AWKWARD WORKING POSTURES AND PRECISION PERFORMANCE AS AN EXAMPLE OF THE RELATIONSHIP BETWEEN ERGONOMICS AND PRODUCTION QUALITY

BY

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THESIS

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ABSTRACT

Ergonomics aims to improve worker health and enhance productivity and quality. Knowledge and practical evidence of this relationship would be instrumental for optimising organisational performance particularly in industrially developing countries where the discipline is still in its developmental stages. Therefore this thesis set out to analyse the relationship between ergonomics deficiencies and performance. A survey was first conducted to establish the severity of quality problems in the South African manufacturing industry and to determine if these were related to Ergonomic deficiencies. The results indicated that quality problems continue to plague industry, a challenge associated with huge cost implications. Furthermore organisations were not cognisant of the fact that ergonomics deficiencies such as poor workstation design and awkward or constrained working postures are a major contributing factor to poor quality and performance decrements. This demonstrates that much is yet to be done in raising awareness about the benefits of ergonomics in South Africa and other industrially developing countries. However, for this to be effective, tangible evidence of these purported benefits is required.

In lieu of this, a laboratory study was then conducted to establish the relationship between awkward working postures and the performance of precision tasks. Acknowledging that the task and the worker are interrelated elements, the impact of precision task demands on the postural strain experienced by the human was also investigated. A high and low precision task quantified positional precision while a force task (combination of pushing and pulling) was utilised to assess the ability to maintain a precise force over time. These three tasks were performed in eight different postures; namely seated, standing, stooping 30^0 and 60^0, working overhead, lying supine, and twisting to either side. A combination of the tasks and postures resulted in 24 experimental conditions that were tested on forty eight healthy male and female participants. The performance related dependent variables were movement time, deviation from the centre of the target, and the trend/slope followed by the force exerted. Muscle activity of eight arm, shoulder and back muscles, supplemented with heart rate and local ratings of perceived exertion, were utilised to quantify the impact of the tasks and the postures on the individual.

The results revealed that awkward working postures do in fact influence performance outcomes. In this regard, awkward working postures (such as overhead work and lying supine and stooping) were evidenced to significantly affect movement time, deviations from the target and the ability to maintain a constant force over time. These variables have a direct relationship with organisational priorities such as productivity and quality. Furthermore, the results indicated that high precision demands augment postural strain elicited through high muscle activity responses and may have negative implications for the precipitation of musculoskeletal disorders. Essentially, the work done on this thesis reflected the complex nature of ergonomics by drawing on both macro and micro-ergonomics approaches. In so doing, challenges perceived to be relevant to industry as reported by organisations formed the foundation for further laboratory studies. Therefore, more collaborative research and knowledge transfer between industry and ergonomics researchers is a necessity particularly in industrially developing countries where ergonomics is still in its developmental stages.

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INTRODUCTION

Ergonomics is a rapidly growing discipline that is gradually permeating industrially developing countries (IDCs) (O'Neill, 2005). This growth is fuelled by a growing body of literature and research that aims to improve working conditions while simultaneously achieving organisational objectives of increasing productivity and quality (Pheasant, 1996). In this regard, ergonomics research has made headway in the former to the extent that the discipline is associated with occupational health and safety issues (Lee, 2005; Hermans and Van Peteghem, 2006; Dul and Neumann, 2008) and less with organisational priorities relating to performance. As such, the other objective of improving productivity and quality has received less attention. In this context, and now more than ever, organisations are facing pressures from an ever-changing environment driven by a dynamic and highly competitive global market. This calls for more holistic processes and techniques that consciously integrate all worker and performance related elements within the system in order to optimise performance (Dempsey, 1998; Drury, 2000; Wilson, 2000; Guastello, 2006; Genaidy **et al.**, 2007).

Optimal performance hinges on a balance between the ability to fulfil task objectives in a manner that produces the desired outcomes and the time taken in achieving this feat (Guastello, 2006; Genaidy **et al.**, 2007). Accordingly, organisations continually concern themselves with finding tools, techniques and philosophies that will enhance productivity and quality where high quality products and services are produced in the fastest possible time. Total quality management (TQM), lean production and six-sigma, for example, bear testimony to such efforts (Eklund, 1997; Lee, 2005). The discipline of ergonomics also purports to have the potential to positively impact on organisational performance. However there is a paucity of studies showing the direct relationship between ergonomics applications and performance outcomes such as productivity and quality.

Of the few studies conducted on the impact of ergonomics on performance variables, the majority have focused on productivity and less on quality (Gunasekaran **et al.**, 1994). However, organisations have become increasingly aware of the importance of quality, hence the growth in the research interest in this area over the past decades (Lee, 2005). The varied research focal points of existing literature reflect the complexity of the aetiology of quality problems which require an equally holistic approach to overcome. For example, environmental factors such as lighting, noise and vibration have been documented to have a direct influence on performance outcomes such as error rate (Eklund, 1995). Appropriate implementation and adherence to quality assurance systems that are sensitive to worker capabilities and weaknesses have also been reported to impact positively on quality (Gonzalez **et al.**, 2003). Furthermore, reductions in productivity of up to 40% have been associated with poor quality (Gunasekaran **et al.**, 1994). In line with this, Eklund (1995) classified tasks performed in a car assembly plant in terms of ergonomics deficiencies and related these to quality statistics. It transpired that tasks with ergonomics deficiencies compromised quality and overall performance and were associated with worker reports of discomfort, fatigue and pain.

Gonzalez and colleagues (2003) also illustrated how introducing worker-centred interventions that reduced ergonomics deficiencies (such as awkward working postures and handling heavy loads) in the work environment can lead to quality improvements and costs attributable to poor quality. Although the exact nature of these improvements was not explicated, the interventions minimised the complexity of the task and the effort required to execute it. Comparisons of pre and post quality records reflected reductions in rejected parts, material wastage, and an increase in parts produced to the prescribed specifications the first time. These authors ascribed these quality and cost related improvements to simplified work processes and a subsequent reduction in mental and physical fatigue. No quantitative evidence of this was provided and the underlying processes driving these changes were not outlined.

Existing literature suggests that ergonomics can enhance production quality. However, many of these cases are usually qualitative and subjective reports gained from field research (Drury and Paquet, 2004). The evidence provided for the relationship between ergonomics and performance is usually inconclusive and at times contradictory. Moreover, the mechanisms and processes involved in mediating the relationship between ergonomics factors and quality of output are not clearly elucidated. While not questioning the value and authenticity of these measurements, quantitative evidence showing clear relationships between the relevant factors is usually more convincing and preferable, particularly when motivating for change within organisations. This is particularly significant given the challenges facing the growth and development of ergonomics in industrially developing countries (IDCs), of which South Africa is one.

Ergonomics in IDCs is not well understood in practice and is thus not accepted as integral for organisational success or worker well being (Lee, 2005). In Industrially developed countries (IACs) legislation, worker compensation costs and high labour costs have been effective motivators driving the implementation of ergonomics interventions in organisations. Nonetheless, even in advanced countries ergonomics is not fully appreciated for its contribution to quality improvements. One of the hurdles restricting the spread and acceptance of ergonomics in industry is the perception that ergonomics favours workers at the expense of organisational performance (Lee, 2005). This is exacerbated by the paucity of practical evidence for a positive relationship between Ergonomics and quality. It has furthermore been proposed that organisations have been slow to put ergonomics into practise as means of implementing interventions have not yet been provided (Lee, 2005). Moreover, the manner in which research is structured makes it difficult to apply to real work settings and in cases where it is, this is not effectively communicated to the industry in question. As such, there appears to be a chasm and a lack of knowledge transfer between industry needs (which are not well understood by researchers) and ergonomics research (which is commonly confined to the laboratory and at times may be perceived to be irrelevant for the ever-changing industrial context) thereby limiting application to industry.

It is the view of the current author that knowledge of the circumstances in industry will aid in attaining a complete picture of the challenges, strengths and opportunities relating to ergonomics in the country. This will inevitably involve a certain degree of qualitative and subjective research and will be critical in also understanding the culture prevalent within the South African context. In conjunction with this, quantitative research will be essential for presenting tangible data and evidence of the benefits of ergonomics for organisational success.

Taking the current state of affairs in industry and drawing on existing literature the current thesis was structured into two components. The first component undertook a macro-ergonomics approach to establish the relationships between ergonomics and quality concerns in industry at the level of the organisation. This study was structured as a qualitative survey that aimed to assemble information regarding quality problems in the manufacturing sector in South Africa and to further ascertain if these quality problems were related to ergonomics deficiencies. The first part of the thesis laid the foundation for the second part which, drawing on the results from the survey and considering the gaps in literature, reduced the research focus to a simple interaction between two factors; namely awkward working postures and precision task performance. The second study was conducted in the laboratory where the objective was to establish the link between awkward working postures and performance of precision tasks. As such, the second part of the study employed a micro-ergonomics approach. Therefore the two sections are presented separately starting with 'Section 1: Industry Survey on Quality and Ergonomics' followed by 'Section 2: Awkward postures, precision performance and quality' and final concluding remarks. Since the survey in 'Section 1' formed the preliminary study for 'Section 2', it is much shorter than 'Section 2'.

