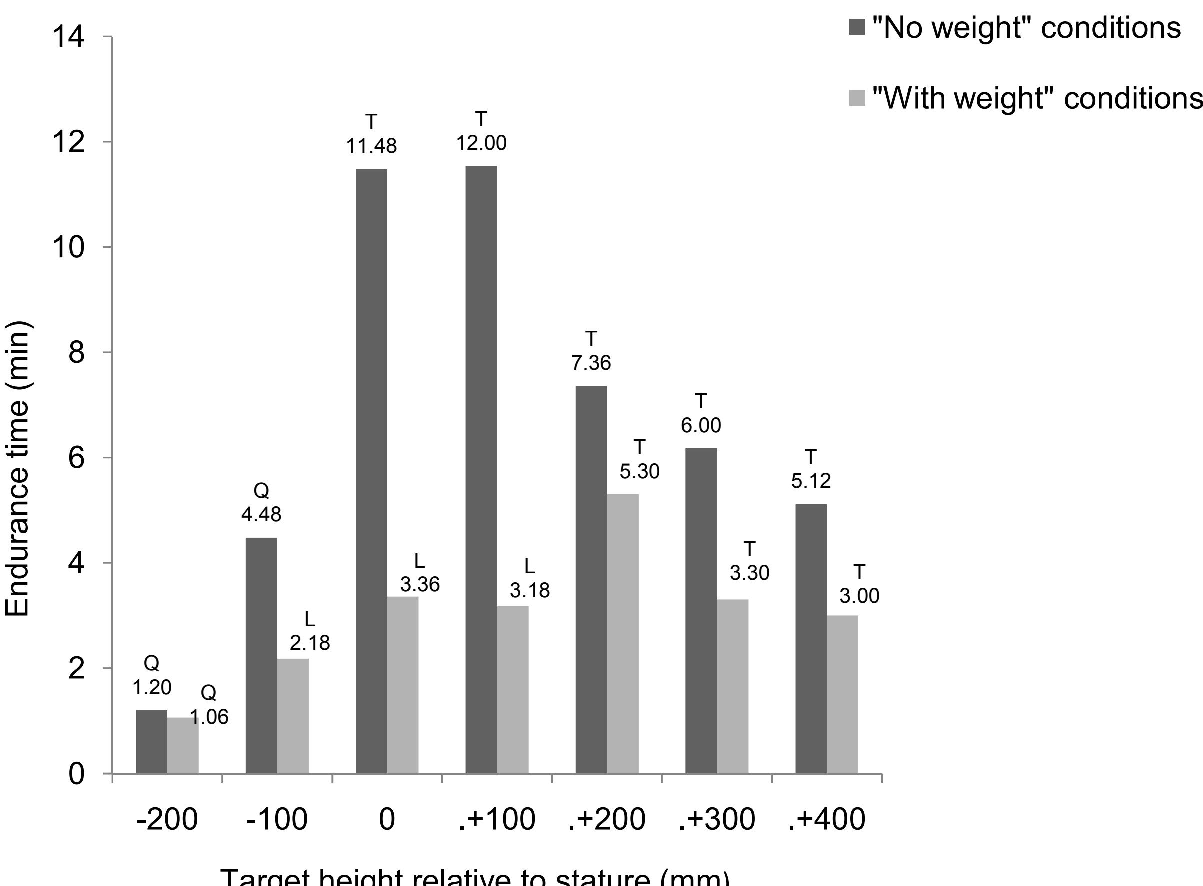
Table XXI shows that there are gender related differences for all of the muscles tested (except the trapezius muscle) as a result of the change in height (p<0.05). There was a limited amount of difference between the sexes when looking at the gender effects of weight and the interactive effect of weight and height. The female responses exhibited a similar yet higher trend to those of the male responses, indicating that the muscles were

activated to a higher degree and they perceived body discomfort to be greater (see Appendix E). The physiological variables showed gender differences were affected to a limited extent by the change in height, weight and the interactive effect of weight and height. The statistical output therefore indicate the importance of assessing responses of males and females separately when looking at muscles and discomfort during a change in height.

Table XXII: Numeric overall differences in the results obtained for the female (n=14) sample when compared to the male sample (n=14).

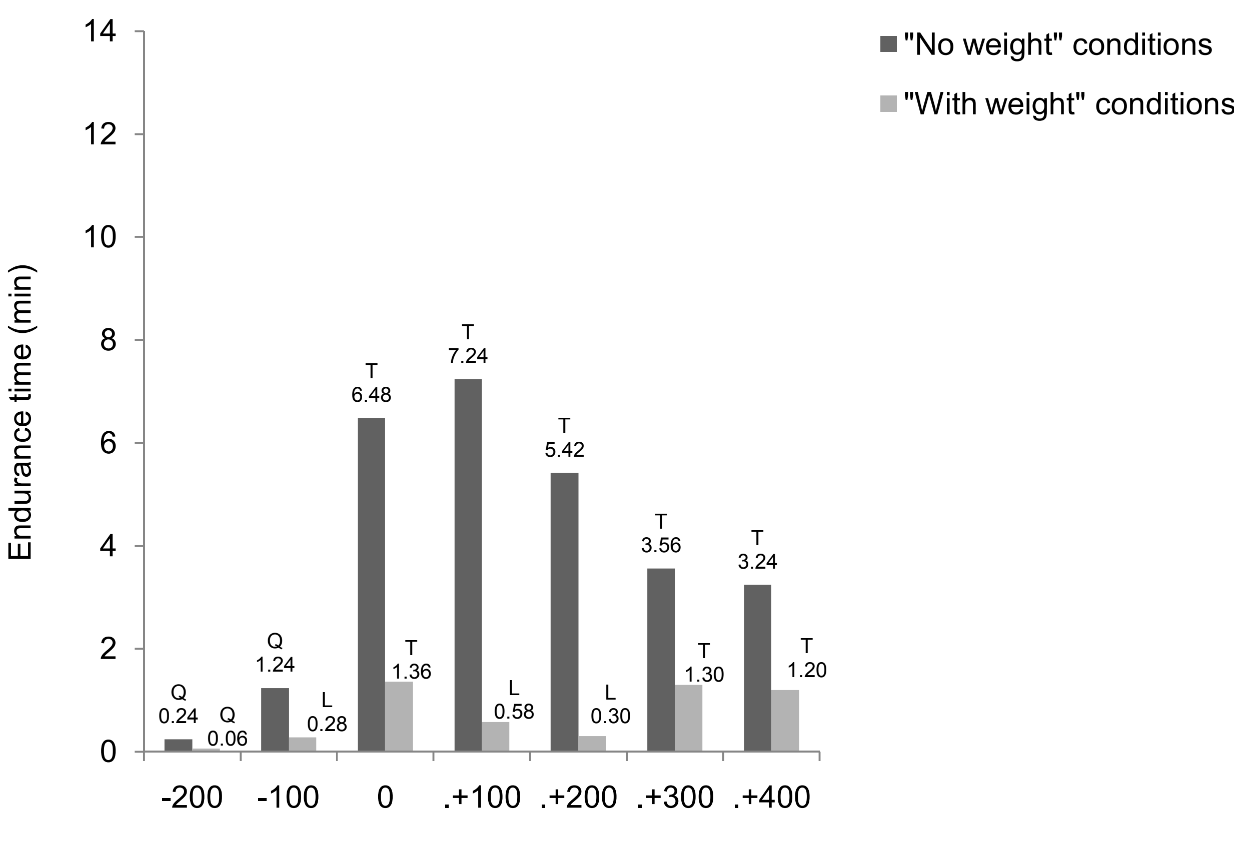
Biomechanical variables	**Male (mean of all conditions tested)**	**Female (mean of all conditions tested)**	**% difference i.e. comparing females to males**
Biceps brachii	4.82	8.84	+83.48%
Middle deltoid	7.68	15.31	+99.24%
Trapezius	16.40	23.67	+44.31%
Latissimus dorsi	13.39	17.30	+29.21%
Upper erector spinae	10.84	11.51	+6.22%
Lower erector spinae	8.40	8.73	+3.83%
Quadriceps	7.39	10.23	+38.50%
Semitendinosus	2.30	2.96	+28.45%
Physiological variables			
Breathing frequency (Rf)	17.69	20.85	+17.89%
Tidal volume (VT)	0.98	0.71	-28.08%
Minute ventilation (VE)	15.40	14.17	-7.97%
Heart rate (HR)	86.00	98.65	+14.71%
Oxygen consumption (VO_2)	482.65	371.47	-23.04%
Energy expenditure (EE)	141.90	108.67	-23.42%
Body discomfort			
Body discomfort	8.34	6.52	-21.88%

Table XXII illustrates how different the female responses were in comparison to the male responses. Overall the muscle activity values were higher for females with the biceps brachii muscle (83.48%) and middle deltoid muscle (99.24%) exhibiting the greatest difference. In comparison the smallest difference was noted with the lower back muscles (both the upper and lower erector spinae muscles), whereby values were considerably lower than the average computed for all the muscles (39.43%). The average difference between females and males for all of the muscles also indicates how the females' were strained to a higher degree with muscle activity values 39.43% higher than the male responses. The heart rate and breathing frequency was higher for females yet the tidal volume, minute ventilation, oxygen consumption and energy expenditure were lower than that of the male population. Similar findings were shown for the body discomfort ratings where males perceived the conditions to cause more discomfort (21.88%) even though the female sample were under more strain. Gender related differences were also assessed for endurance time according to the %MVC activation of the muscles and are shown in Figures 35 and 36.



Where: Q = quadriceps muscle; L = latissimus dorsi muscle; T = trapezius muscle (i.e. these represent the limiting muscles in each condition).

Figure 35: Estimated maximum endurance time for 95% of the male population (n=14) for the “no weight” and “with weight” (2×2kg) conditions.



Where: Q = quadriceps muscle; L = latissimus dorsi muscle; T = trapezius muscle (i.e. these represent the limiting muscles in each condition).

Figure 36: Estimated maximum endurance time for 95% of the female population (n=14) for the “no weight” and “with weight” (2×2kg) conditions.

The nature of the results was found to be similar to the endurance time computed for the population as a whole. The lowest endurance time was again found with the restrictive conditions of -200mm and -100mm, and the longest was with the 0mm and +100mm “no weight” conditions (Figures 35 and 36). When looking at the difference found between the male and female responses, the limiting muscles remained similar yet the endurance time changed. Overall, females (Figure 36) had lower endurance times when compared to males, with, for example, the “with weight” upright overhead conditions, females had endurance times of less than 1 minute and 30 seconds when compared to males who had endurance times of greater than 3 minutes. The

differences found between the male and female responses are important to consider as this would aid in preventing MSDs by placing the appropriate worker at a task they can perform to the best of their capabilities.

SUMMARY

Effect of height on responses

The biomechanical responses were identified to be dependent on the change in height ($p<0.05$). The results showed that the -200mm and -100mm restricted overhead conditions and the +200mm, +300mm and +400mm upright overhead conditions elicited the highest biomechanical, physiological and psychophysical responses. The 0mm and +100mm conditions elicited the least amount of strain on the individuals and it is therefore recommended that static overhead work be completed within this range.

Biomechanical responses

The risk of incurring a WRMSD increases with increased muscle activity (Straker and Mekhora, 2000) and therefore it is an important measure to consider. Arm positions and work postures which are unsuitable have also been suggested as being causative factors for shoulder pains, and this should be dealt with through ergonomic planning of the industrial work area (Herberts *et al.*, 1980). With regard to the muscle activity responses in this study in particular, the conditions which generally imposed the least amount of strain were the 0mm and +100mm conditions. The average muscle activation was 9%MVC and 11%MVC during the 0mm and +100mm conditions respectively, which demonstrates the reduced muscular load imposed by these conditions compared to the others in the study protocol. This indicates that these conditions reduce the risk of the development of MSDs to a large degree although it is not eliminated. Higher muscle activity levels were found during the conditions in the extreme reaches of the range of heights tested. One exception was however found with the latissimus dorsi muscle which had the least amount of activation during the +400mm condition, as the higher the

arms were raised the lower the activation within this muscle. Values obtained during the 0mm condition for this muscle were however below the recommended 15-20%MVC (Rohmert, 1960), and therefore a compromise would have to be reached whereby postures would have to be adopted within the 0mm to 100mm range, although the latissimus dorsi is under more strain than it would be higher overhead. This should however be kept in mind as the long term effects of working overhead for eight-hour work shifts may exacerbate the strain on this muscle

Many assembly tasks in the motor industry usually cause lower back stress, yet this is found more with tasks which require stretching, stooping, reaching and the utilisation of a load during the task (Charteris and Scott, 2001). This study identified that the upright overhead postures elicit less strain on the back, and it concurs with the findings by Charteris and Scott (2001) where awkward restricted postures which require the manipulation of load and reach cause an increase in lower back stress i.e. muscle activation.

It was also found that the quadriceps were the most activated in the restrictive postures and the trapezius muscle in the upright overhead postures. This is supported by various authors who found hand positions at or below 50% shoulder height elicit discomfort in the lower back and legs, whereas hand positions at or below 100% shoulder height elicit discomfort in the shoulders and arms (Jørgensen *et al.*, 1988; Rose *et al.*, 1992; Sommerich *et al.*, 1993; Miedema *et al.*, 1997).

The most appropriate working height to adopt which would elicit the least amount of activation for each muscle should be as close as possible to head height. This supports findings whereby the height at which work is completed with the hand dictates the extent of work load on the musculature (Herberts *et al.*, 1980).