It is hoped that this work will shed light on the characteristics of the industrial landscape within South Africa with respect to ergonomics deficits, information that will be critical in any awareness raising campaigns and future research in this field. A second objective was to research a commonly occurring ergonomics deficit and demonstrates its influence on workers and performance outcomes. This information shall make a contribution to ergonomics literature and is potentially beneficial in alerting organisations of the importance of ergonomics in remaining competitive.

SECTION 1: INDUSTRY SURVEY ON QUALITY AND ERGONOMICS

CHAPTER I
INTRODUCTION AND BACKGROUND TO STUDY

Although the awareness of ergonomics in the industries of industrially developing countries (IDCs) has significantly grown in the last decade (Scott, 2005) there still seems to be a lack of knowledge regarding how ergonomics can positively contribute to the economic success of an organisation.

Productivity and quality of output have considerable bearing on any organisation's level of competitiveness (Helander and Burri, 1995; Klatte **et al**., 1997). Implementing ergonomics principles has been proposed as exerting a positive influence on productivity and quality (Pheasant and Haslegrave, 2006). Despite this, there have been few attempts to research and explicitly document the manner in which applying ergonomics can improve quality of output (Govindaru **et al**., 2001). This might be due to the very limited options available for researchers to establish a clear relationship between ergonomics attributes and quality in field studies. Thus laboratory studies and practical expertise are important for preparing Ergonomic interventions that can be applied in industry. Research in this area should aim to address quality problems that can be effectively resolved through introducing ergonomics precepts as this is potentially instrumental in alleviating quality deficits in industry.

To aid with this, knowledge of managers' perceptions regarding the causes of quality problems is necessary in order for Ergonomists to effectively focus their efforts on issues that are relevant and applicable to organisations. This is particularly the case in IDCs where production systems from developed countries are used which have been technically simplified and then transferred into a very different socio-cultural and socio-economic context. However, quality requirements are mostly similar to those applied all over the world (e.g. in automotive industry). Knowledge concerning managers' perception is relevant in order to address organisations with ergonomics issues related to quality. This information would also be invaluable in contributing to the establishment of ergonomics awareness campaigns, which is especially relevant for the South African context where ergonomics is still in its developmental stages.

In this context, the aim of this study was to establish managers' perceptions of the quality concerns in the local South African manufacturing industry. This would assist in understanding, from an ergonomics perspective, the quality related challenges faced by local manufacturing organisations. A further objective was to determine whether and to what extent by managers would relate the quality concerns expressed to known ergonomics deficits documented in literature. Since ergonomics is not widely practiced in South Africa, it was necessary to ascertain the level of awareness regarding the link between ergonomics deficiencies and worker performance. Such information could inform and assist in developing future ergonomics awareness raising campaigns in the country.

SECTION 1

CHAPTER II
METHODOLOGY

To ascertain the causes to which managers attributed quality deficiencies in industry, a questionnaire was developed (Appendix A.2). The survey consisted of nine primary questions (altogether three pages), of which six questions were related to general quality problems, their causes and possible countermeasures (e.g. effect on productivity and market share, quality improvement strategies). An additional two questions enquired about the organisation and its context (sector of activity and size of the organisation).

For the main question “What, in your experience, are the causes of the quality problems you have encountered?” 32 items had to be rated into three categories (none, minor and high) for their relevance in causing or contributing to quality concerns. Those 32 items covered four broad areas using terms commonly used in industry by managers. These included ‘materials and engineering’ (e.g. “defective raw materials”), ‘organizational factors’ (e.g. “incomplete feedback about performance”), ‘personnel/human factors’ (e.g. “awkward body posture”) and ‘physical and environmental factors’ (e.g. “workstation design” or “inadequate illumination”). The list of items was compiled according to the findings of Eklund (1995), Drury (1997) and Getty and Getty (1999) for potential causal factors axiomatic in industry that have a debilitating effect on quality.

Various Chambers of Commerce within South Africa were approached for contact details of manufacturing organisations that could be invited to participate in the study. In addition to this, other organisations were sought through the use of databases available on the internet. The sample was broad in that organisations from different manufacturing industries were targeted. Although these organisations produce different products, and hence have varying product-specific quality concerns, characteristics common to the manufacturing sector will have some influence on all the organisations.

Pilot tests of the questionnaire were conducted on managers from four different manufacturing organisations within Grahamstown. In this regard, managers were required to complete the questionnaire after which an interviews. These were performed in order to clarify if the terminology and context knowledge requirements would be interpreted correctly. This was necessary as some of the language used in the questionnaire could be perceived to be technical. This is particularly important in the IDC context where managers often have a broad range of responsibilities and very little ergonomics background (MacKinnon and Negash, 1998). After conducting pilot tests on the questionnaire revision were made taking into consideration the feedback from the interviews. Although individual experiences may still have been influential in the interpretation of the questions by participants of the survey, a factor that cannot be avoided, the questions related to ergonomics were considered to be comprehensive enough and utilised a common language that could be understood by managers.

A total of 400 surveys were distributed to manufacturing organisations throughout South Africa, of which 67 (17% return rate) responded by returning the relevant documentation. Although a return rate of 20 to 30% has been cited as being typical for surveys sent through mail to a large sample of organisations (Baruch, 1999), lower response rates, as from this study, have been reported to be commonly encountered when conducting survey research in industrially developing countries (IDCs) (MacKinnon and Negash, 1998). Therefore, although the low response rate may limit the extent to which the results can be generalised to the wider manufacturing sector, these results are nonetheless valuable since no such data is currently available in the South African context.

The information given to participating managers is outlined in the cover letter accompanying the survey in Appendix A1. It is important to note that all the organisations participating in the survey were given the option to remain anonymous and they were assured that all information provided would be confidential. However, it was also important to ensure that those organisations that wanted to remain anonymous yet receive feedback about the survey were able to do so without compromising their anonymity. Thus, they had the following options; return the questionnaire with their contact details, return it without their contact details and/or mail the return slip separately. To aid with this, and make the process more convenient, all surveys were sent out with a return envelope with the address already printed on it.

SECTION 1

CHAPTER III
RESULTS

ORGANISATIONS PARTICIPATING IN THE STUDY

From a total of 67 organisations that responded, 48 (72%) acknowledged that quality was a relevant problem. The results that will be discussed will only focus on the responses of those 48 organisations. The organisations that participated in this study varied in size and could be categorised into small, medium, and large enterprises in terms of the number of individuals employed by the organisation as prescribed by Naude and Serumaga, (2001).

Table 1.I: Organisations participating in the survey (n =48)

Size of enterprise (number of employees)	Small (10 – 49)	Medium (50 – 249)	Large (≥ 250)
Organisations from the current study	21% (n = 10)	43% (n = 20)	36% (n = 18)

The majority of the organisations (43%) were classified as being medium enterprises (50 to 249 employees), the small organisations (10 to 49 employees) and the large organisations (≥ 250 employees) were represented by 21% and 36 %, respectively (Table 1.I). Thus, although the sample size was limited, the various sizes of organisations were all represented in this study. 66% of enterprises were small and medium sized, which is characteristic of the South African economy (Centre for Development and Enterprise, 2004).

LINK BETWEEN QUALITY AND OTHER ORGANISATIONAL VARIABLES

The organisations were asked to comment on whether they thought quality improvements could be instrumental in contributing to key indicators such as productivity, market share, profit, the organisation's reputation, and certification requirements. In this regard, organisations experiencing quality problems reported quality improvements to be critical for both profit (94%) and the organisation's reputation (91%) (Table 1.II). 77% of organisations also remarked that market share could be enhanced by quality improvements while 74% of organisations expected a similar response with respect to certification requirements. 87% of managers perceived that enhancing quality would have positive spin-offs for productivity, contrary to a common misconception about there being a trade-off between quality and productivity (Drury, 1997). The results indicate that, from the managers' perspective, quality has a strong association with the above-mentioned indicators and attests to the possibility that quality of output is deemed as a top priority for most companies. This, despite the fact that 92% of the participating managers alluded to the fact that quality issues have been found to be an additive factor to the overall costs to the organisation.

Table 1.II: Managers' perceptions about how quality improvements can be instrumental in contributing to organisational variables.

INDICATOR	YES
Productivity	87%
Market share	77%
Profit	94%
Organisation's reputation	91%
Certification requirements	74%

These results confirm that one of the main goals of any organisation is to reduce or eradicate the impact of variables that will negatively affect their customers, workers, processes and return on investment. This is in line with Crosby (1979) who stated that the manner and extent to which quality of output can affect or impinge upon other organisational functions and processes has a considerable impact on the degree of importance that is attached to quality issues. It is not surprising then, that in most cases management interest and commitment to quality issues is directly associated with the financial losses experienced by the organisation as well as the degree to which it contributes to the depreciation of other organisational functions.

CAUSAL FACTORS ASSOCIATED WITH QUALITY PROBLEMS

Several authors (Eklund, 1995; Drury, 1997; Getty and Getty, 1999) have identified potential causal factors axiomatic in industry that have a debilitating effect on any quality conformance efforts. For the purposes of clarity, these factors (32) were grouped into four domains, namely ‘Materials and Engineering’, ‘Organizational Factors’, ‘Human Factors’, and ‘Environmental Factors’. Figure 1.1 depicts the overall results for the four domains where the organisations were asked to indicate the level of relevance (high, minor, or none) they perceived the different factors had on the resulting quality of output.

When considering both high and minor ratings of relevance, materials and engineering processes (defective raw materials and poor product design) and the organisational factors were the domains to which the majority of quality defects were ascribed (both 78%) (Figure 1.1). Human/personnel factors were also found to be influential on quality of output according to 72% (both high and low) of participating managers. This suggests that a substantial proportion of quality defects could be attributed to this domain. Over half of the organisations (53%) had not experienced environmental factors to be linked to the deterioration of quality of output. However, the remaining 47% (high and minor relevance) remarked that environmental factors could be seen as having minor influence (33%) as opposed to being highly relevant (14%) to resulting quality of output.

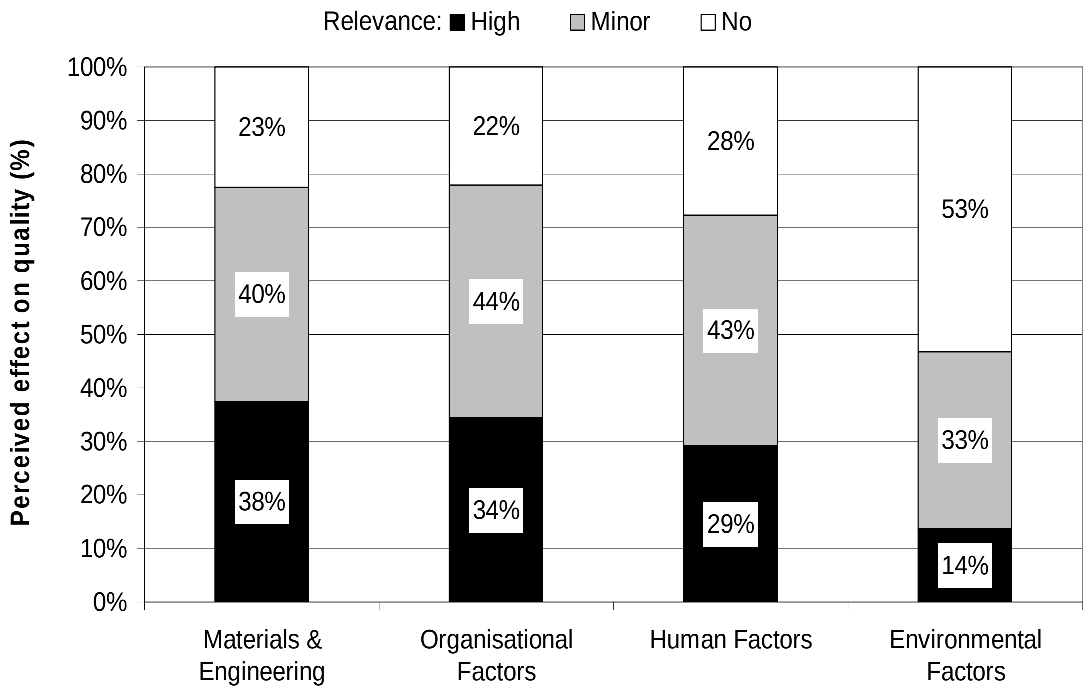


Figure 1.1: Managers' perceptions about causal factors of quality deficits for the four domains (summary results).

In order to ascertain if any variations existed between different sized organisations in terms of causal factors for quality issues, a comparison of responses from the various organisations was performed. Of prime interest were the causal factors that were reported to have high relevance for quality deficits. The high relevance rating indicates that these factors have to be addressed with a sense of urgency to prevent further deterioration of the quality of product output.

According to figure 1.2, medium and large enterprises show similar characteristics with slightly higher overall ratings in medium sized enterprises; materials and engineering factors rank first (48% and 38%), organization rank second (40% and 32%), human/personnel factors ranking third (31% and 30%) and environmental factors rank last (21% and 15%). Contrary to this, small enterprises appear to suffer the least from the impact of all factors, especially the environmental factors which were perceived to have no relevance in terms of the impact on quality of product output. This suggests that quality related priorities vary in different sized enterprises and calls for a closer inspection of the different domains.

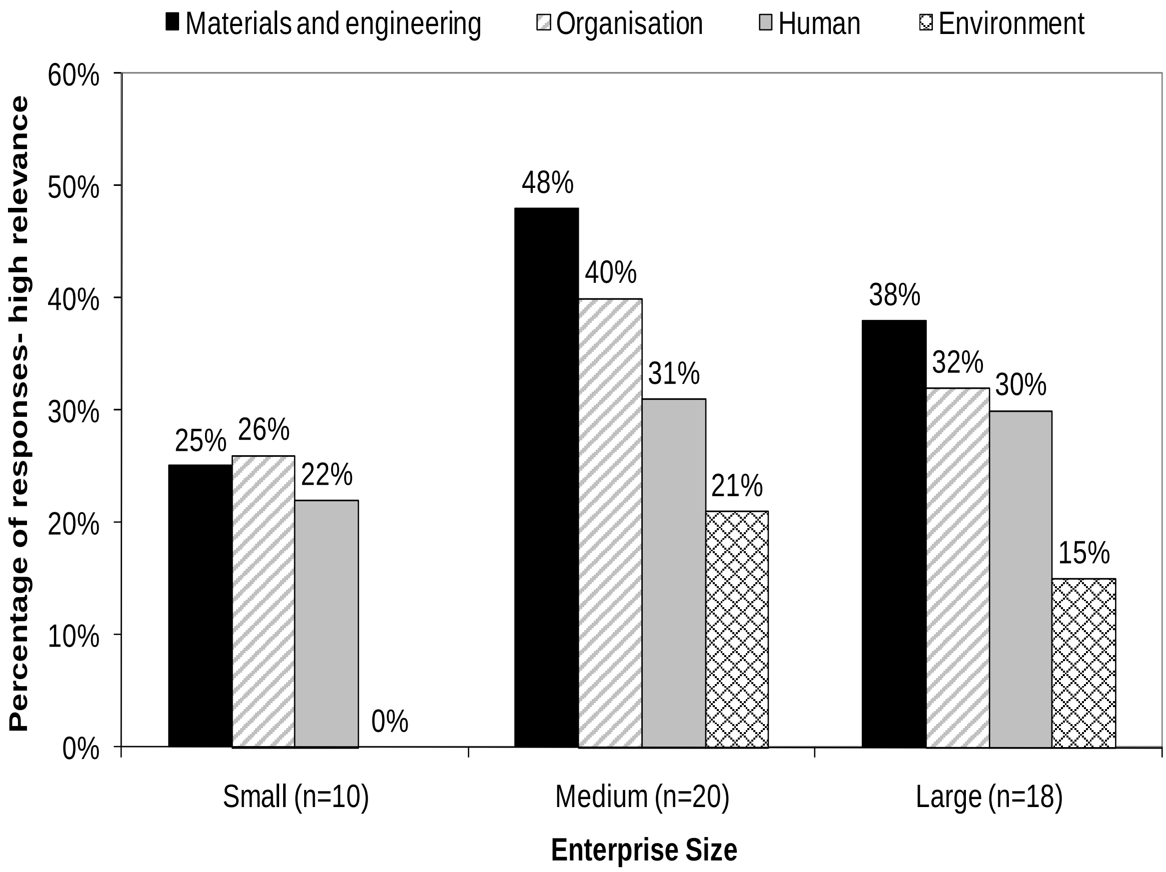


Figure 1.2: Percentage of companies that assigned high relevance ratings for the causal factors of quality deficits.

MATERIALS AND ENGINEERING DOMAIN

Product design and the raw materials being utilised to manufacture a product have considerable bearing on the quality of the outcome (Klatte **et al**., 1997). These two variables are crucial as they influence the effectiveness of all factors in the other domains. It is important that a differentiation be made with regards to the ergonomics of product design and the ergonomics of the production processes. The former relates to user-centred features of a product and the way they affect the end-user which is the customer in this case (Gunasekaran **et al.**, 1994), while the latter refers to the ease of assembling the product and the manner in which workstation design affects workers during the manufacturing phase. Poorly designed products have negative implications in terms of the impact on the workers assembling the product as well as the subsequent failure to meet customer needs (Eklund, 1995; Pheasant and Haslegrave, 2006). For the purposes of this survey, the materials and engineering domain encompassed only factors relating to product design and raw materials. This differentiation from the outset made it possible to distinguish between quality problems attributable to ergonomics deficiencies beyond the organisation as opposed to those in the scope of their influence.