Physiological responses

All the physiological variables exhibited similar responses to those of muscle activation and were dependent on the change in height ($p<0.05$). The highest responses were obtained in the restrictive conditions (-200mm and -100mm) below the subjects' stature, and the lowest values were obtained in the varying upright overhead conditions (0mm, +200mm, +300mm and +400mm). The physiological responses were however found to be below limits for work shifts set by various authors (Snook and Irvine, 1969; Sanders and McCormick, 1993; McArdle *et al.*, 2001) and they were therefore found not to be a limiting factor when considering static overhead work conditions. Assembly work within the automotive industry has been classed as 'light' to 'medium', which is also not physiologically taxing (Dimitriadis, 2006) and this is supported by findings in this study. These results therefore indicate that physiological strain is not prominent on assembly lines; however, caution should be maintained when applying these findings *in situ* as workers will have different physical and physiological capacities and have to maintain these job demands over eight-hour work shifts. One also has to consider the effect of cumulative fatigue due to repetitive sub-maximal exertions found in industry as results in this study were over a short duration.

Psychophysical responses

The body discomfort ratings were dependent on the change in height ($p<0.05$). Overall the body discomfort ratings indicated that the restrictive overhead conditions gave rise to the highest levels of discomfort of all conditions. Minimal discomfort in comparison to the other conditions was rated in the 0mm condition indicating that this would be preferable to most subjects.

Focus should therefore be placed on the musculoskeletal system. The holistic approach taken in this study has however allowed one to therefore identify muscle activity to be a limiting factor when performing static overhead work tasks.

Effect of weight on responses

The activation of the muscles was higher with the two kilogram weight in each hand when compared to having no weight. Similarly, the physiological responses and psychophysical ratings exhibited differences between the “without weight” and “with weight” conditions with higher values being obtained when the individuals held weight, indicating an influence of weight.

This indicates that even a relatively small, evenly distributed and symmetrically held weight will elicit higher values and demands from an individual. The use of hand tools in the automotive assembly industry is a necessary requirement for the successful completion of tasks, yet as shown in this study, a weight of two kilograms in each hand is enough to elicit higher activation levels of muscles, thus tool use should be kept at a minimum and the weight of the tools utilised should be monitored.

The results therefore illustrate how changes in height of 100mm cause significant changes in biomechanical, physiological and psychophysical responses. With the optimal height to adopt within the range tested being identified as 0mm to 100mm above stature, these changes were clearly illustrated in the results. With the middle deltoid muscle as an example, the muscle activation during the 0mm to 100mm conditions was within a range of 6-7%MVC (with no weight) and increased to 11%MVC with an increase of 100mm in the target height. These values were elevated further when weight was an added factor in the conditions. This was also shown with the endurance time which was 7.54 minutes and 9 minutes for the 0mm and 100mm no weight conditions respectively. When the other no weight conditions of this study were adopted the endurance time was reduced to a range of 1.54 minutes to 6.24 minutes. The endurance time also identified limiting muscles which were the trapezius muscle without weight, the latissimus dorsi muscle with weight and the quadriceps during the specific restrictive conditions of the study. In comparison to the reference positions studied, all the muscles indicated an increase in activation illustrating the general effect of overhead work. The limiting muscles identified during this comparison were once

again the quadriceps during the restrictive conditions and the middle deltoid during all of the target heights. These findings are also shown in the high muscle activity values for the quadriceps muscle during the restrictive conditions.

Although the physiological responses were classified as being placed under a low to moderate strain, certain positions elicited elevated values with heart rate for instance increasing by 25bt.min^{-1} when completing the -200mm restrictive condition compared to the optimal range of 0mm to 100mm. An individual's body discomfort was also shown to increase when subjects were required to complete the condition out of the optimal range. If the work was therefore kept within this range, workers would perceive the task differently and this would also reduce the amount of body discomfort felt.

This has many practical implications with regard to overhead work found in industry whereby work should be completed within a range of 0mm to 100mm above an individual's head and as close to head height as possible. Any deviation from this range and the addition of weight (2×2kg) has shown to impact on an individual's responses.

CONCLUSION

In conclusion, the biomechanical, physiological and psychophysical data has helped to make data available on which firm recommendations regarding static overhead work in the automotive industry may be based. The results reveal that varying heights elicit high muscle activation and body discomfort ratings with a low physiological demand.

The most critical finding of the study is the high muscle demands on an individual's system. To be able to detect more differences and effects of the overhead tasks, more objective measures and methods may be necessary. The information obtained through the selected experimental methods is aimed at aiding the design of work so that it can be performed safely and without undue fatigue by the majority of people in the population (Bridger, 1995). This is made possible through the analysis of the

biomechanical, physiological and psychophysical aspects and information can then be extracted.

Recommendations based on this study’s findings therefore include the height level at which the worker completes a static overhead task and the maintaining of weight in the hands. With regard to these findings, the restrictive overhead conditions below an individual’s stature should be avoided, due to the high level of muscle activation these restrictions create. Work tasks should incorporate a level between 0mm and 100mm above an individual’s stature to complete a task. The use of hand tools should also be avoided where possible, yet if necessary, the weight should be kept to a minimum. It is essential that these findings are utilised in the automotive industry, altering the nature of the requirements of certain overhead tasks, as musculoskeletal complaints and injuries continue to arise. If conditions similar to those in the extremes of the range studied, continue to be allowed, this will place strain on the musculoskeletal system which will increase the risk of injury.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

With work changing due to globalisation, altering workforce demographics, and increased work intensity and task demands, this affects the work that people perform where task demands may exceed human capabilities. These demands are prevalent in many industries, with the automotive industry being one such example. With the core activity within this industry being the production process, assembly lines provide many areas which may be hazardous to the workforce (Ruppert, 2002). Many of the tasks on these lines also require the worker to perform the work in awkward postures with the aid of tools. While humans do have the ability to adjust to these less than optimal working postures and to tolerate substantial stress, there are limits. If these limits are not curtailed this will negatively affect the worker both physically and mentally (Jafry and O'Neill, 2000). Results may include an excessive biomechanical strain, physiological cost and an increased risk of incurring musculoskeletal disorders (MSDs) (Shahnavaz, 1987). These findings are particularly prevalent for highly repetitive and monotonous tasks such as those found in the automotive industry. Tasks therefore need to be analysed to develop a safe environment ensuring that employees work within their capabilities thereby maintaining their productive capacity adequately.

Risk analysis identified a certain area of an automotive plant which needed ergonomic assessment. The work tasks on this section of the assembly line required the majority of the work to be completed overhead. The aim of this research was therefore to examine what effect a change in height, which is often found in assembly processes in the automotive industry, would have on an individual's responses. The study incorporated a holistic analysis with the main purpose being to determine the effect of changes in height on the biomechanical, physiological and psychophysical responses of an individual.

SUMMARY OF PROCEDURES

The experimental phase of the study was performed in a laboratory environment in the Human Kinetics and Ergonomics Department, Rhodes University. Fourteen male and fourteen female subjects between the ages of 18 and 28 years, with a mean stature of 1726mm and mean body mass of 69kg volunteered to participate in the study.

The protocol consisted of eight different conditions of varying working heights which required the subject to maintain a static overhead posture. The conditions were permutated ensuring each subject had a randomly assigned execution of the conditions, which included a comparative reference condition, two restrictive overhead conditions below the subject's stature (-200mm and -100mm), a 0mm condition at head height, and four overhead conditions above the subject's stature (+100mm, +200mm, +300mm and +400mm). Each condition was maintained for a duration of one minute with a two minute rest break in between. These conditions were required to be maintained without load and while holding two kilograms in each hand, therefore resulting in the subject adopting sixteen conditions in total.

Muscle activity of the biceps brachii, middle deltoid, trapezius, latissimus dorsi, upper and lower erector spinae, quadriceps and semitendinosus muscles was assessed using a surface electromyography (EMG) device. Physiological variables including selected respiratory responses (breathing frequency, tidal volume and minute ventilation), heart rate, oxygen consumption and energy expenditure were measured utilising an ergospirometer and a heart rate monitor. Body Discomfort was recorded, gaining a perceptual indication from each subject. The variables tested were analysed using basic descriptive statistics and Two factorial analyses for both of the dependent variables of height and weight.

SUMMARY OF RESULTS

The results obtained in this study provided insight into the biomechanical, physiological and psychophysical demands placed on individuals during variable heights within which overhead tasks in the automotive industry have to be completed.

Biomechanical findings

Electromyography (EMG) of the muscles chosen for analysis in this study gave insight into the effects of the target height on the muscle activation responses and the added effect of weight. Conditions which elicited the most biomechanical strain included those conditions which were at the extremes of the height range tested i.e. the restricted overhead conditions of -200mm and -100mm relative to stature, and the +300mm and +400mm upright overhead conditions relative to stature. The middle deltoid seemed to be the most active throughout testing of all the conditions. The quadriceps muscle reached the highest activation level and the semitendinosus muscle was the least activated.

Physiological findings

The physiological findings identified that static overhead work conditions elicit a ‘light’ to ‘moderate’ strain on an individual. The variables are influenced by the target height and are also affected by the added factor of weight. Similar patterns as those found with the biomechanical responses were observed within the physiological variables, with a greater strain identified during the restrictive and upright overhead conditions, including the -200mm, -100mm, +200mm, +300mm and +400mm conditions relative to stature. These findings support previous literature which identified assembly work not to be physiologically taxing (Dimitriadis, 2006).

Psychophysical findings

The perceptual ratings obtained from the subjects were dependent on the factors of height and weight. Overall, the body discomfort ratings support the biomechanical and physiological data, indicating that the restrictive overhead conditions gave rise to the highest levels of discomfort of all conditions. Minimal discomfort was rated in the 0mm upright overhead condition indicating that this would be preferable to most subjects.

Considering the biomechanical, physiological and psychophysical variables tested, it is therefore recommended to adopt postures closer to head height, within a range of 0mm to 100mm overhead. It is also preferable to complete these tasks with a weight that is below four kilograms or without any weight in the hands where possible.

HYPOTHESES

The research hypothesis proposed that there would be biomechanical stress, physiological exertion and body discomfort due to changes in working height. Findings support this whereby it was found that these variables were dependent on the change in height and weight.

Hypothesis 1:
The study tested the null hypothesis which proposed that a change in height would not affect the biomechanical variables tested in this study.

H_O: $\mu_{\text{Condition 1, EMG}} = \mu_{\text{Condition 2, EMG}} = \ldots\ldots\ldots\ldots = \mu_{\text{Condition n, EMG}}$

Comparison of the different working heights yielded statistical significance for the biomechanical variable of muscle activity. The null hypothesis is therefore rejected for all the muscles tested. The alternative hypothesis is therefore tentatively accepted.

Hypothesis 2:

The second null hypothesis considered the physiological responses and suggested that no changes would occur in these responses due to the change in height.

$H_O: \mu_{Condition\ 1,\ physiol} = \mu_{Condition\ 2,\ physiol} = \ldots\ldots\ldots = \mu_{Condition\ n,\ physiol}$

The null hypothesis is therefore rejected as a significant difference was found over all responses including the respiratory, cardiovascular and metabolic cost variables, due to the change in height.

Hypothesis 3:

The third and final null hypothesis assessed the perceptual responses of the individual through the use of the Body Discomfort Map and Scale and proposed that perceptions of discomfort would not depend on changes in height, and thus all ratings would be similar.

$H_O: \mu_{Condition\ 1,psychophys} = \mu_{Condition\ 2,psychophys} = \ldots\ldots\ldots = \mu_{Condition\ n,psychophys}$

The null hypothesis is rejected as ratings were dependent on the change in height.

CONCLUSIONS

By utilising a laboratory-based study of overhead tasks the results provided data on the effect different overhead work heights had on an individual. This therefore provided advice to facilitate in recommending the most appropriate height to adopt in industry. Given that there was a recognised problem with regard to MSDs among industrial workers together with evidence for overhead work being an important risk factor to take into account, which cannot be wholly eliminated from industry, the current study represented part of the ongoing effort to derive the consequences of such work.

Significant effects were identified for the biomechanical, physiological and psychophysical responses due to the changing height conditions tested in this study indicating responses are dependent on the height at which tasks are completed. It is therefore imperative that one control the work environment and ensure that workers are completing tasks within their capabilities and at the optimal height. The effect of weight is also evident when completing overhead work tasks and this should be monitored within industry, thereby ensuring less strain is placed on the individual. By incorporating the aforementioned information into overhead assembly tasks, this may prove to be beneficial in reducing the strain placed on the musculoskeletal and physiological systems.

RECOMMENDATIONS

Future studies in this area should consider the following recommendations:

1) The overhead protocol should be adjusted to incorporate different scenarios including a wider variation in height levels, loads and detailed postural analysis. Once this information has been expanded it may be possible to then determine whether the above factors will further affect the responses obtained during overhead work. A similar methodology to the one adopted in this study could be utilised in this recommendation.

2) The sample should include a representative sample of industrial workers who are accustomed to the demands of overhead work on assembly lines within the automotive industry.

3) The duration of the conditions could be tested for longer than one minute as this would then allow one to identify if physiological 'steady state' is reached and the effect of fatigue. Such an investigation could also identify whether a relationship between physiological stresses and outcomes such as fatigue, injury and loss of

productivity exist. It would be preferable for this research to be conducted within industry and complete such a study over the course of a complete working day and including varying work shifts.