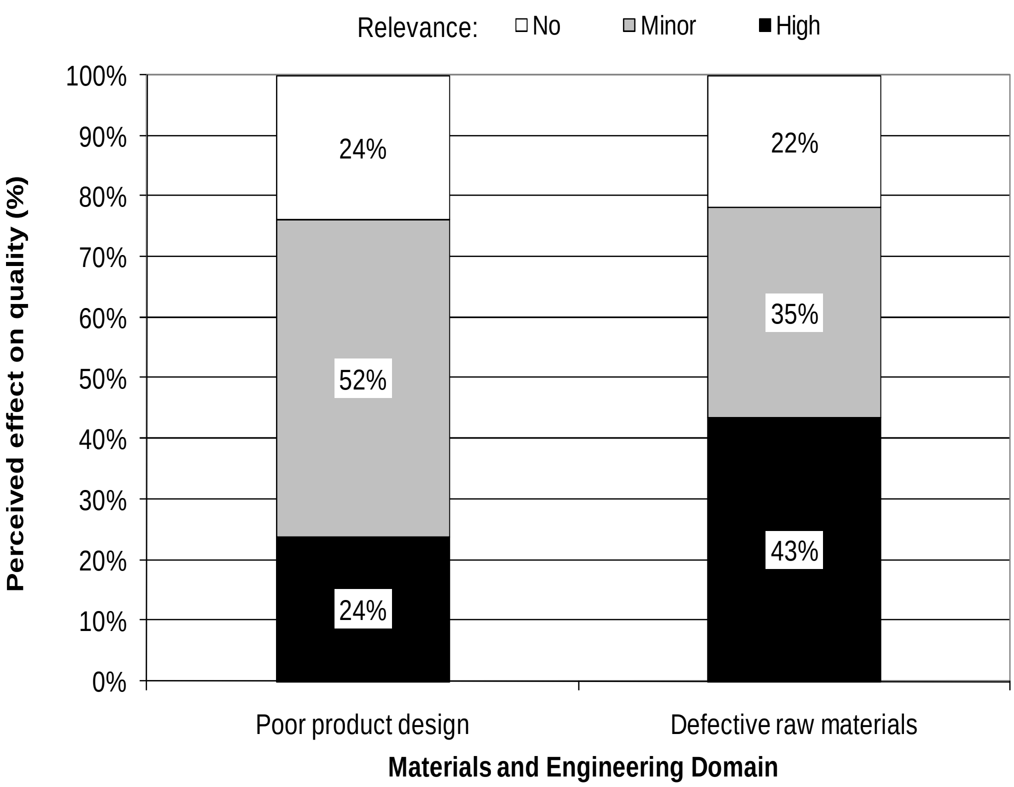


Figure 1.3: Managers' perceptions about causal factors of quality deficits for the Materials and Engineering domain.

Based on the results of the current study, defective raw materials accounted for the greatest frequency (43%) of causal factors perceived to be of high relevance to quality defects as opposed to 24% for poor product design (Figure 1.3). Moreover, these factors were perceived to be of highest relevance for medium and large enterprises (Figure 1.2). However, considering that materials and engineering are mostly beyond the control for local plants, there might be a tendency to shift or assign the responsibility externally. Alternatively, the design and engineering of products may not adequately consider the local conditions of production.

ORGANISATIONAL FACTORS DOMAIN

The most prominent factor within the organisational factors domain that managers have experienced to be detrimental to quality is insufficient communication, which was seen to be of high relevance by 54% of responders (Figure 1.4). Other factors that were perceived to have a considerable effect on quality of output included lack of awareness regarding quality requirements (44%), inadequate quality control (41%), incomplete feedback about performance (33%) and difficult manufacturing processes (30%). Although it is obvious that organisational design will have a direct effect on the quality of product output (Drury, 1997), most of the aforementioned aspects cannot be controlled directly but have to be addressed through considering other root factors (e.g. qualification, time allocation, motivation). Thus, it is imperative that definite steps are taken by organisations to alleviate the impact of the above-mentioned variables.

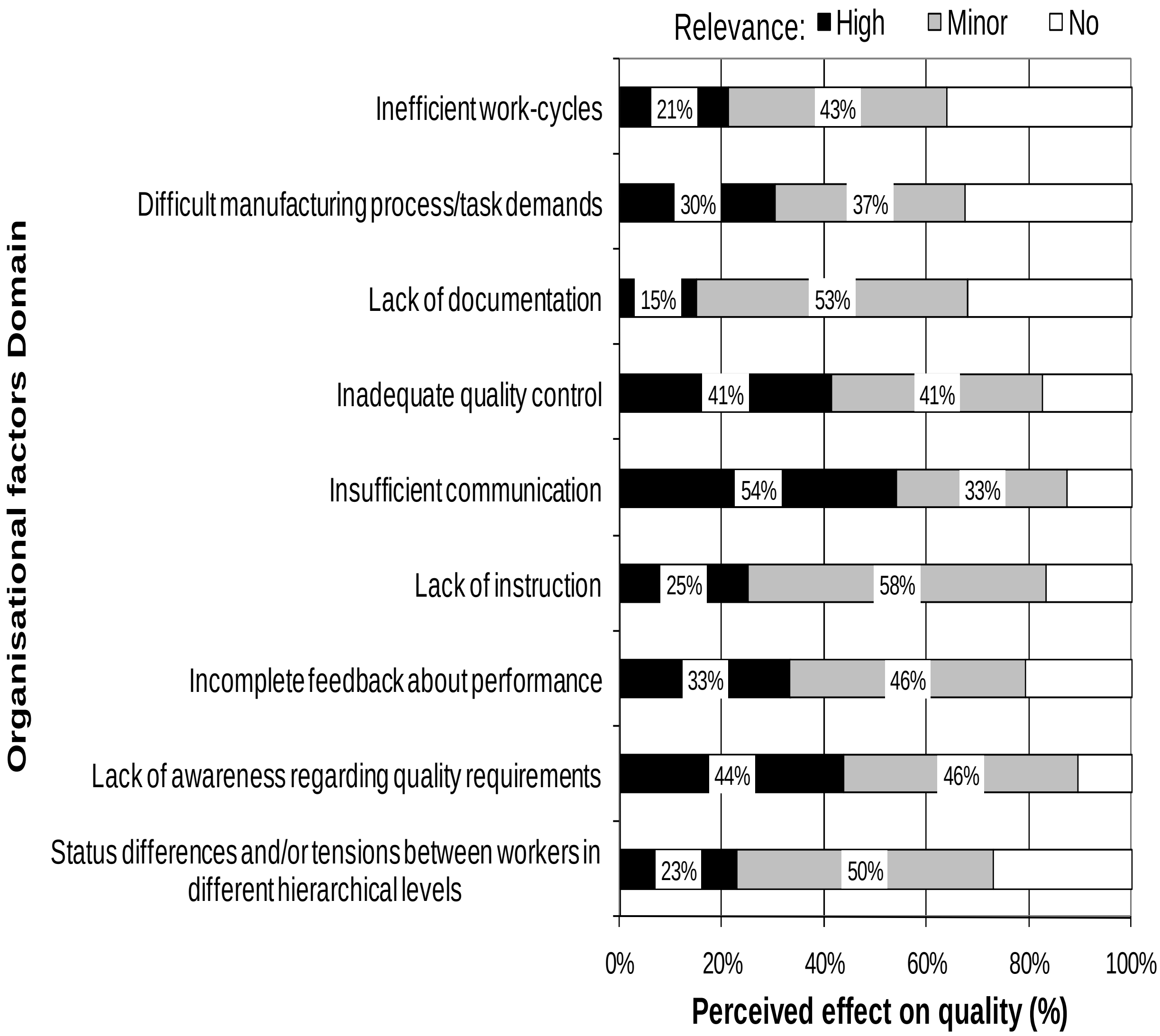


Figure 1.4: Managers' perceptions about causal factors of quality deficits for the Organisational Factors domain.

HUMAN/PERSONNEL FACTORS DOMAIN

Automation has been instrumental in improving work processes and reducing the workload imposed on the worker. In the face of these technological advances, the human operator still remains a significant part of any work system (Govindaru **et al.**, 2001) and particularly in South African organisations where manual labour and automation co-exist. In addition, South African organisations have to cope with a workforce with low educational and skill levels, mostly due to past socio-political events (Negash and MacKinnon, 1998).

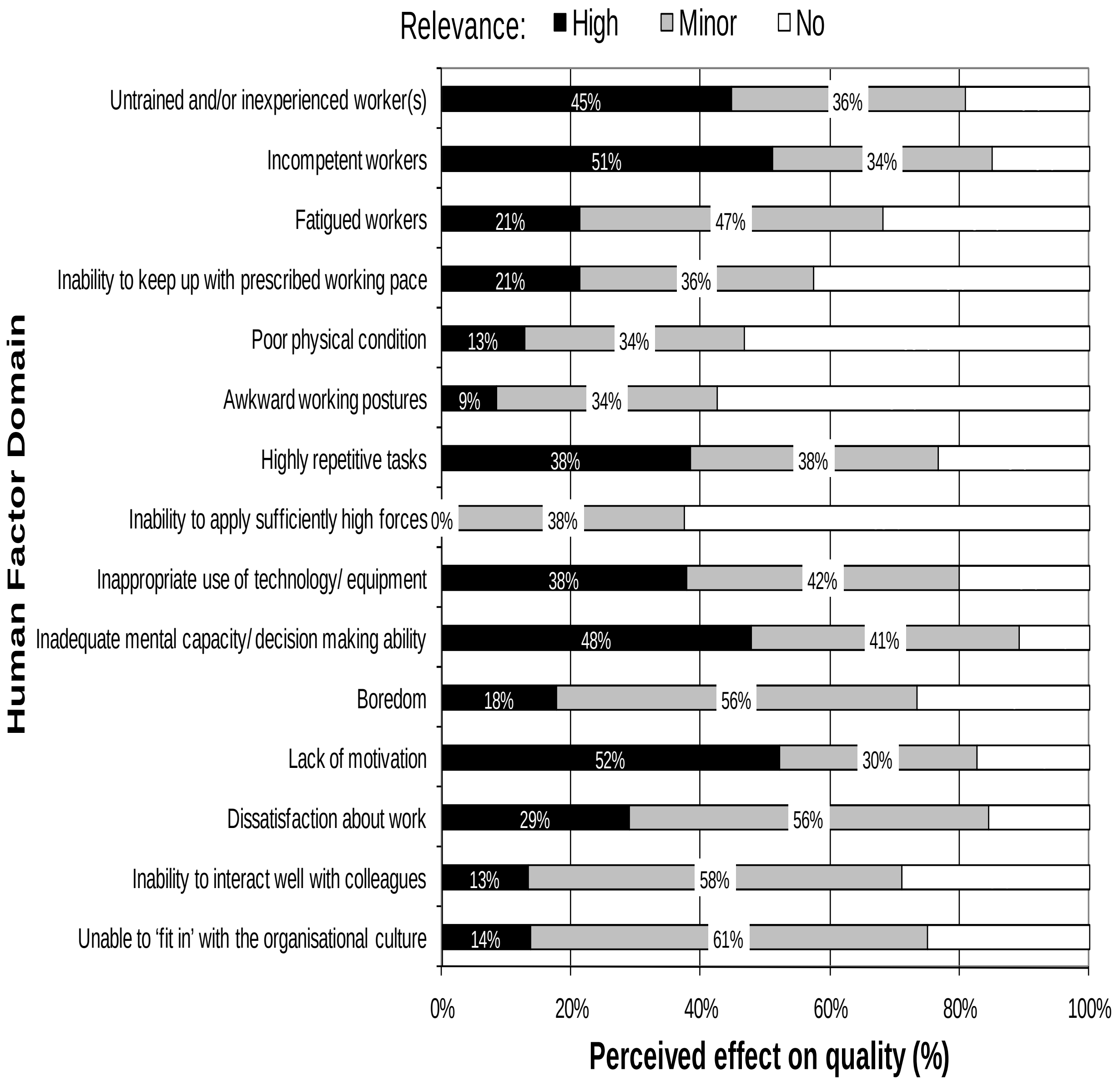


Figure 1.5: Managers' perceptions about causal factors of quality deficits for the Human/Personnel Factors domain

The findings from this survey reiterate the assertions made in literature as the managers' responses suggest that a lack of motivation (52%), incompetent workers (51%), workers' inadequate mental capacity and decision making ability (48%) as well as untrained and/or inexperienced workers (45%) (Figure 1.5) were perceived to be highly relevant causes for quality deficits. Although these assertions by managers are authentic, it must be highlighted that the general trend some managers adopt is to associate most problems with the capability of the workers. This was reported by Getty and Getty (1999) where 80-90% of quality defects were ascribed to worker related factors, which is a particular concern given the largely poorly qualified South African workforce. This is further corroborated by results from a survey conducted by MacKinnon and Negash (1998) on selected South African managers where over 50% of accidents were perceived to have been caused by worker negligence. Factors such as the workers' inability to apply sufficiently high forces (0%), awkward working postures (9%), the inability to 'fit in' with the organizational culture (14%) or interact well with colleagues (13%) and boredom (18%) (Figure 1.5) received some of the lowest ratings in terms of relevance to quality issues. This effect may be ascribed to the fact that most managers do not consider the aforementioned factors to be relevant to quality problems. This is not consistent with assertions from several authors (Eklund, 1995; Helander and Burri, 1995; Drury, 1997; Getty and Getty 1999) who argued that some of these factors have a significant influence on the quality of product output, as manifested in the human operator's performance.

ENVIRONMENTAL FACTORS DOMAIN

Most managers did not perceive environmental factors to have a significant effect on quality deficits. Some of the highest ratings for relevance were allocated to climatic conditions (21%), inappropriate tools (17%) and inadequate ventilation (15%) (Figure 1.6). However, workstations design (9%), which also relates directly to constrained working postures (11%), were both perceived to be some of the least relevant factors. This is in direct contention to the reality of poorly designed workstations characteristic of most industrially developing countries, such as South Africa, and suggests that there is possibly a lack of awareness about the impact environmental factors may have on quality of output. If this is the case much remains to be done in educating managers and workers regarding workstation design and beneficial ergonomics applications that can be used to enhance worker performance (Getty and Getty, 1999).

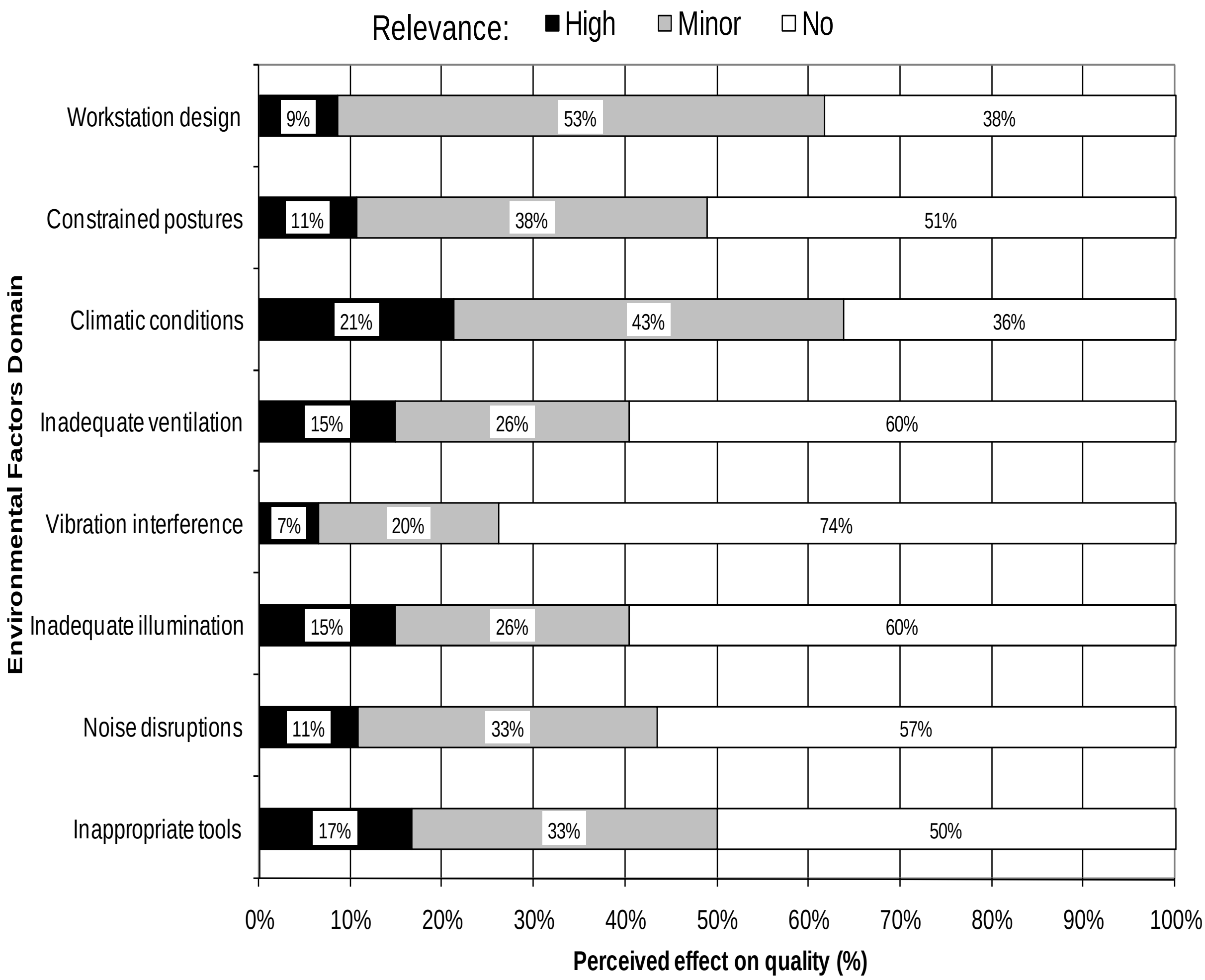


Figure 1.6: Managers' perceptions about causal factors of quality deficits for the Environmental Factors domain.