4) As mentioned in Chapter I, the risk assessment conducted during the preliminary work of the study identified both the ‘Mech 1’ and ‘Trim 2’ lines as needing an ergonomic study. This study only focused on the ‘Mech 1’ line which involved a large deal of overhead work, and therefore a study could be conducted on the ‘Trim 2’ line within the automotive industry where awkward postures are prevalent as this would aid in gaining information of the effects of this type of work.

Further research is needed within this area; even though this industry is becoming automated, the human aspect will always be necessary. By identifying those conditions which also alleviate the demands placed on individuals during such tasks, this will lead to a better match between the worker and their job. This will also ensure that the efficiency of the worker will be enhanced and the human operator can be better understood within the context of their external environment.

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APPENDICES

APPENDIX A: INDUSTRY MEDICAL FORMS

A standard medical record folder for an employee at the local automotive plant included the following (unnecessary documentation which was not utilised for the purposes of this study was left out e.g. visual acuity results etc.):

Pre-placement medical assessment
Pre-placement medical examination: medical history
Morbidity record
Sick certificate record
Pre-placement medical examination: physical examination

Pre-placement medical assessment

	Pre-placement Medical Assessment

Name:	S
Date	Number:
Job Preference: ASSEMBLER	Medical Classification: A1

Person-job Match Assessment

Job Category	*Person-job Match*				*Comments*
Welder	(1)	2	3	4	
Assembler	(1)	2	3	4	
Spray Painter	(1)	2	3	4	
Paintshop Assembler	(1)	2	3	4	
Materials Handler	(1)	2	3	4	
Artisan Assistant	(1)	2	3	4	

KEY	1 : Optimal	2 : Good	3 : Sub-optimal	4 : Poor

Pre-existing Medical Conditions

Assessed	Signed:

Pre-placement medical examination: medical history

PRE-PLACEMENT MEDICAL EXAMINATION : MEDICAL HISTORY

(To be completed by the Applicant)

BLOOD GROUP: ... A BLOOD DONOR? : NO

HAVE YOU OR ANY MEMBER OF YOUR FAMILY EVER SUFFERED, OR ARE ... NG FROM ANY OF THE FOLLOWING : (If yes, tick the appropriate block)

EPILEPSY (FITS)	X	HEADACHES	X	EYE DISEASE	X SPECS
EAR DISEASE	X	BRONCHITIS	X	PNEUMONIA	X
PLEURISY	X	ASHTMA	X	ULCER	X
DIABETES	X	TUBERCULOSIS	X	ALCOHOLISM	X
BLOOD PRESSURE	X	HEART DISEASE	X	MENTAL ILLNESS	X
HERNIA	X	RHEUMATISM	X	SKIN DISEASE/ALLERGY	X
BACKACHE	X	KIDNEY/BLADDER DISEASE	X	CANCER	X

ANY DISEASE NOT MENTIONED: NIL MEDICATION

PLEASE STATE DATE AND TYPE OF OPERATION:	PLEASE STATE DATE AND TYPE OF INJURY:
N/A	NIL
ALCOHOL CONSUMPTION PER WEEK: —	CIGARETTE CONSUMPTION PER DAY: —

PREVIOUS EMPLOYMENT

DATE			
FROM:	TO:	COMPANY	DESIGNATION
		N/A	

As part of my application for employment with ..., I hereby consent to a full physical examination and any medically appropriate investigations.

I hereby certify that the above answers are true and correct and agree that any false information may invalidate the ... t.

I hereby agree to report any injury (occuring during my working hours) to my Team Manager and Medical Department **immediately** and I shall not consult any Medical Practitioner in connection with a work injury without prior permission from the Medical Department

SIGNATURE OF APPLI...

Morbidity record

MORBIDITY RECORD

M.P. P/C.

DATE/ TIME		SIG.
27/10/04	Chronic Backache. Specialist recommendation (See letter ...) classification B4. Please make a copy of recommendation	
21.02.05	Has done [illegible] 11/04 r/for post test counselling	
4.4.05	cold Rx [illegible] DPH. Vit C	
17.10.05	Cervical glands - for Dr → Has referral letter given for Dr [illegible]	
6.3.06	Flu. Rx Sinuend II, Panamol II } Stat.	
8.3.06	Flu like symptoms Rx [illegible] II stat, Alcophyllin [illegible]	
9.3.06	c/o Blocked Nose Rx Sinuend II, Panamol II } Stat.	
4/5/6	c/o frontal headache, general [illegible] since yesterday. Rx. panamol plus 2 tabs P.O. stat, [illegible] ea stat, [illegible] 2 tabs P.O. stat	
8.5.06	appears to have shingles. Refer to see Dr. Shingles © [illegible] Rx Diclofenac Panamol Cole [illegible] Vyrahexal 800 mg 5x/d	
24/07/06	c/o Sore throat since this am. [illegible] cold. Rx Throat [illegible] 1 QID (12), Sinuend 1 TDS (12)	

MBSA\Medical\F20

Sick certificate record

SICK CERTIFICATE RECORD

DATE RCVD.	DATE OFF	DATE RTND.	DIAGNOSIS	DOCTOR CONSULTED
97.04.23	23.4.97	26.4.97	Backache	
6.8.98	6.8	8.8.97	Bache	
7/1/98	3/12	3/12	BACK ACHE	
9-3-98	27-2-98	3-3-98	Backache.	
8-5-98	4-5-98	7-5-98	U.R.T.I.	
13.10.98	9.10	13.10	Bache	
18-5-99	10-5-99	13-5-99	U.R.T.I.	
99.11.29	25-11-99	27.11.99	URTI.	
00.06.13	8.6.	9.6.	Branchites	

Pre-placement medical examination: physical examination

PRE-PLACEMENT MEDICAL EXAMINATION

PHYSICAL EXAMINATION

(To be completed by the Medical Department)

DATE	95. 03. 01	TIME 15H50	
HEIGHT	1.70 m	MASS	66 kg.
BLOOD PRESSURE	110/70	PULSE	68
URINE ANALYSIS	NAD	Cannabinoids	Neg
VISION (without glasses)	L 6/6 R 6/6	READING TEST	✓
VISION (with glasses)	L 6/ R 6/	COLOUR PERCEPTION	
EYES	✓	EARS ✓	
MOUTH	✓	TEETH ✓	
NOSE	✓	THROAT ✓	
CHEST & LUNGS cxR: NAD	Clear	HEART	Sounds closed
BREASTS		PREGNANCY TEST	
ABDOMEN	✓	HERNIA	nil
GENITALIA		Audiogram	- 33 dBA
SPINE	✓	REFLEXES	Good ✓✓
EXTREMITIES	No problem	VARICOSITIES	
SKIN	✓	SCARS Stab wound (lt) posterior chest	

POSITION APPLIED FOR :

DEPARTMENT :

FOLLOWING EXAMINATION, I HAVE FOUND THE ABOVE EMPLOYEE TO BE :

FIT FOR EMPLOYMENT / FIT FOR SELECTED WORK / FIT FOR RESTRICTED WORK / UNFIT

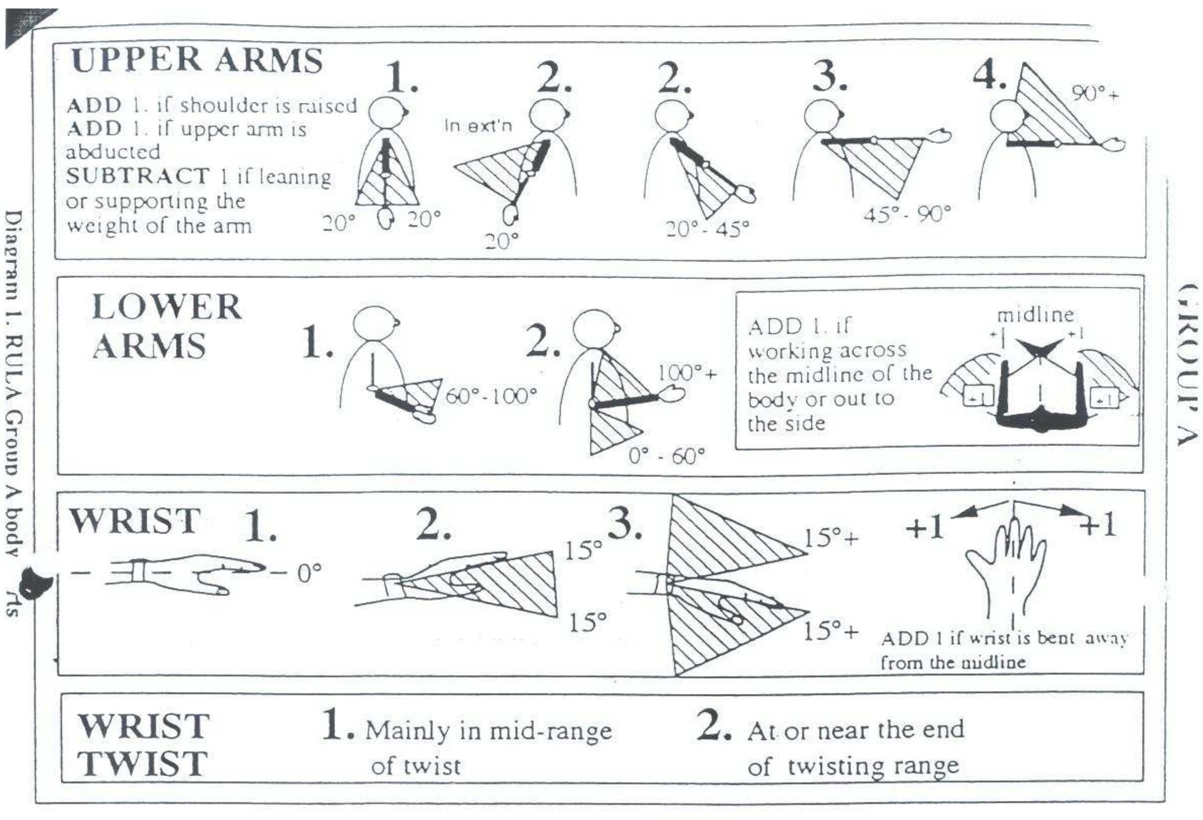
SIGNATURE OF EXAMINING PHYSICIAN: ....

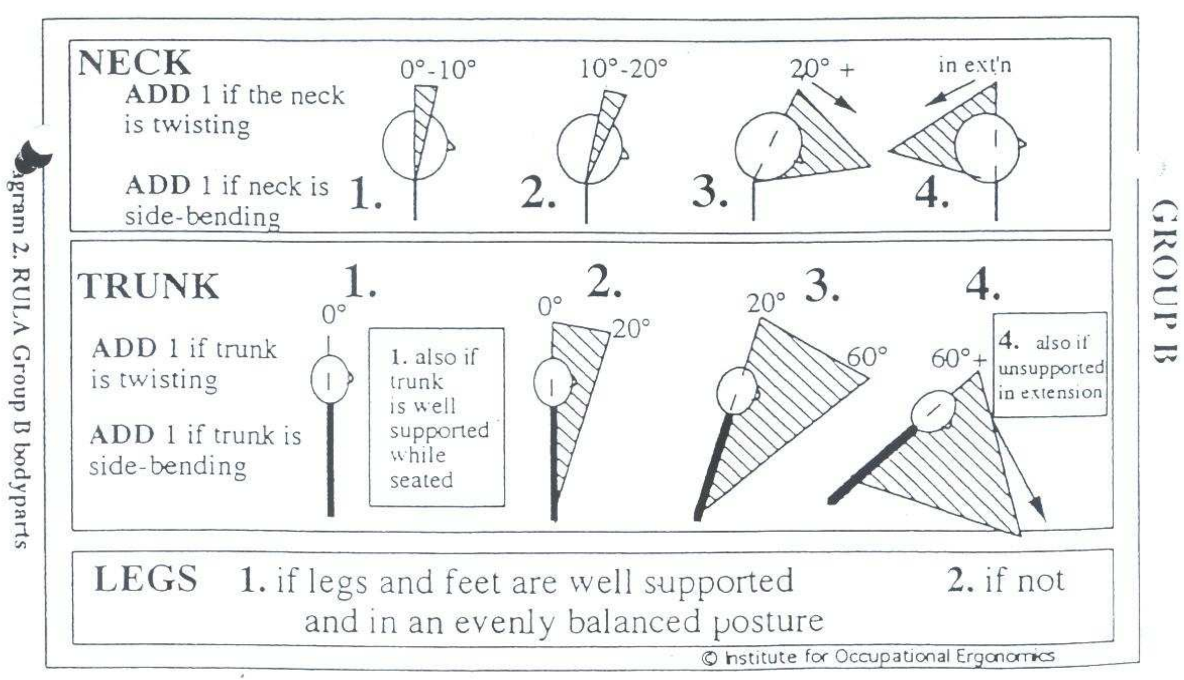
APPENDIX B: RISK ASSESSMENT TOOLS

Rapid Upper Limb Assessment Tool (RULA) worksheet

Rapid Entire Body Assessment Tool (REBA) worksheet

Rapid Upper Limb Assessment Tool (RULA) worksheet





Rapid Entire Body Assessment Tool (REBA) worksheet

REBA

Rapid Entire Body Assessment (REBA) Date: / /

Task	Analyst

Group A			Group B			
Posture/Range	Score	Total	Posture/Range	Score	Total: Left and Right	
Trunk			**Upper Arms** (Shoulders)		L	R
Upright	1	If back is twisted or tilted to side: +1	Flexion: 0-20° Extension: 0-20°	1	Arm Abducted / Rotated: +1 Shoulder Raised: +1 Arm Supported: -1	
Flexion: 0-20° Extension: 0-20°	2		Flexion: 20-45° Extension: >20°	2		
Flexion: 20-60° Extension: >20°	3		Flexion: 45-90°	3		
Flexion: >60°	4		Flexion: >90°	4		
Neck			**Lower Arms** (Elbows)		L	R
Flexion: 0-20°	1	If neck is twisted or tilted to side: +1	Flexion: 60-100°	1	No Adjustments	
Flexion: >20° Extension: >20°	2		Flexion: <60° Flexion: >100°	2		
Legs			**Wrists**		L	R
Bilateral Wt Bearing; Walk; Sit	1	Knee(s) Flexion 30-60°: +1 Knee(s) Flexion >60°: +2	Flexion: 0-15° Extension: 0-15°	1	Wrist Deviated / Twisted: +1	
Unilateral Wt Bearing; Unstable	2		Flexion: >15° Extension: >15°	2		
Score from Table A			**Score from Table B**		L	R
Load / Force			**Coupling**		L	R
< 5 kg < 11 lb	0	Shock or Rapid Buildup: +1	Good	0	No Adjustments	
5 - 10 kg 11 - 22 lb	1		Fair	1		
> 10 kg > 22 lb	2		Poor	2		
Score A [Table A + Load/Force Score]			Unacceptable	3	Left	Right
Activity			**Score B** [Table B + Coupling Score]		L	R
One or more body parts are static for longer than 1 minute	+1		**Score C** (from Table C)		L	R
Repeat small range motions, more than 4 per minute	+1		**Activity Score**		L	R
Rapid large changes in posture or unstable base	+1		**REBA Score** [Score C + Activity Score]		L	R