SECTION 1

CHAPTER IV
DISCUSSION

RELEVANCE OF ERGONOMICS CRITERIA TO QUALITY

On consideration of all the 32 causal factors of quality problems, 15 were rated by more than 50% of the participating managers to be instrumental in negatively impacting on quality of product output. Table 1.III shows the aggregated results of the highest ranked factors when minor and high ratings of relevance were combined. In this regard, human/personnel factors and organisational factors were in the majority.

The top 5 factors (Table 1.III) common within most organisations relate to management practices and processes (lack of awareness about quality requirements, 90%; insufficient communication, 87%; lack of instruction, 83% and inadequate quality control, 80%). The importance attached to these factors in causing quality problems alludes to the possibility that more rigorous quality management systems are necessary. Inadequate mental capacity/decision making ability (86%) and incompetent workers were reported to be prominent causal factors for poor quality. Therefore training programmes aimed at capacitating workers must be implemented in conjunction with employee placement strategies that are better aligned to job demands.

Based on the results of the highest ranked factors the reported challenges emanate from macro-ergonomics issues, thus quality improvement efforts should be tailored at that level of the organisation. The lower ranked factors relate to issues that are at a micro-ergonomics level where quality problems can be ascribed to a breakdown and mismatch in the man-environment interaction. This includes workstation design (60%), inability to maintain the required working pace (56%), climatic conditions (63%) and fatigued workers (67%) (Table 1.III). Other micro-ergonomics issues such as awkward working postures (41%) and the inability to apply sufficient forces (31%) feature much lower down on the list of management priorities as far as quality problems are concerned. In fact, these two factors were perceived by almost 60% of managers to have no relevance whatsoever in causing quality problems.

Table 1.III: Factors perceived to be of high and/or minor relevance in causing quality problems displayed in rank order (including only those rated by >50% of respondents)

Rank	Item	Category	* % of respondents
1	• Lack of awareness regarding quality requirements	Organis	90%
2	• Insufficient communication	Organis	87%
3	• Inadequate mental capacity/ decision making ability	Human/Pers	86%
4	• Lack of instruction • Incompetent worker(s)	Organis Human/Pers	83%
5	• Inadequate quality control	Organis	80%
6	• Incomplete feedback about performance • Untrained and/or inexperienced worker(s) • Lack of motivation • Dissatisfaction about work	Organis Human/Pers Human/Pers Human/Pers	79%
7	Highly repetitive tasks	Human/Pers	76%
8	• Defective raw materials • Inappropriate use of technology/ equipment	Mat & Eng Human/Pers	75%
9	• Poor product design • Status differences and/or tensions between workers in different hierarchical levels	Mat & Eng Organis	73%
10	• Boredom • Unable to 'fit in' with the organisational culture	Human/Pers Human/Pers	69%
11	• Lack of documentation • Fatigued worker(s) • Inability to interact well with colleagues	Organis Human/Pers Human/Pers	67%
12	• Difficult manufacturing process/ task demands	Organis	64%
13	• Inefficient work-cycles • Climatic conditions	Organis Enviro	63%
14	• Workstation design	Enviro	60%
15	• Inability to keep up with prescribed working pace	Human/Pers	56%

* Percentage of respondents who perceived that factor to be of high and/or minor relevance to quality
Organis: Organisational factors Human/Pers: Human/Personnel Factors
Mat & Eng: Materials and Engineering Factors Enviro: Environmental Factors

INTERDEPENDENCE OF ERGONOMIC ISSUES & ORGANISATION/ PERFORMANCE CRITERIA

A cross correlation analysis was performed between the 32 ergonomics items, the organisational characteristics and the performance criteria outlined in Table 1.II above. This analysis was conducted in order to determine if any common links existed between the different factors, especially those that may not initially be perceived to be related. No significant correlation was found between any ergonomics criterion and organisation size or between any ergonomics criterion and the sector of activity. On consideration of the effect of ergonomics issues on quality on the performance criteria; 'productivity' significantly correlated to 3 of the 9 organisation related criteria and to the experience and training level of workers ($p<0.05$). The effects on 'market share' correlated to 5 of the 9 organisation related criteria and to the competency and decision making ability of workers, motivation and satisfaction and organisational culture ($p<0.05$). No significant correlations to ergonomics criteria were found for 'profit', 'reputation' and 'certification' criteria. Thus, although the managers rated the importance of quality on performance criteria very high (table 1.II) only very few correlations to ergonomics variables were expressed.

Cross correlations between the items were used to further analyse the individual interdependence between the ergonomics items. In total, 336 of 1122 possible correlations (30%) were significant ($p<0.05$). Table 1.IV depicts the number of significant correlations between the different categories of ergonomics items and outlines the association and potential relationships between factors in the different categories.

Although the percentage of significant correlations is mostly higher within each category, many significant correlations also existed between the categories. For instance, 67% of all item combinations between organisational factors and physical/environmental factors correlated to each other in terms of their relevance for quality (Table 1.IV). This was similarly the case for 63% of the human/personnel factor items and the physical/environmental factor items (Table 1.IV). Due to the nature of correlations, the results in Table 1.IV are merely an indication of the variance in the different categories and should not be interpreted as potential cause-effect relationships.

Table 1.IV: Number of significant correlations ($p<0.05$) between ergonomics items within the four categories.

Category	Materials & Engineering (2 items)	Organisation (9 items)	Personnel factors (15 items)	Physical & Environmental factors (8 items)
Materials & Engineering (2 items)	0% (0 of 2)	39% (7 of 18)	20% (6 of 30)	44% (7 of 16)
Organization (9 items)		53% (19 of 81)	46% (62 of 135)	67% (48 of 72)
Human/Personnel factors (15 items)			68% (71 of 105)	63% (76 of 120)
Physical & Environmental factors (8 items)				100% (28 of 28)

Considering only the highest ranked factors (outlined in Table 1.III), 61-85% of all items correlated significantly with each other. This did not however include the materials and engineering criteria or task repetitiveness. Particularly high correlations (those that explained variance greater than 35%: $r>.71$) were found between the following items:

- "Inability to keep up with prescribed working pace" and "poor worker physical working condition" ($r=0.81$),
- "Lack of instruction" and "insufficient communication" ($r=0.74$),
- "Inability to apply sufficiently high forces" and "Inability to keep up with prescribed working pace" ($r=0.73$),
- "Constrained working conditions" and "Inability to interact well with colleagues" ($r=0.72$) and
- "Inadequate illumination" and "inadequate ventilation" ($r=0.72$)

COSTS ASSOCIATED WITH QUALITY PROBLEMS

Ninety two (92%) of managers alluded to the fact that quality issues have been found to be an additive factor to the overall costs to the organisation. The cost factors were described by the managers in response to questions requiring free-text answers. These responses were then classified into the four broad categories (Materials and engineering, Organisation, Human/Personnel, and Environmental) for clarity. From this, it was evident that the greatest number of costs were assigned to organisational factors. In this regard, labour costs accounted for the highest frequency of costs (88%) (Table 1.V). Some of the variables that were incorporated into labour costs included factors such as overtime for sorting “out of spec” products; time spent on reworking (‘double-handling’) non-conforming products; extra resources for inspection; and the costs of employing more people to resolve quality defects. Other organisational factors that were associated with high costs were related to customer dissatisfaction (31%), reduction in efficiency and productivity (24%), transportation and delivery costs (19%) and the organisation’s reputation (17%) (Table 1.V).

When products do not conform to specified requirements extra raw materials may have to be used to remake the product or make adjustments to correct the defects. In some cases, not much can be done to restore the products and it has to be rejected. These concerns were expressed by 55% of managers (table 1.V). Costs related to the human/personnel and environmental factors were not seen as being a major cause for concern and were only relevant for 2-7% of managers participating in this study.

When considering all the costs associated with quality, it is possible that the cost implications are far greater than what is perceived by the managers because other ‘hidden’ costs were not accounted for (Getty and Getty, 1999). It is thus in the best interest of any organisation to take cognisance of, and effectively manage, quality issues as this will contribute significantly to organisational success. It is also the dual duty of organisations and Ergonomists to examine and systematically research the causes of quality deficits and make recommendations for how these could be resolved.