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APPENDIX C: GENERAL INFORMATION

Equipment Checklist

Protocol information for subjects

Subject Consent Form

Pre-test instructions

Feedback issues

Equipment Checklist

General equipment

Stationery

Batteries for EMG unit

Subject Data Sheets

Informed Consent Form

Letter to Subject

Order of procedures

Clock

Paper towelling

Camera

Milton

Cotton wool

Fixomull tape

Anthropometrical equipment

Scale

Stadiometer

Dynamometer for strength measurements

Biomechanical equipment

Electromyography (EMG) unit and laptop

Electrodes

Physiological equipment

Quark b^2 (including 3L syringe, masks and head caps, gas cylinder, laptop)

Heart rate monitors

Psychophysical equipment

Body Discomfort Map and Scale

Protocol information for subjects

Dear ______________________________,

Thank you for your offer to participate in this study, your assistance is much appreciated. This letter will explain the aim of the project, the procedures that will be followed, and the potential risks and benefits involved. Please read it carefully and sign the accompanying consent form.

AIM OF THE STUDY

Your heart rate (HR), rate of oxygen consumption (VO_2) and muscle activity will be measured during different static overhead postures, and then used to identify the effect of overhead work found within many automotive industries. It is hoped that the postures you adopt will elicit responses and will thereby give an indication of the strain of certain overhead tasks. The study focuses on the overhead tasks that workers have to perform in car assembly lines, and the aim is to identify and highlight the effects that this has on their bodies.

PROCEDURES

You will be required to attend one session of approximately 45 minutes at the Human Kinetics and Ergonomics Department. Your stature and mass will be recorded, and you will then practise and perform the overhead protocol. The protocol will require you to maintain varying static postures, ranging from a reference position with your arms comfortably placed in front of you, to a posture with an overhead reach distance of 40cm added to your individual stature, and a restricted posture of 20cm below your stature. There are seven different postures which will be adopted and you will be required to complete two sets of the postures, including holding only your arms above your head, and the other half requiring the holding of 4kg overhead. This test will last for

45 minutes, during which time your HR, VO_2, muscle activity and body discomfort will be recorded.

VO_2 will be measured by gas analysis equipment, which requires you to wear a mask over your nose and mouth. It is important that you do not talk or laugh during the tests as this will interrupt your breathing pattern, which will influence results. Your HR will be measured with a heart rate monitor, consisting of a strap worn around your chest under your clothing. At the end of each test you will be shown a diagram of the various areas of the body, and asked to point out which areas experienced the most discomfort during the protocol and assign a rating from 1 (mild discomfort) to 10 (severe discomfort), by pointing to the chart every two minutes. Your muscle activity will be monitored with an electromyography (EMG) unit, via electrodes placed on the location of eight different identified muscles.

RISKS AND BENEFITS

It is unlikely that you will experience any injuries during this study as the procedures involved are well-established and safe. Possible risks include the chance of muscular discomfort. If you feel unable to complete the protocol you may stop the test at any point. Please also report any symptoms such as dizziness, difficulty in breathing or nausea, to the tester immediately.

In the unlikely event of incurring an injury during the study, the Human Kinetics and Ergonomics Department will be liable for any costs which may ensue and will reimburse the subject to the full amount i.e. Doctor's consultation, application of inflammatory medication (e.g. topical gel) etc. The Department will also assist in applying rehabilitation sessions for the injury if need be. The Department will however waiver any legal recourse against the researcher or Rhodes University in the event the injury is proved to be self-inflicted or due to the negligence of the subject themselves.

Benefits include an increased knowledge of your body’s capacity for work, and you will also contribute to an improved understanding of the demands placed on industrial workers in countries such as South Africa. This will ultimately help to make the work environment a safer and better and place for all.

Thank you again for your participation and cooperation!

Yours sincerely,
Andrew Elliott (Bsc Hons – Department of Human Kinetics and Ergonomics).

Subject Consent Form

I, ____________________________, do hereby consent to participate in the study entitled: *"RISK ASSESSMENT AND THE EFFECTS OF OVERHEAD WORK – AN AUTOMOTIVE INDUSTRY EXAMPLE*". I agree that I have been fully informed, both verbally and in writing, of the procedures involved in this study. I have also been made aware of any potential risks associated with the protocol including muscle discomfort.

I realise that whilst my anonymity will be protected at all times, my results may be published or used for scientific and statistical purposes. I understand the conditions with which I am expected to comply for the duration of the tests, and any queries I have with regards to this have been answered to my satisfaction.

By voluntarily consenting to participate in this research I accept joint responsibility together with the Human Kinetics and Ergonomics Department, whereby should any injury be sustained, the Department will cover any fees incurred and take steps to rehabilitate the injury. I do however waive any legal recourse against the researcher, or against Rhodes University, and will take full responsibility in the event the injury is shown to be self-inflicted. I will inform the researcher immediately if at any point I experience distress or abnormality, and am fully aware that I may withdraw from participation in this study at any time.

I have read and understood the above information, as well as the information provided in the letter accompanying this form. Signed at the Department of Human Kinetics and Ergonomics, Rhodes University, on ___ August 2007.

SUBJECT: ___________________ **(NAME)** _______________________ **(SIGN)**

WITNESS: ___________________ **(NAME)** _______________________ **(SIGN)**

RESEARCHER: ___________________ **(NAME)** _______________________ **(SIGN)**

Pre-test instructions

Please inform the researchers of any factors that you think may influence your results on the day of testing, for example if you are taking prescription medication, are asthmatic, or are ill. Note that if you are injured or have any back or upper limb problems, it is advised that you do not participate in this study. In order for our results to be accurate, we require you to follow certain instructions before completing the test:

FOR 24 HOURS PRIOR TO TESTING:

- **Do not drink alcohol.**
- **Do not participate in strenuous exercise.**
- **Do not take medication (such as painkillers, aspirin, flu tablets etc) unless absolutely necessary.**
- **Try to get at least 8 hours of sleep the night before the test.**

ON THE DAY OF TESTING:

- **Eat a good meal about 2 hours before the test.**
- **Do not eat anything for 1.5 hours prior to testing.**

Please try to comply with these rules as it will help us greatly in our data collection. We appreciate your cooperation.

Feedback issues

All subjects will be provided with written feedback, individually, at the start of the fourth term of 2007, by which time all testing will have been completed. The project itself will not be completed until 15 December 2007.

Privacy, anonymity and confidentiality issues

a) Data will be archived on the computer software package used during data collection, known as the Quark b^2 and electromyography (EMG) unit. The physiological and biomechanical responses of the subject during the exercise testing will be recorded and stored in a folder on this computer, for use by the researcher (Andrew Elliott).

b) Only one copy of the data will be stored.

c) Data will be stored indefinitely, as students may or may not require access to the data in the future.

d) Data will be stored so that it can be used as an example of how the Quark b^2 and EMG operates, and can contribute to the establishment of a larger database on the energy costs of manual labour.

e) Subjects were numbered in this project and therefore their names, and correspondingly their identities, were not made available to others.

Subjects were informed in their consent forms that although their anonymity would be protected at all times, their results may be used for scientific and statistical purposes. In this way their consent was ethically extended for re-usage of their data.
The Rhodes University Human Kinetics and Ergonomics department will be used as the location for testing to take place, as is customary for postgraduate studies.

APPENDIX D: DATA COLLECTION

Order of procedures

Permutation table of order of conditions for each subject

Data collection sheets:

- Subject data sheet
- Biomechanical data sheet
- Physiological and psychophysical data sheet

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 using a polar heart rate monitor which 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 looking at is your EE and oxygen consumption.

Biomechanical equipment:

Using EMG, which monitors muscle activity throughout testing. This is done by placing electrodes all on specific muscles. We will locate the muscles by asking you to palpate the muscles or 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 in time, 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 say three.

5. Are there any questions?
6. If you could please read a letter of information on the project, and then if you have any more questions please ask. Then once you have read the information on the protocol and are happy, if you could sign a letter of informed consent for ethical reasons. Also this clears you of any injury and that you are able to participate.
7. Opportunity to practise protocols.

8. Any questions?

9. Room 30: take stature and mass.

10. If there no more questions, find out suitable date to come in for testing.

Pre-test: 07h20 (every morning)

- charge batteries
- calibrate Quark b^2
- place markers on measured beam to match stature of individual to be tested.

Testing

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

24. 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

Permutation tables

Table D1: Permutation table indicating the randomised order of the conditions during the first laboratory testing session for each subject.

Subjects	**Conditions**													
1	7	14	10	6	3	4	13	9	11	8	2	5	1	12
2	1	13	9	12	11	7	6	8	5	4	10	2	3	14
3	10	4	8	2	5	12	3	14	7	13	11	1	9	6
4	13	10	14	8	2	9	7	1	12	6	5	3	4	11
5	9	11	5	10	14	6	8	12	4	3	13	7	2	1
6	2	6	3	9	10	14	4	5	1	12	7	13	11	8
7	3	1	4	5	12	10	14	7	2	11	8	6	13	9
8	14	3	6	7	8	2	9	13	10	5	1	11	12	4
9	4	2	1	13	6	5	12	11	8	14	3	9	7	10
10	5	7	12	14	9	8	11	4	13	1	6	10	2	3
11	6	5	13	11	7	1	10	2	3	9	14	12	8	4
12	8	9	11	4	1	3	2	10	6	7	12	14	5	13
13	11	12	7	3	4	13	1	6	9	2	10	8	14	5
14	12	8	2	1	13	11	5	3	14	10	9	4	6	7

Table D1 only refers to fourteen subjects as this randomised order was merely doubled for the remaining fourteen subjects. Each order of the conditions was therefore utilised twice throughout testing (total number of subjects: n = 28).

Table D2: Permutation table indicating the randomised order of the conditions during the retest (for the 0mm condition) for each subject.

Subjects	**Conditions**					
1	1	6	5	3	4	2
2	3	4	1	5	2	6
3	4	2	1	5	6	3
4	2	1	6	3	5	4
5	1	2	6	3	5	4
6	6	4	3	5	2	1

Table D2 only refers to six subjects as this randomised order was merely repeated for the remaining 22 subjects. Each order of the conditions was therefore utilised four times throughout testing, with some having to be adopted five times as the number of subjects was not divisible by the number of conditions (total number of subjects: n = 28).

SUBJECT DATA SHEET

NAME: ______________________________ **CODE:** ____

AGE: __________________

STATURE: __________________

MASS: __________________

BMI: __________________

RESTING HR: __________________

ADDITIONAL COMMENTS: ____

____

____

Biomechanical data sheet

CONDITION (in random order)	**START TIME**	**END TIME**	**TIME**
-200 no weight (7)			
Rest			
-200 with weight (14)			
Rest			
+200 with weight (10)			
Rest			
-100 no weight (6)			
Rest			
+200 no weight (3)			
Rest			
+300 no weight (4)			
Rest			
-100 with weight (13)			
Rest			
+100 with weight (9)			
Rest			

+300 with weight (11)			
Rest			
Reference with weight (8)			
Rest			
+100 no weight (2)			
Rest			
+400 no weight (5)			
Rest			
Reference no weight (1)			
Rest			
+400 with weight (12)			

Physiological and psychophysical data sheet

			Body discomfort			
Condition (in random order)	**Time**	**Heart rate** (bt.min^{-1})	**Area**	**R/L**	**A/P**	**Rating**
+300mm W						
Rest						
+400mm W						
Rest						
-200mm NW						
Rest						
+200mm NW						
Rest						
+300mm NW						
Rest						
-100mm W						
Rest						

			Body discomfort			
Condition	**Time**	**Heart rate (bt.min^{-1})**	**Area**	**R/L**	**A/P**	**Rating**
Reference NW						
Rest						
-100mm NW						
Rest						
+100mm W						
Rest						
+100mm NW						
Rest						
+200mm W						
Rest						
Reference W						
Rest						

			Body discomfort			
Condition	**Time**	**Heart rate** (bt.min^{-1})	**Area**	**R/L**	**A/P**	**Rating**
-200mm W						
Rest						
+400mm NW						
Rest						
End task						

APPENDIX E: SUMMARY REPORTS

Physiological formulae and variables

Statistica Printout

Ergospirometer (Quark b^2) Printout

Physiological Findings

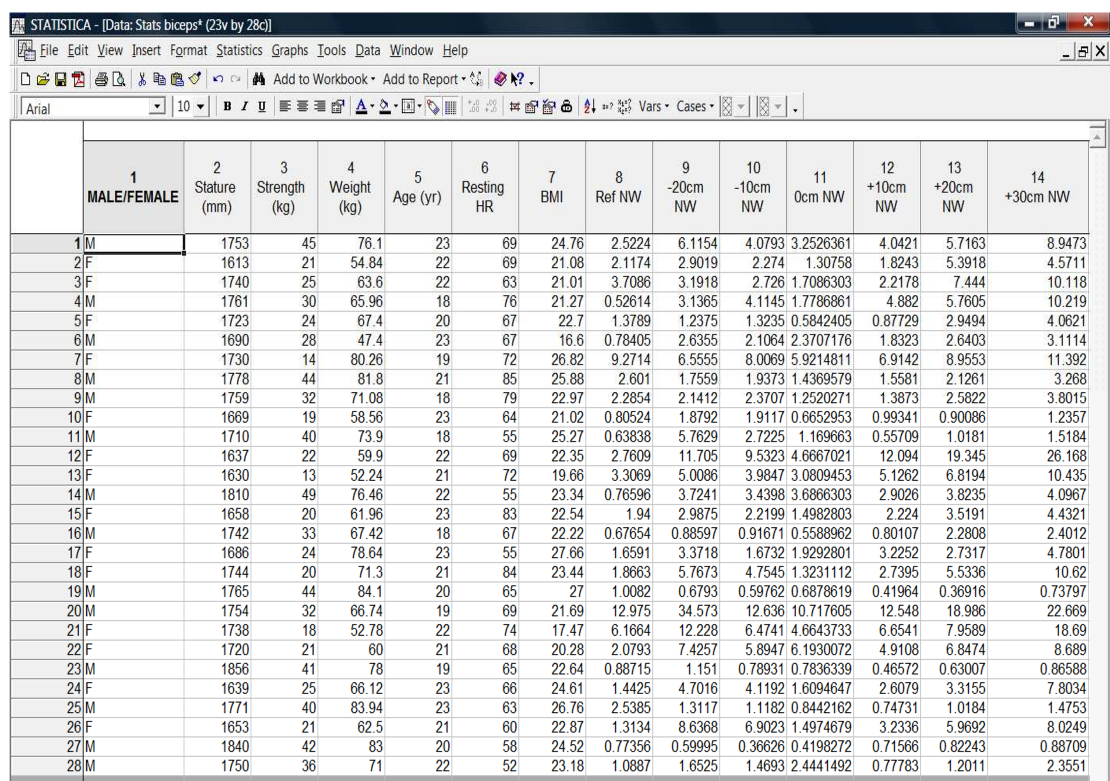
EMG Printout

Biomechanical Findings

Differences in the male and female responses

Statistica printout

Main table for each muscle and physiological variable (not all conditions are shown on the screen due to space)



STATISTICA - [Data: Stats biceps* (23v by 28c)]

File Edit View Insert Format Statistics Graphs Tools Data Window Help

	1 MALE/FEMALE	2 Stature (mm)	3 Strength (kg)	4 Weight (kg)	5 Age (yr)	6 Resting HR	7 BMI	8 Ref NW	9 -20cm NW	10 -10cm NW	11 0cm NW	12 +10cm NW	13 +20cm NW	14 +30cm NW
1	M	1753	45	76.1	23	69	24.76	2.5224	6.1154	4.0793	3.2526361	4.0421	5.7163	8.9473
2	F	1613	21	54.84	22	69	21.08	2.1174	2.9019	2.274	1.30758	1.8243	5.3918	4.5711
3	F	1740	25	63.6	22	63	21.01	3.7086	3.1918	2.726	1.7086303	2.2178	7.444	10.118
4	M	1761	30	65.96	18	76	21.27	0.52614	3.1365	4.1145	1.7786861	4.882	5.7605	10.219
5	F	1723	24	67.4	20	67	22.7	1.3789	1.2375	1.3235	0.5842405	0.87729	2.9494	4.0621
6	M	1690	28	47.4	23	67	16.6	0.78405	2.6355	2.1064	2.3707176	1.8323	2.6403	3.1114
7	F	1730	14	80.26	19	72	26.82	9.2714	6.5555	8.0069	5.9214811	6.9142	8.9553	11.392
8	M	1778	44	81.8	21	85	25.88	2.601	1.7559	1.9373	1.4369579	1.5581	2.1261	3.268
9	M	1759	32	71.08	18	79	22.97	2.2854	2.1412	2.3707	1.2520271	1.3873	2.5822	3.8015
10	F	1669	19	58.56	23	64	21.02	0.80524	1.8792	1.9117	0.6652953	0.99341	0.90086	1.2357
11	M	1710	40	73.9	18	55	25.27	0.63838	5.7629	2.7225	1.169663	0.55709	1.0181	1.5184
12	F	1637	22	59.9	22	69	22.35	2.7609	11.705	9.5323	4.6667021	12.094	19.345	26.168
13	F	1630	13	52.24	21	72	19.66	3.3069	5.0086	3.9847	3.0809453	5.1262	6.8194	10.435
14	M	1810	49	76.46	22	55	23.34	0.76596	3.7241	3.4398	3.6866303	2.9026	3.8235	4.0967
15	F	1658	20	61.96	23	83	22.54	1.94	2.9875	2.2199	1.4982803	2.224	3.5191	4.4321
16	M	1742	33	67.42	18	67	22.22	0.67654	0.88597	0.91671	0.5588962	0.80107	2.2808	2.4012
17	F	1686	24	78.64	23	55	27.66	1.6591	3.3718	1.6732	1.9292801	3.2252	2.7317	4.7801
18	F	1744	20	71.3	21	84	23.44	1.8663	5.7673	4.7545	1.3231112	2.7395	5.5336	10.62
19	M	1765	44	84.1	20	65	27	1.0082	0.6793	0.59762	0.6878619	0.41964	0.36916	0.73797
20	M	1754	32	66.74	19	69	21.69	12.975	34.573	12.636	10.717605	12.548	18.986	22.669
21	F	1738	18	52.78	22	74	17.47	6.1664	12.228	6.4741	4.6643733	6.6541	7.9589	18.69
22	F	1720	21	60	21	68	20.28	2.0793	7.4257	5.8947	6.1930072	4.9108	6.8474	8.689
23	M	1856	41	78	19	65	22.64	0.88715	1.151	0.78931	0.7836339	0.46572	0.63007	0.86588
24	F	1639	25	66.12	23	66	24.61	1.4425	4.7016	4.1192	1.6094647	2.6079	3.3155	7.8034
25	M	1771	40	83.94	23	63	26.76	2.5385	1.3117	1.1182	0.8442162	0.74731	1.0184	1.4753
26	F	1653	21	62.5	21	60	22.87	1.3134	8.6368	6.9023	1.4974679	3.2336	5.9692	8.0249
27	M	1840	42	83	20	58	24.52	0.77356	0.59995	0.36626	0.4198272	0.71566	0.82243	0.88709
28	M	1750	36	71	22	52	23.18	1.0887	1.6525	1.4693	2.4441492	0.77783	1.2011	2.3551

Example of Statistica printout for repeated measures ANOVA

Repeated Measures Analysis of Variance (Stats biceps)
Sigma-restricted parameterization
Effective hypothesis decomposition

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	18752.54	1	18752.54	33.74136	0.000004
MALE/FEMALE	1706.38	1	1706.38	3.07028	0.091524
Error	14450.10	26	555.77		
WEIGHT	1521.46	1	1521.46	19.96169	0.000137
WEIGHT*MALE/FEMALE	273.72	1	273.72	3.59119	0.069258
Error	1981.70	26	76.22		
HEIGHT	2867.82	6	477.97	17.99422	0.000000
HEIGHT*MALE/FEMALE	658.25	6	109.71	4.13018	0.000705
Error	4143.74	156	26.56		
WEIGHT*HEIGHT	385.37	6	64.23	3.68783	0.001871
WEIGHT*HEIGHT*MALE/FEMALE	150.15	6	25.02	1.43688	0.203830
Error	2716.92	156	17.42		

Physiological formulae and variables

Age Predicted Maximum Heart Rate (HR_{max}) in bt.min^{-1}:

HR_{max} = 220 – age (in years)

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

Number of breaths per minute

Tidal Volume (VT) in L:

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

Minute ventilation (VE) in L.min^{-1}:

The amount of air breathed in every minute, a function of breathing rate and tidal volume:

VE = Breathing frequency × Tidal volume

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

The amount of oxygen consumed by the body each minute.

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

Energy expenditure (EE):

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

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

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

Metabolic equivalent (MET):

Multiple of resting metabolic rate:

1 MET = 3.5ml.kg^{-1}.min^{-1}

Ergospirometer (Quark b^2) printout

(limited section shown as duration of protocol was 45 minutes)

	A	B	C	D	E	F	G	H
1	t	Rf	HR	VT	VE	VO2	EEm	
2	hh:mm:ss	b/min	bpm	l	l/min	ml/min	Kcal/min	
3								
4	00:00:01	22.6415	89	0.60013	13.5878	344.165	1.66808	
5	00:00:05	18.6335	93	0.71954	13.4076	395.977	1.87253	
6	00:00:10	14.6699	94	0.63687	9.34286	230.435	1.11887	
7	00:00:13	20.339	90	0.58788	11.9569	235.277	1.17714	
8	00:00:16	16.2162	85	0.64708	10.4932	237.455	1.17393	
9	00:00:20	18.4615	82	0.68586	12.6621	353.283	1.69278	
10	00:00:23	18.4615	81	0.53277	9.83571	244.553	1.14893	
11	00:00:26	18.1818	83	0.64504	11.7279	316.879	1.51956	
12	00:00:30	15.5844	82	0.49705	7.74617	188.096	0.88666	
13	00:00:34	14.2518	82	0.68382	9.74566	207.837	1.03352	
14	00:00:38	14.4928	81	0.6236	9.03773	252.01	1.19433	
15	00:00:42	15.1515	82	0.63789	9.66503	245.976	1.18644	
16	00:00:45	18.5185	84	0.59503	11.019	324.751	1.52404	
17	00:00:49	18.2371	84	0.58584	10.684	249.321	1.20636	
18	00:00:53	15.6658	85	0.56747	8.88985	219.564	1.05107	
19	00:00:57	13.8889	84	0.60115	8.3493	194.494	0.95182	
20	00:01:00	18.5759	84	0.61136	11.3565	254.029	1.24799	
21	00:01:03	19.6078	84	0.81446	15.9698	463.791	2.20012	
22	00:01:06	24.6914	84	0.58992	14.566	397.282	1.86816	
23	00:01:09	18.1818	84	1.08901	19.8002	584.584	2.83228	
24	00:01:12	22.7273	84	0.5787	13.1522	288.541	1.42369	
25	00:01:13	42.8571	84	0.36028	15.4406	314.279	1.46988	
26	00:01:18	13.1579	81	1.70445	22.4269	661.222	3.21026	
27	00:01:20	23.5294	80	0.37253	8.76539	203.858	0.93379	
28	00:01:23	24.4898	78	0.5491	13.4473	351.368	1.67131	
29	00:01:26	18.8679	77	0.67872	12.806	365.497	1.74058	
30	00:01:29	20.339	76	0.6828	13.8875	397.612	1.92404	
31	00:01:32	16.9972	77	0.61442	10.4434	314.916	1.49953	
32	00:01:36	16.3488	77	0.70321	11.4967	334.342	1.60268	
33	00:01:39	18.75	76	0.60319	11.3098	257.072	1.27196	
34	00:01:43	16.5746	72	0.67361	11.1649	329.912	1.58008	
35	00:01:46	15.7895	69	0.79609	12.5698	419.095	1.97021	
36	00:01:51	13.8249	66	0.63279	8.74824	212.036	1.02244	
37	00:01:55	14.0845	63	0.4552	6.41127	158.799	0.75017	
38	00:01:59	14.2857	61	0.52562	7.5089	224.748	1.04567	
39	00:02:04	13.0152	60	0.68382	8.90005	228.742	1.1253	
40	00:02:08	14.8515	62	0.51542	7.65471	199.2	0.94813	
41	00:02:12	13.9535	64	0.57665	8.04634	241.589	1.12268	
42	00:02:16	14.6699	65	0.495	7.26168	186.763	0.88828	

Sheet1 Sheet2 Sheet3

Physiological Findings

Table E1: Conditions which elicited the highest and lowest physiological values (target height relative to stature with muscle activity values (µV) in brackets).