Table: 1.V: Costs associated with quality deficits as described by managers.

COST FACTOR	Frequency	%
MATERIALS AND ENGINEERING		
Equipment and processes to improve quality	8	19%
Extra use of raw materials due to high scrap and reject (write-offs) rates (added burden if materials are imported)	23	55%
Extra running costs (eg: electricity)	1	2%
Extra storage space for products that have to be reworked, rejected, disposed	3	7%
Re-packaging of reworked product	4	10%
ORGANISATIONAL FACTORS		
Labour costs (training, overtime for reworking & sorting/ inspection, employing extra people)	37	88%
Reputation (loss of sales/ market share)	7	17%
Profit/ sales	3	7%
Customer dissatisfaction (replacing and reworking product, product returns)	13	31%
Reduction in efficiency, productivity and increase lead time	10	24%
Certification issues	4	10%
Transportation- repeat & late/delayed deliveries & petrol/diesel	8	19%
Research &development to improve quality	4	10%
HUMAN/PERSONNEL FACTORS		
Overtime for reworking	2	7%
Disciplinary action if worker cant correct recurring quality problem	1	5%
Employee morale and motivation	3	2%
ENVIRONMENTAL FACTORS		
Costs associated with dumping or discarding un-usable waste products from scrap or rejected products	3	7%

Given that quality has far reaching consequences and serious cost implications, it would be expected that organisations would be more proactive in investing in processes that will address quality issues. However, the fact that only 19% of organisations expend extra resources on equipment and processes aimed at improving quality (Table 1.IV) implies that most organisations do not actually take the necessary steps to combat quality issues although they state that quality is a priority. On the other hand, it may also be possible that managers are not aware of any other means by which they can address this issue, in which case, this would be a good opportunity to introduce ergonomics as a strategic tool and ‘technology’ for alleviating quality concerns.

SECTION 1

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

Although the sample size was limited, the survey was able to shed light on some of the key problems experienced by organisations in the manufacturing sector. The surveys were completed by managers and may be viewed as biased as they reflect only the perceptions from the organisations' perspectives. However objective data on the matters covered in the current survey are rarely available and those accessible commonly lack sufficient detail or are incomplete. Therefore, managers' perceptions are an initial step in establishing the severity of quality issues in industry and they also give insight into the priorities of organisations.

The survey revealed that quality issues still pervade industry and have huge cost implications for organisations. Moreover, managers perceived there to be a strong relationship between quality and performance factors. They further considered many ergonomics criteria as relevant for quality of output as well. However, there was very little correlation between the relevance of performance criteria and the relevance of ergonomics criteria to quality. This suggests that managers do not have an accurate understanding of how ergonomics criteria affect specific performance parameters.

Furthermore, for the different categories the organisational and human/personnel factors were rated higher than physical/environmental factors, although their basic effect is evident and a lot of deficits in this area still exist in South Africa. This once again suggests that managers lack detailed knowledge and experience regarding the cause-effect relationships for ergonomics criteria. In addressing this challenge research should focus on quality issues with the aim of providing tangible evidence regarding the impact of ergonomics deficiencies on quality of output and overall organisational performance. In this regard the focus should be on micro-ergonomic issues centering on the basic interactions of the human operator in the working environment and providing support for the benefits ergonomics purports to have. In order for this research to be effective the results from such studies should then be communicated to organisations thus allowing managers to use the information in making informed decisions.

The survey was conducted in South Africa, which is still a developing country that makes use of technology from industrially advanced countries within its unique socio-cultural context. As ergonomics is yet to be accepted and implemented in industry, information from the current survey and existing literature should be incorporated into ergonomics awareness campaigns in South Africa. As the results from this survey are not only relevant for South African organisations, obtaining comparative data of the relevant factors to other regions in the world would greatly enhance the value of this study.

Based on the results of the current survey the following recommendations should be incorporated into future studies in this area:

1. More awareness raising campaigns about ergonomics as a discipline and the potential benefits to the organisation and the workers stemming from the appropriate implementation of ergonomics interventions are required.
2. Research that clearly elucidates the relationship between ergonomics deficiencies and performance outcomes. Particular attention should initially be drawn to micro-ergonomics issues such as workstation design and awkward postures as managers are not aware that these factors may be as important as macro-ergonomics factors in contributing to quality deficits and other performance criteria.

SECTION 2: AWKWARD POSTURES, PRECISION PERFORMANCE AND QUALITY

CHAPTER I
INTRODUCTION

BACKGROUND TO THE STUDY

The survey discussed in Section 1 was a preliminary study that investigated the link between ergonomics factors and the prevalence of quality problems in the manufacturing sector in South Africa. The results indicated that quality problems continue to plague industry, a challenge associated with significant cost implications. Furthermore, organisations did not seem to be aware that ergonomics deficiencies endemic in industry, such as poor workstation design and awkward or constrained working postures, can contribute to poor quality as some literature suggests (Eklund, 1995; Drury, 1997; Getty and Getty, 1999; Gonzalez **et al.**, 2003). These assertions made in literature are however seldom supported by empirical evidence of quality improvements brought about by ergonomics applications (Govindaru **et al.**, 2001). Therefore further research regarding the impact of ergonomics deficits (particularly awkward working postures as they are related to a host of other factors) occurring at the level of the human machine interface on performance outcomes is required.

Awkward working postures (involving twisting, stooping and extended reaches for example; see figure 2.1) are commonplace in industry and have become embedded and accepted as an intrinsic part of many jobs requiring manual effort from the human operator (Haslegrave, 1994; Chung **et al.**, 2001; Gallagher, 2005). This is particularly a concern for precision tasks despite being primarily classified as light tasks. Precision tasks involve a high degree of static muscular contractions paired with highly controlled movements and requirements for mental attentiveness (Haslegrave, 1994; Das and Sengupta, 1996; Helander, 1997). These characteristics have been incriminated in forcing workers into awkward working postures therefore compounding the physical demands on the human operator (Laville, 1985; Das and Sengupta, 1996; Warternberg

et al., 2004). Although as early as the 1950s Fitts demonstrated that high precision demands, for example, lead to longer task completion times (Vercruyssen and Simonton, 1994; Warternberg **et al.,** 2004) a clear link still needs to be made with regards to precision task performance under different awkward postures.

Screwing during seat manufacturing and in assembly line

Clipping dashboard in assembly line

Welding tasks in body shop

Screwing overhead in assembly line

Figure 2.1: Common awkward postures observed in the automotive industry where workers are performing precision tasks.

The majority of literature regarding awkward working postures has focussed on their effect on balance (Danion **et al.**, 1999), lifting capacity (Lee and Bruckner, 1991), force production (Lee and Bruckner, 1991), physiological (Pheasant, 1996) and biomechanical (Marras **et al.** 1998) responses and associated health ramifications

(Westgaard and Winkel, 1997; Grieco **et al.**, 1998). Awkward working postures are seen as a health concern due to static muscular contractions, trunk and spinal loading; all of which are exacerbated by force application, inherent in most tasks (Haslegrave, 1994; Marras **et al.**, 1998). Discomfort, fatigue, musculoskeletal disorders (MSDs) and injury are also interlinked events associated with cumulative exposure to work in awkward postures (Haslegrave, 1994; Bridger, 2003).

Less attention has been afforded to investigating the relationship between awkward working postures and task performance. An overview of the literature indicates that further research is necessary as contradictory results have emerged regarding the relationship between awkward working postures and performance of manual assembly and computer tasks. Drury and Paquet (2004) referred to various studies (Pustinger **et al**., 1985; Porter **et al**., 1992; Mozrall **et al**., 2000) which suggested that the physiological and psychophysical impact of awkward postures had no significant bearing on performance outcomes. In contrast, some authors (Karhu **et al.,** 1977; Hasslequist, 1981; Wangenheim **et al.**, 1986) reported improvements in performance following a reduction in worker exposure to awkward working postures. Substantial evidence for why this occurred and the processes and mechanisms driving these changes were however not clearly elucidated.

With respect to different postures; standing, seated, stooping and lying postures have been considered in several studies in terms of their comparative influence on performance (Vercruyssen **et al.**, 1989; Cann, 1990, Mozrall **et al**., 2000). Although the health effects of different postures are known, there is limited knowledge regarding the costs and benefits of different postures on performance. In this regard, Vercruyssen **et al.** (1989) found that reaction time was faster in the standing posture when compared to the seated posture. In accordance with these results Simonton **et al.** (1991), also reported faster reaction times while standing. Drury and Paquet (2004) draw attention to the fact that the speed-accuracy trade-off cannot be ruled out in these cases because although faster reaction times were attained, the number of errors committed also increased. Because of this, these authors suggested that these two performance variables should not be studied in isolation as was commonly found in previous studies.