Variable	No weight		With weight 4kg	
	Highest (mm)	Lowest (mm)	Highest (mm)	Lowest (mm)
Rf **(br.min^{-1})**	-200 (19.81%MVC)	+400 (17.26%MVC)	-200 (23.32%MVC)	+300 (18.40%MVC)
HR **(bt.min^{-1})**	-200 (109.99%MVC)	+200 (81.42%MVC)	-200 (121.06%MVC)	+400 (88.25%MVC)
VT **(L.br^{-1})**	-200 (1.15%MVC)	+200 (0.70%MVC)	-200 (1.14%MVC)	0 & +200 (0.78%MVC & 0.78%MVC)
VE **(L.min^{-1})**	-200 (20.01%MVC)	+200 (11.85%MVC)	-200 (23.78%MVC)	+300 (13.39%MVC)
VO_2 **(ml.min^{-1})**	-200 (661.52%MVC)	+200 (315.12%MVC)	-200 (746.45)	0 (363.85%MVC)
EE **(kcal.h^{-1})**	-200 (194.67%MVC)	+200 (91.77%MVC)	-200 (221.00%MVC)	0 (107.20%MVC)

Physiological Findings (continued)

Table E2: Mean respiratory responses conditions in the protocol. * denotes statistical significance between the "no weight" and "with weight" conditions (standard deviation in brackets, % refers to coefficient of variation).

Condition	Breathing frequency (Rf) (br.min^{-1})		Tidal volume (VT) (L)		Minute ventilation (VE) (L.min^{-1})	
	No weight	With weight (4kg)	No weight	With weight (4kg)	No weight	With weight (4kg)
Reference	16.72* (±3.97) 23.77%	19.10* (±4.14) 21.67%	0.68 (±0.21) 30.61%	0.70 (±0.26) 37.06%	10.52* (±2.37) 22.57%	12.37* (±2.89) 23.37%
-200mm	19.81)* (±5.86) 29.61%	23.32* (±6.01) 25.77%	1.15 (±0.53) 46.07%	1.14 (±0.42) 36.47%	20.01* (±4.68) 23.37%	23.78* (±5.65) 23.77%
-100mm	19.44)* (±5.67) 29.20%	19.80* (±4.95) 25.02%	1.01 (±0.41) 41.16%	1.07 (±0.37) 34.25%	17.13)* (±3.88) 22.62%	19.32* (±4.48) 23.16%
0mm	19.16)* (±5.99) 31.29%	19.09* (±5.63) 29.48%	0.74 (±0.54) 73.03%	0.78 (±0.29) 37.09%	12.03* (±4.17) 34.64%	13.54* (±3.98) 29.40%
+100mm	18.36* (±4.38) 23.85%	20.26* (±5.97) 29.46%	0.78 (±0.41) 52.55%	0.80 (±0.24) 30.10%	12.63* (±3.17) 25.11%	15.03* (±4.81) 32.03%
+200mm	18.50* (±4.58) 24.76%	21.17* (±5.23) 24.70%	0.70 (±0.27) 38.25%	0.78 (±0.26) 33.19%	11.85* (±2.74) 23.11%	15.19* (±3.24) 21.31%
+300mm	18.46 (±4.05) 21.94%	18.40 (±4.37) 23.75%	0.73 (±0.23) 31.27%	0.79 (±0.29) 36.25%	12.51 (±2.37) 18.93%	13.39 (±3.15) 23.51%
+400mm	17.26 (±4.20) 24.34%	19.46 (±4.38) 22.51%	0.85 (±0.39) 46.41%	0.80 (±0.30) 37.20%	12.93 (±3.27) 25.25%	14.38 (±3.49) 24.29%

Physiological Findings (continued)

Table E3: Mean oxygen consumption over all the conditions. * denotes statistical significance between the changes in height levels and the "no weight" and "with weight" conditions (standard deviation in brackets, % refers to coefficient of variation).

Condition	VO_2 (ml.min^{-1})		VO_2 (ml.kg^{-1}.min^{-1})	
	No weight	With weight (4kg)	No weight	With weight (4kg)
Reference	280.51 * (±77.94) 27.79%	325.48 * (±75.61) 23.23%	4.09 * (±0.90) 22.04%	4.74 * (±0.77) 16.15%
-200mm	661.52 * (±156.54) 23.66%	746.45 * (±174.75) 23.41%	9.68 * (±1.82) 18.77%	10.95 * (±2.16) 19.79%
-100mm	556.81 * (±138.61) 24.89%	634.59 * (±133.22) 20.99%	8.10 * (±1.49) 18.37%	9.34 * (±1.81) 19.33%
0mm	320.89 * (±111.05) 34.61%	363.85 * (±107.17) 29.45%	4.63 * (±1.25) 26.92%	5.29 * (±1.23) 23.17%
+100mm	349.53 * (±118.71) 33.96%	404.09 * (±123.15) 30.47	5.06 * (±1.34) 26.42%	5.89 * (±1.59) 27.04%
+200mm	315.12 * (9±2.36) 29.31%	415.71 * (±114.01) 27.42%	4.58 * (±0.97) 21.27%	6.09 * (±1.50) 24.66%
+300mm	345.94 * (±97.21) 28.10%	369.08 * (±91.34) 24.75%	5.04 * (±1.16) 23.10%	5.38 * (±1.06) 19.65%
+400mm	351.05 * (±122.44) 34.88%	392.40 * (±104.91) 26.73%	5.04 * (±1.26) 24.99%	5.72 * (±1.23) 21.58%

Physiological Findings (continued)

Table 4: Overall mean energy expenditure of all target heights relative to stature (standard deviation in brackets, % refers to coefficient of variation). * denotes statistical significance between the changes in height levels and the weight conditions

Condition	EE ($kcal.min^{-1}$)		EE ($kcal.h^{-1}$)		EE ($kcal.kg^{-1}.day^{-1}$)		MET	
	No weight	With weight (4kg)	No weight	With weight (4kg)	No weight	With weight (4kg)	No weight	With weight (4kg)
Reference	1.36* (±0.38) 28.01%	1.59* (±0.38) 23.97%	81.60 (±22.86) 28.01%	95.32 (±22.84) 23.97%	28.50 (±6.09) 21.36%	33.25 (±5.30) 15.94%	1.17 (±0.26) 22.04%	1.35 (±0.22) 16.15%
-200mm	3.24* (±0.81) 24.98%	3.68* (±0.90) 24.33%	194.67 (±48.62) 24.98%	221.00 (±53.78) 24.33%	68.20 (±13.16) 19.30%	77.58 (±15.62) 20.13%	2.76 (±0.52) 18.77%	3.12 (±0.62) 19.79%
-100mm	2.71* (±0.69) 25.61%	3.10* (±0.68) 21.90%	162.36 (41.59) 25.61%	185.84 (±40.71) 21.90%	56.57 (±10.33) 18.25%	65.53 (±12.70) 19.39%	2.31 (±0.43) 18.37%	2.67 (±0.52) 19.33%
0mm	1.55* (±0.55) 35.47%	1.79* (±0.57) 31.73%	93.27 (33.09) 35.47%	107.20 (±34.01) 31.73%	32.22 (±8.72) 27.06%	37.35 (±9.29) 24.88%	1.32 (±0.36) 26.92%	1.51 (±0.35) 23.17%
+100mm	1.70* (±0.58) 34.28%	1.99* (±0.63) 31.64%	102.06 (34.99) 34.28%	119.48 (±37.80) 31.64%	35.40 (±9.36) 26.46%	41.75 (±11.72) 28.07%	1.45 (±0.38) 26.42%	1.68 (±0.46) 27.04%
+200mm	1.53* (±0.47) 30.54%	2.04* (±0.56) 27.35%	91.77 (±28.02) 30.54%	122.26 (33.44) 27.35%	31.92 (±7.04) 22.05%	42.93 (±10.45) 24.35%	1.31 (±0.28) 21.27%	1.74 (±0.43) 24.66%
+300mm	1.68* (±0.48) 28.55%	1.80* (±0.47) 26.11%	100.84 (±28.79) 28.55%	108.14 (28.24) 26.11%	35.20 (±8.04) 22.84%	37.76 (±7.65) 20.26%	1.44 (±0.33) 23.10%	1.54 (±0.30) 19.65%
+400mm	1.71* (±0.60 34.96%	1.93* (±0.53) 27.36%	102.77 (±35.93) 34.96%	115.96 (31.72) 27.36%	35.37 (±8.70) 24.60%	40.44 (±8.48) 20.98%	1.44 (±0.36) 24.99%	1.63 (±0.35) 21.58%

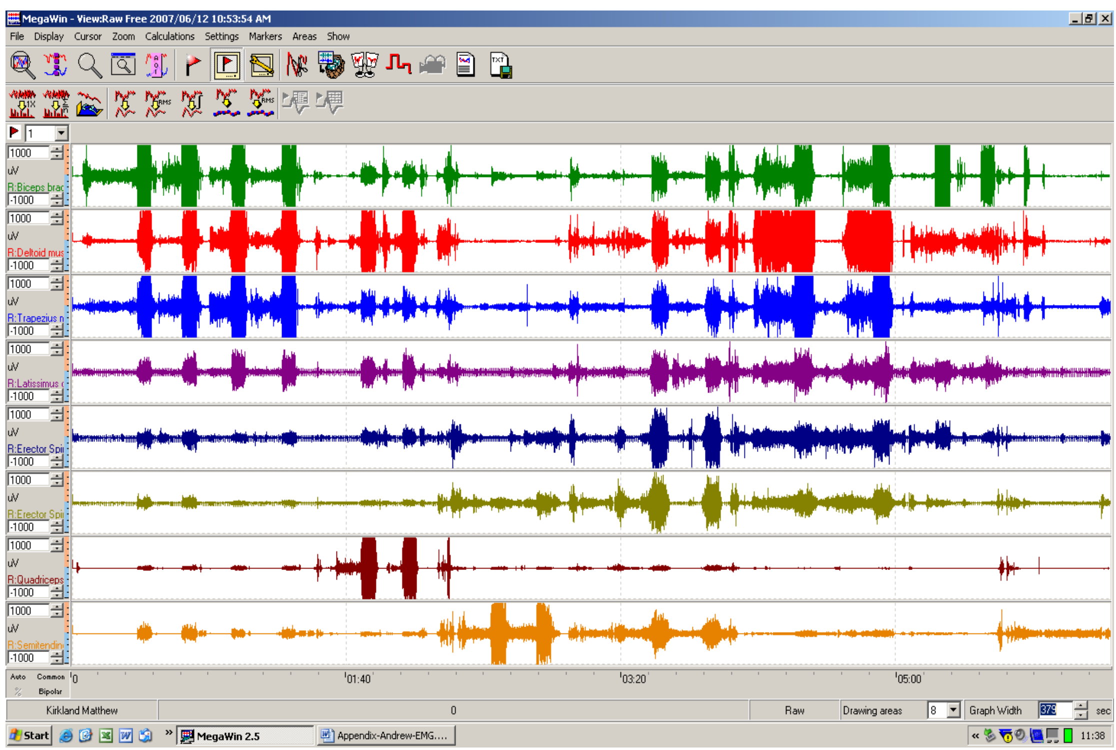
Table E5: Results of t-test which illustrate whether physiological steady state was reached within the variables tested (no sign indicates steady state; a negative indicates a downward trend; a positive indicates an upward trend).

	No weight							**With weight (2x2kg)**						
Variables	**-200 mm**	**-100 mm**	**0 mm**	**+100 mm**	**+200 mm**	**+300 mm**	**+400 mm**	**-200 mm**	**-100 mm**	**0 mm**	**+100 mm**	**+200 mm**	**+300 mm**	**+400 mm**
Breathing frequency (Rf)									+					-
Heart rate (HR)	-	-			+	+			+		+	+	+	+
Tidal volume (VT)					-									
Minute ventilation (VE)									-	+				
Oxygen consumption (VO_2)					+				-	-				
Energy expenditure (EE)					+				-	-				

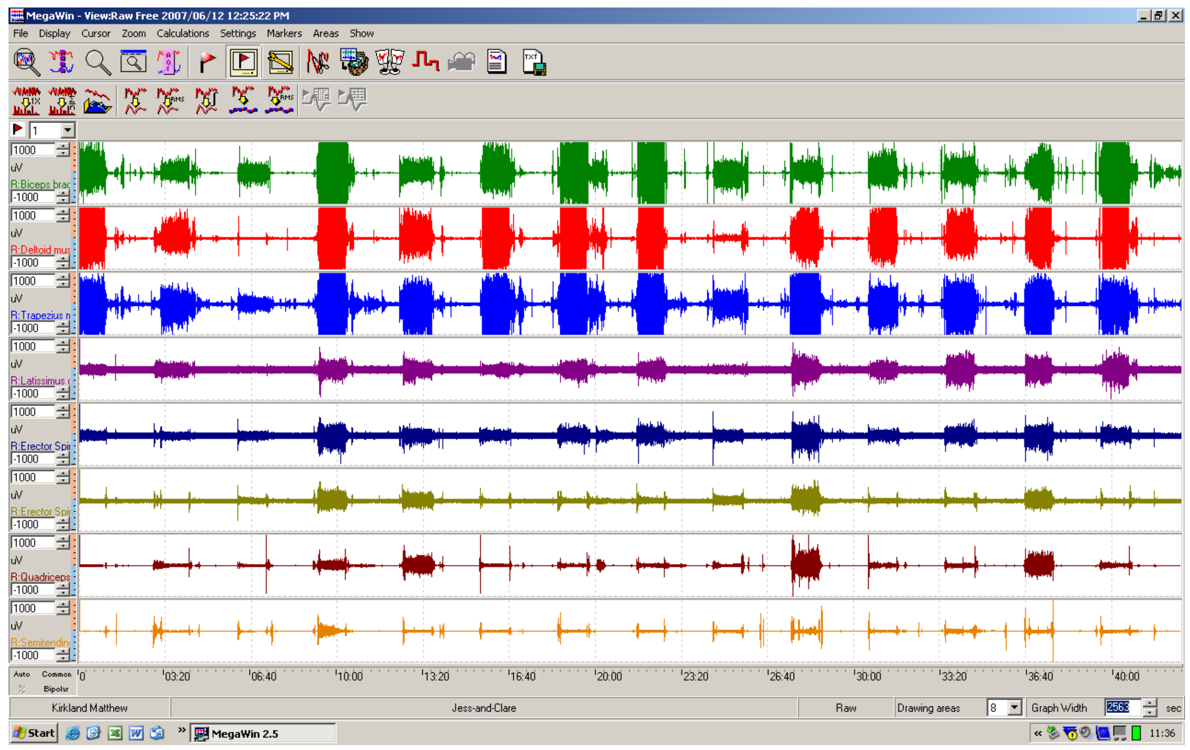
The analysis periods which were compared in the t-test, were from 30 seconds into the condition to the 45 second mark, and this was compared to the last 15 seconds, i.e. from 45 seconds to 1 minute. The majority of the physiological responses (64 out of 84) did not show a significant difference for both periods of time, with a few (9 out of 84) indicating a decrease in activation of the duration of the condition and 11 out of showing an increase.

EMG Printout

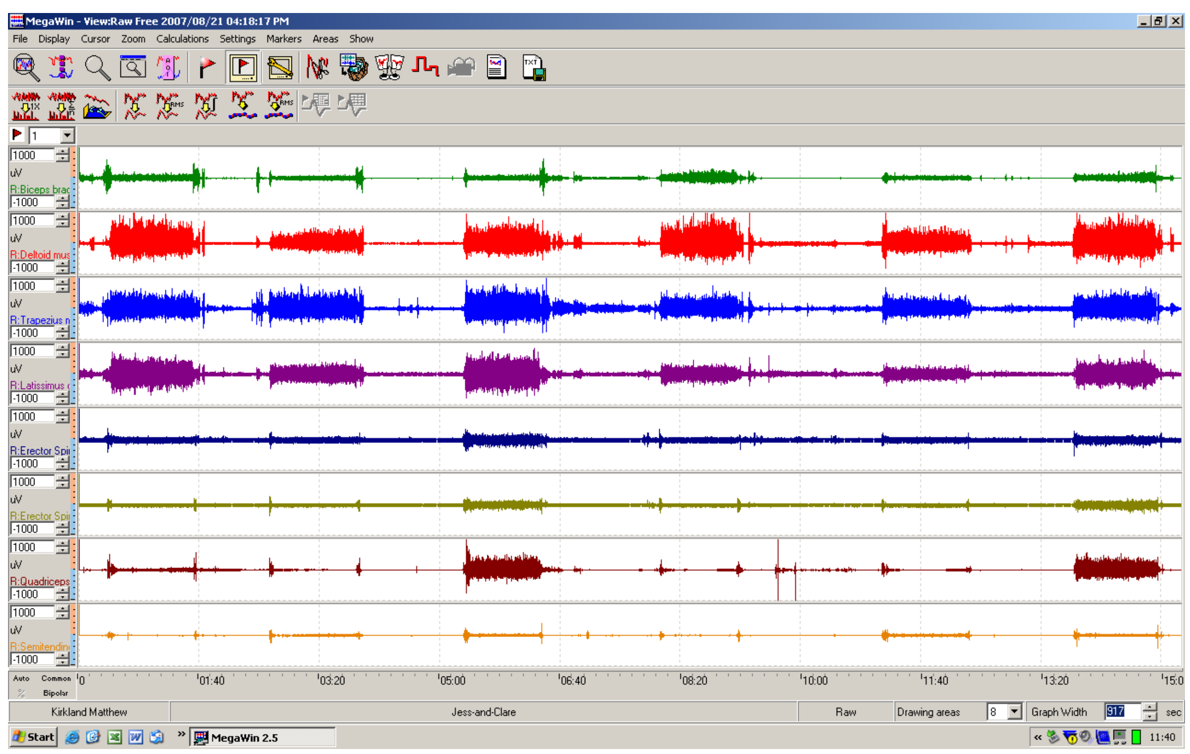
Example of MVC protocol raw data



Example of protocol (14 target heights relative to stature)



Example of retest protocol (addition of 0mm condition)



Biomechanical Findings

Table E6: Target heights relative to stature (mm) which elicited the highest and lowest muscle activity values.

Muscle	No weight		With weight (4kg)	
	Highest (mm)	Lowest (mm)	Highest (mm)	Lowest (mm)
Biceps brachii	+400 (8.36%MVC)	0 (2.43%MVC)	+400 (13.74%MVC)	0 (3.77%MVC)
Middle deltoid	+400 (18.42%MVC)	0 (5.56%MVC)	+400 (25.35%MVC)	0 (7.48%MVC)
Trapezius	-200 (20.97%MVC)	+100 (12.96%MVC)	-200 (33.93%MVC)	+100 (21.45%MVC)
Latissimus dorsi	-200 (17.48%MVC)	+400 (6.52%MVC)	-200 (33.54%MVC)	0 (9.52%MVC)
Upper erector spinae	-200 (23.62%MVC)	+300 (4.49%MVC)	-200 (34.78%MVC)	+400 (7.56%MVC)
Lower erector spinae	-200 (19.75%MVC)	+300 (3.08%MVC)	-200 (27.16%MVC)	+400 (4.75%MVC)
Quadriceps	-200 (33.26%MVC)	0 (1.79%MVC)	-200 (40.38%MVC)	+300 (1.40%MVC)
Semitendinosus	-200 (4.34%MVC)	+200 (1.33%MVC)	-200 (5.28%MVC)	+300 (2.27%MVC)

Table E7: Results of t-test which illustrate whether biomechanical steady state was reached within the variables tested (no sign indicates steady state; a negative indicates a downward trend; a positive indicates an upward trend).

Muscles	No weight							With weight (2x2 kg)						
	-200 mm	-100 mm	0 mm	+100 mm	+200 mm	+300 mm	+400 mm	-200 mm	-100 mm	0 mm	+100 mm	+200 mm	+300 mm	+400 mm
Biceps brachii				-			+							
Middle deltoid				-			-				-			-
trapezius		-											+	
Latissimus dorsi								-						
Upper erector spinae														
Lower erector spinae														
Quadriceps														
Semitendinosus														

The analysis periods which were compared were from 30 seconds into the condition to the 45 second mark, and this was compared to the last 15 seconds, i.e. from 45 seconds to 1 minute. The majority of the muscles and conditions (103 out of 112) did not show a significant difference for both periods of time, with a few (7 out of 112) indicating a decrease in activation of the duration of the condition and two out of 112 showing an increase.

Differences in the male and female responses

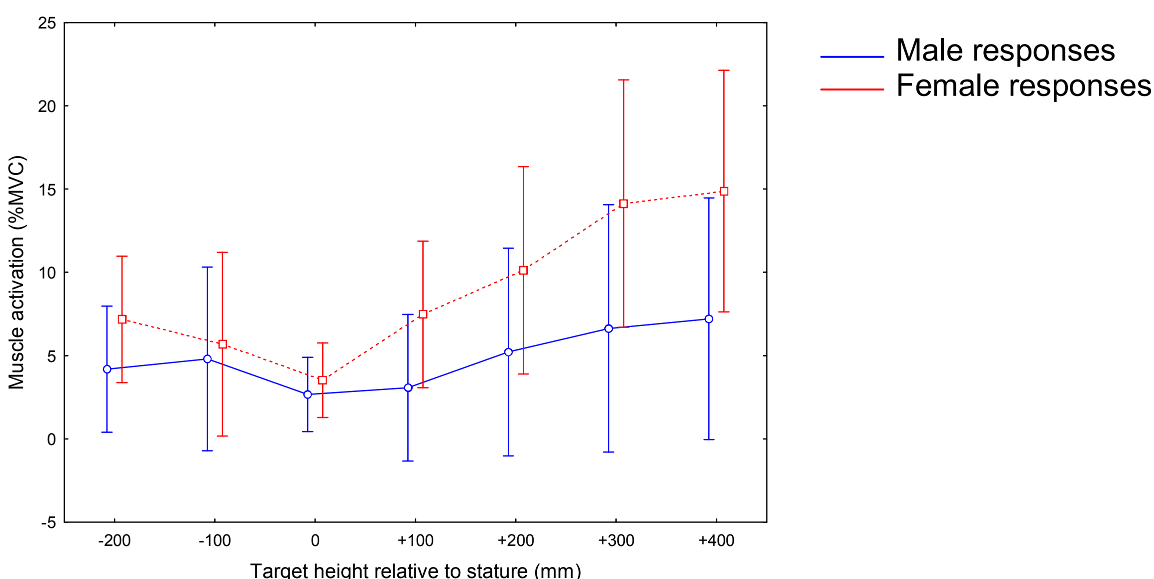


Figure E1: Activation level of the biceps brachii muscle for males and females for the different target heights, represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

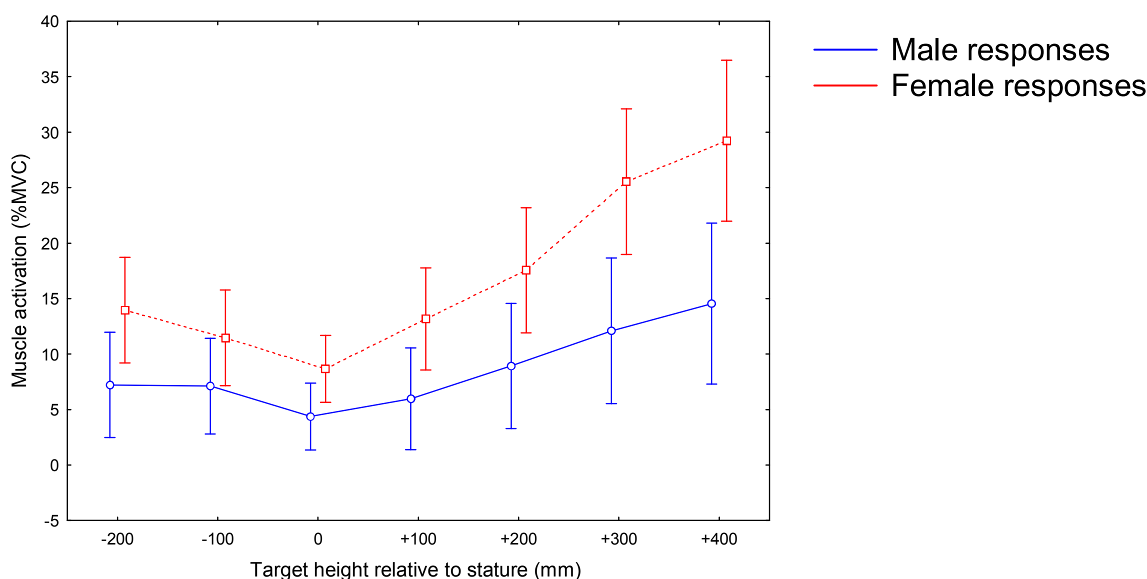


Figure E2: Activation level of the middle deltoid muscle for males and females for the different target heights, represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

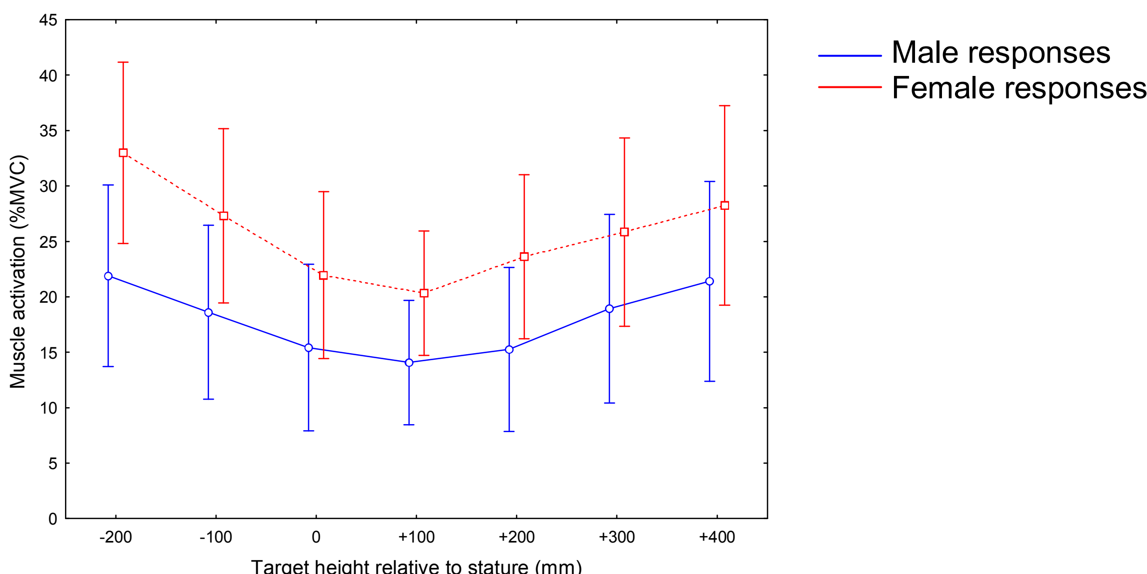


Figure E3: Activation level of the trapezius muscle for males and females for the different target heights, represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

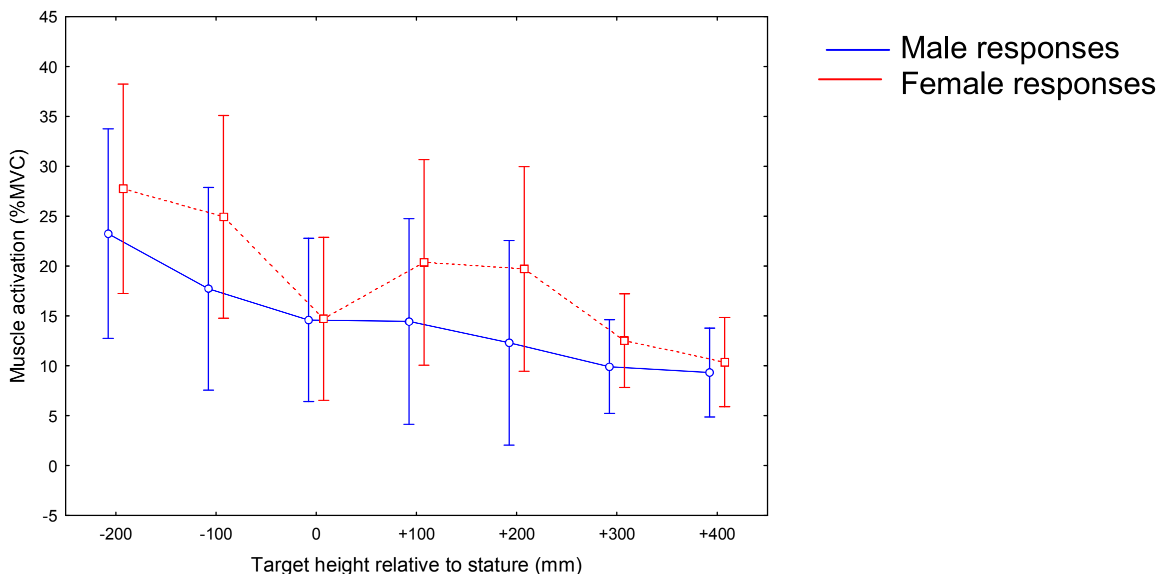


Figure E4: Activation level of the latissimus dorsi muscle for males and females for the different target heights, represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

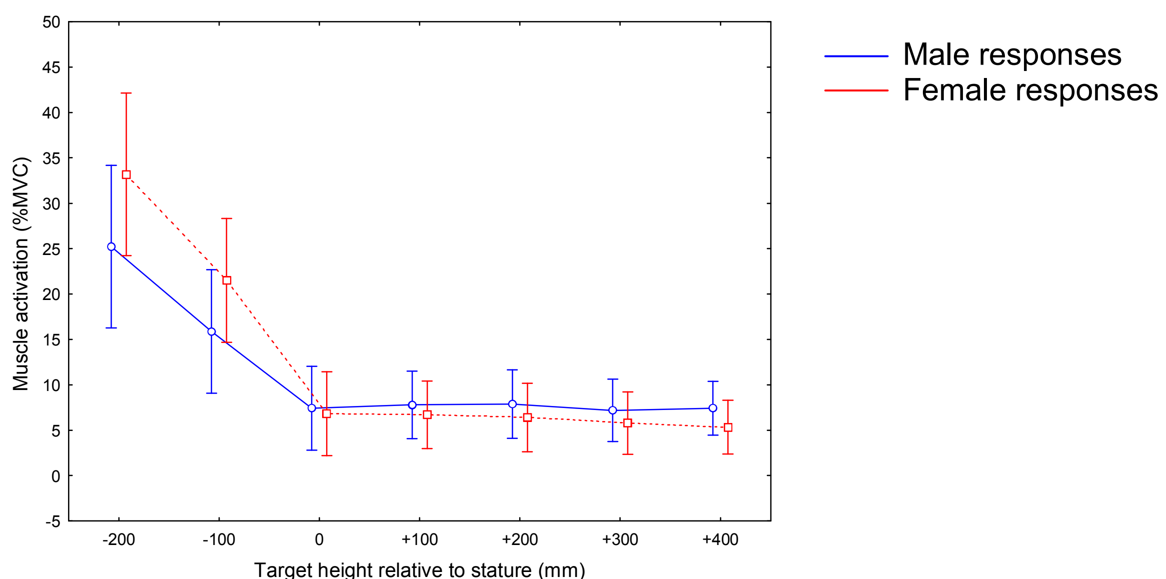


Figure E5: Activation level of the upper erector spinae muscle for males and females for the different target heights, represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

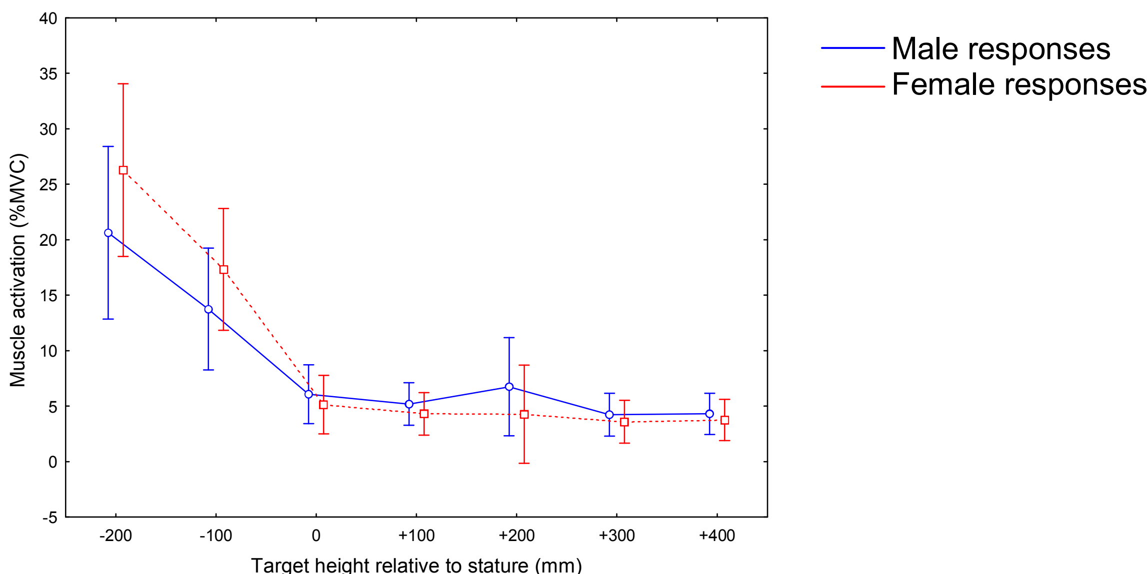


Figure 6: Activation level of the lower erector spinae muscle for males and females for the different target heights, represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

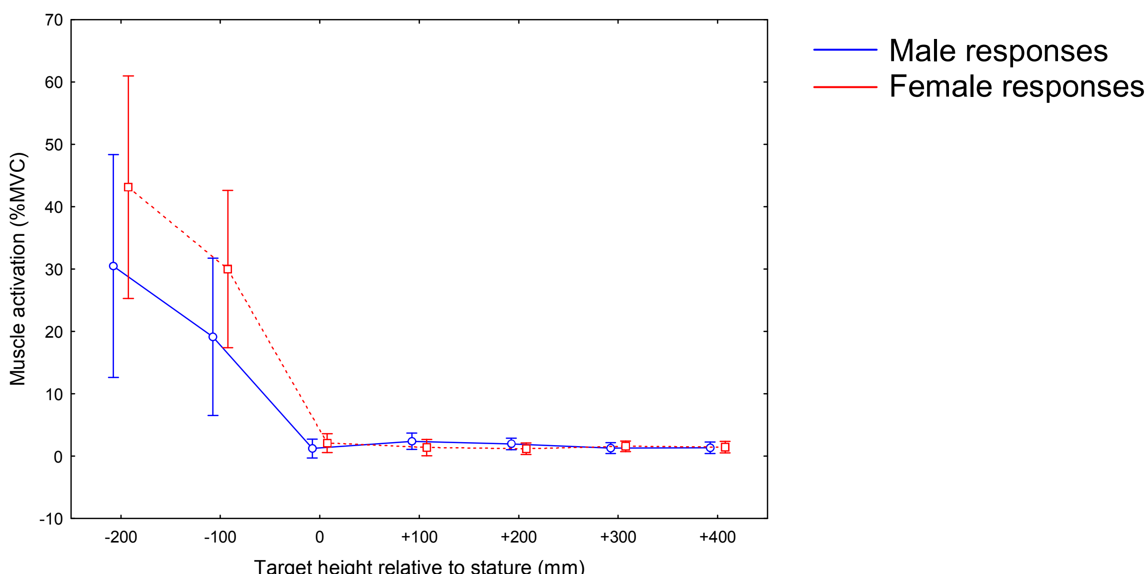


Figure E7: Activation level of the quadriceps muscle for males and females for the different target heights, represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

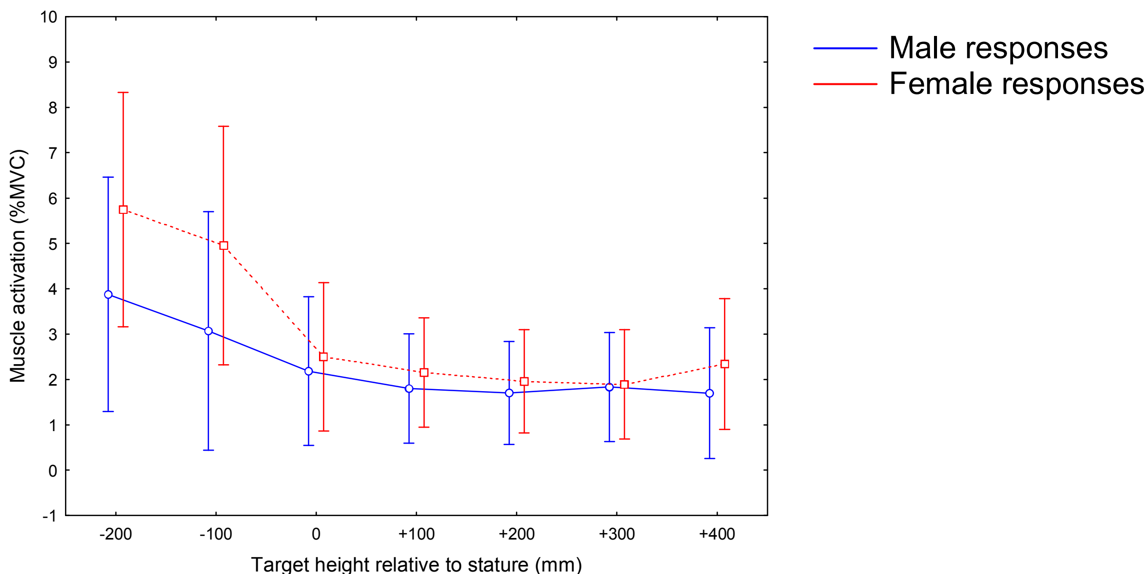


Figure E8: Activation level of the semitendinosus muscle for males and females for the different target heights, represented as a percentage of the maximum voluntary contraction. Vertical bars denote 95% confidence intervals.

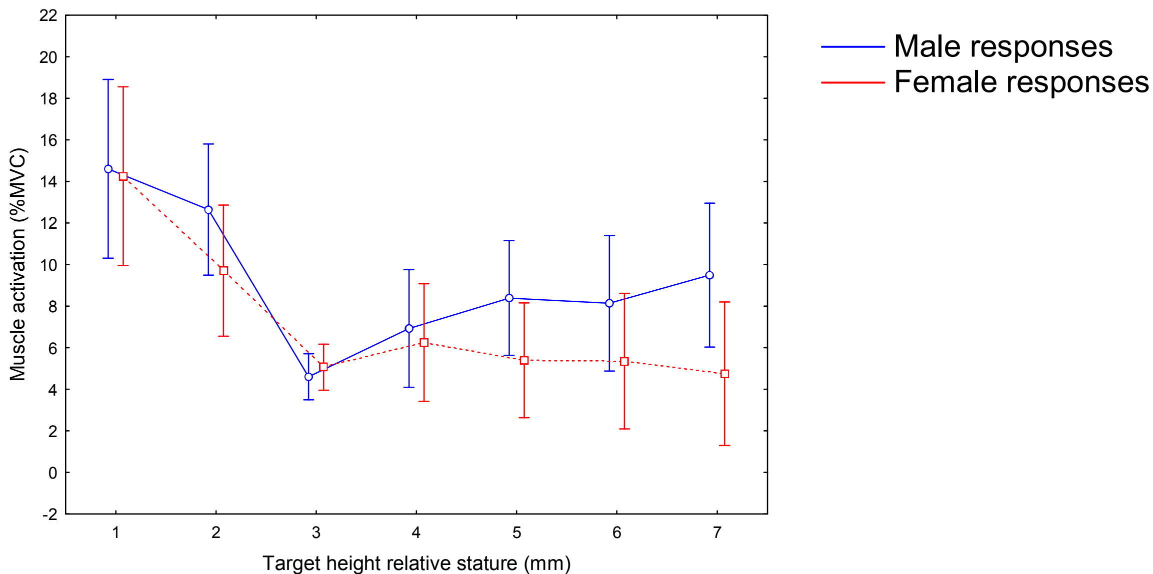


Figure E9: Body discomfort ratings for males and females for the different target heights. Vertical bars denote 95% confidence intervals.