As there are two broad types of research, namely field and laboratory research, it was important to consider past research in this area and decide which would be best suited to the current study. There is a preponderance of laboratory studies conducted in this area of research. This can be attributed partly to the numerous limitations presented by the time pressured workplaces that hinder the rigorous control of variables (Westgaard and Winkel, 1997; Gonzalez **et al.**, 2003). The outcomes of these studies are often difficult to transfer to 'real' work settings thus necessitating field research (Scott and Renz, 2006). However, it has been postulated that the results from field studies make weak associations between awkward postures and performance outcomes and the use of indirect measurements (such as worker discomfort ratings) to infer this relationship has been cited as inadequate (Drury and Paquet, 2004). Therefore, laboratory studies considering the complex interactions of various factors in industry are a necessity. However, these studies should ideally be informed by industry relevant issues and should also be supplemented with practical application in industry.

While there are no definitive results concerning whether awkward working postures affect work performance, evidence in literature shows that they do have profound physiological, biomechanical, and psychophysical influences on the individual (Haslegrave, 1994; Bridger, 2003). Drury and Paquet (2004) also point out that few studies have explicitly analysed performance in terms of the simultaneous effects on speed and accuracy. Although the great range of flexibility and adaptability offered by the human body allows workers to assume varied postures (van Schalkwyk, 2001; Gallagher, 2005) it is not clear if this adaptability remains an asset when performance outcomes are considered.

If industry is to overcome the major quality issues it faces, research that does not stratify organisational performance and worker related factors is a necessity. This speaks to the broader challenge facing the development of the ergonomics discipline; it calls for a better alignment of ergonomics research to organisational goals by addressing issues relating to productivity and quality and highlighting that these organisational priorities interact directly with worker-related factors.

A key objective of this thesis was therefore to determine the relationship between these influences on an individual and their work performance. The main question under investigation was the manner in which, if at all, performance of precision tasks would be altered under the suboptimal conditions of awkward postures. In addition to this, it was important to also examine the influence of precision task demands on the individual. Conflicting conclusions have been drawn in this regard with some authors suggesting that increased precision demands may place additional strain on the worker (Warternberg **et al.,** 2004) while an alternative view has been that workers are able to overcome postural strain with minimal effects on performance (Drury and Paquet, 2004). The evidence available regarding the interaction of awkward working postures and resultant performance is conflicting and at best inconclusive. This calls for further research regarding this subject. The current study therefore endeavoured to establish the relationship between awkward working postures and the performance of precision tasks. Acknowledging that the task and the human operator are interrelated elements, the impact of precision task demands on the postural strain experienced by the human was also investigated.

STATEMENT OF THE PROBLEM

Numerous tasks in industry are performed while workers adopt awkward working postures, particularly during precision tasks as they demand synchronised involvement of mental and postural processes. Although poor workstation design and awkward working postures have been reported to be detrimental to worker health, the simultaneous effects of these Ergonomic deficiencies on performance outcomes are not fully understood, and hence were the focus of this research. Further to this, the effects of precision task performance on the human operator particularly in terms of muscle activity remain a contentious topic that was addressed in this research.

RESEARCH HYPOTHESES

The purpose of this research project was two-fold. The primary focus was to investigate the effects of awkward working postures on precision performance (precision of movement: accuracy and speed of task execution; precision of force application: pushing and pulling). In this regard, it was hypothesised that precision performance would deteriorate when precision tasks are performed under awkward postures.

In accordance with Newton's Third Law (for every action there is an equal and opposite reaction), it can be expected that as far as awkward working postures may affect performance, precision demands would in turn have an effect on the resulting postural load experienced. This relationship was the crux of the secondary aim of the study. It was proposed that varying precision demands would have an influence on the postural load experienced such that tasks with high precision requirements would cause greater strain on the musculoskeletal and physiological systems compared to tasks with lower precision requirements. It is also possible that precision demands may cause greater muscular load through, for example, inducing higher grip force or though more co-contraction for the control of fine movements. The latter possibility was not measured directly as it was not the main focus of the study.

OVERVIEW OF STUDY

While acknowledging that overall performance of any task is susceptible to a plethora of elements within the system (Smith and Sainfort, 1989; Carayon and Smith, 2000; Wilson, 2000; Bridger, 2003; Guastello, 2006), this investigation focused on the interactions between awkward working postures and the resulting performance of precision tasks. In line with the research hypothesis, posture and precision task demands were selected as the dependent variables while performance and individual responses were the independent variables.

Precision performance (precision of movement and precision of force application) was monitored during precision task performance in various postures. Eight postures were selected for analysis in this laboratory study and included standing upright, sitting, stooping 30^0 and 60^0 degrees, lying supine, working overhead, and twisting to the preferred and non-preferred sides. Performance outcomes such as deviations from the centre of the target (accuracy) and movement time (speed) were recorded during the execution of a high and low precision task (both of which were based on a model of Fitts' task). The third performance variable measured the ability to maintain a constant/precise force over time. This was analysed by way of a pushing and pulling task performed with a hand-held load cell.

Additionally, the individual responses (physiological, biomechanical and perceptual responses) that were monitored and evaluated throughout all conditions included muscle activity, heart rate, and local ratings of perceived exertion (RPE). The potential effects on resulting quality of output, as a consequence of the interaction of these factors, were also considered as these could have important implications in linking ergonomics deficiencies to organisational performance.

The current study was delimited to 48 student participants comprised of 24 males and 24 females between the ages of 18 and 26 years with no experience working in industry. The fact that inexperienced students were utilised to research productivity and quality in industry where operators are highly skilled should not be viewed as a limitation. The aim of the study was not concerned with the level of experience an individual had, but rather the effect of posture on individual performance. All participants were right hand dominant so as to standardise electrode placement and to facilitate task execution within the available workstation parameters. A comprehensive description of the experimental concept and the methodology is provided in the following chapter.

SECTION 2

CHAPTER II
REVIEW OF RELATED LITERATURE

INTRODUCTION

Awkward working postures are one of the many factors emanating from ergonomics deficits that are endemic in industry. These factors, as are awkward working postures, are rarely perceived to have a direct influence on performance outcomes and are mostly considered in industrial settings when attempting to curb occupational health repercussions (Lee, 2005). As such, engineering and administrative controls employed by organisations to maximise output fail to consider the human, an element that is central to task performance and organisational success.

Research concerning the effects of awkward working postures has been at most unilateral, primarily focussing on the physical effects on the worker at the neglect of potential performance related outcomes (Dempsey, 1998). To this effect, there is a huge body of literature that supports the notion that awkward working postures are an aggravating factor in the precipitation of musculoskeletal disorders (MSDs) (Kuijer **et al.**, 1999; Carnide **et al.**, 2006). In contrast, literature regarding the impact of awkward postures on organisational priorities such as productivity and quality is sparse and at most inconclusive. This is a particular concern for precision tasks which are closely associated with product quality, yet workstation design and task requirements of these precision tasks inherently impose awkward postures on workers (Laville, 1985; Das and Sengupta, 1996). Therefore, although much remains to be done in alleviating the prevalence of musculoskeletal disorders in industry, there is also a need for research that will incorporate performance outcomes with a special focus on precision tasks.

The survey conducted as a preliminary basis for this study (refer to Section 1) clearly indicated that managers and organisations in South African industries are not aware of the negative implications ergonomics deficits have on quality, nor are they mindful that these challenges can be obviated through appropriate ergonomics applications and interventions. To this end, the current study had two focal points relating to elements within the micro-ergonomics level. The first involved awkward working postures adopted during the execution of precision tasks. In this regard, interest was on performance outcomes as well as the physical and perceptual reactions of the human operator in response to the strain imposed by the postures. Although awkward postures are endemic in industry, the extent to which different postures mediate performance of precision tasks is not well documented.

Task factors are commonly cited as having a direct influence on performance outcomes (Genaidy **et al.**, 2007). Yet it is still not clear how varying precision demands impact on muscle electrical activity and thus perceptions of effort. Findings in this area of research thus far are inconclusive and contradictory. This necessitates further research that will also take cognisance of the different postures in which precision tasks are performed. This formed the basis for the second part of this study, which drew attention to precision task characteristics and their role in influencing the postural strain experienced by the individual.

WORKING POSTURES

'Working posture', a term that is encompassed within the physical ergonomics domain, refers to the alignment and orientation of the human body and its segments in the working environment (Vieira and Kumar, 2004). Any working posture that is adopted by an individual is a direct expression of the interaction between the task demands, the individual factors, workstation design and the tools being utilised (Laville, 1985; Haslegrave, 1994; Das and Sengupta, 1996; Chung **et al.**, 2001; Pheasant, 1996; Vieira and Kumar, 2004). A sample of these factors is provided in figure 2.2. The posture that is ultimately adopted is dependent on the resolution between task objectives and the extent to which the workstation design and individual factors can facilitate these.

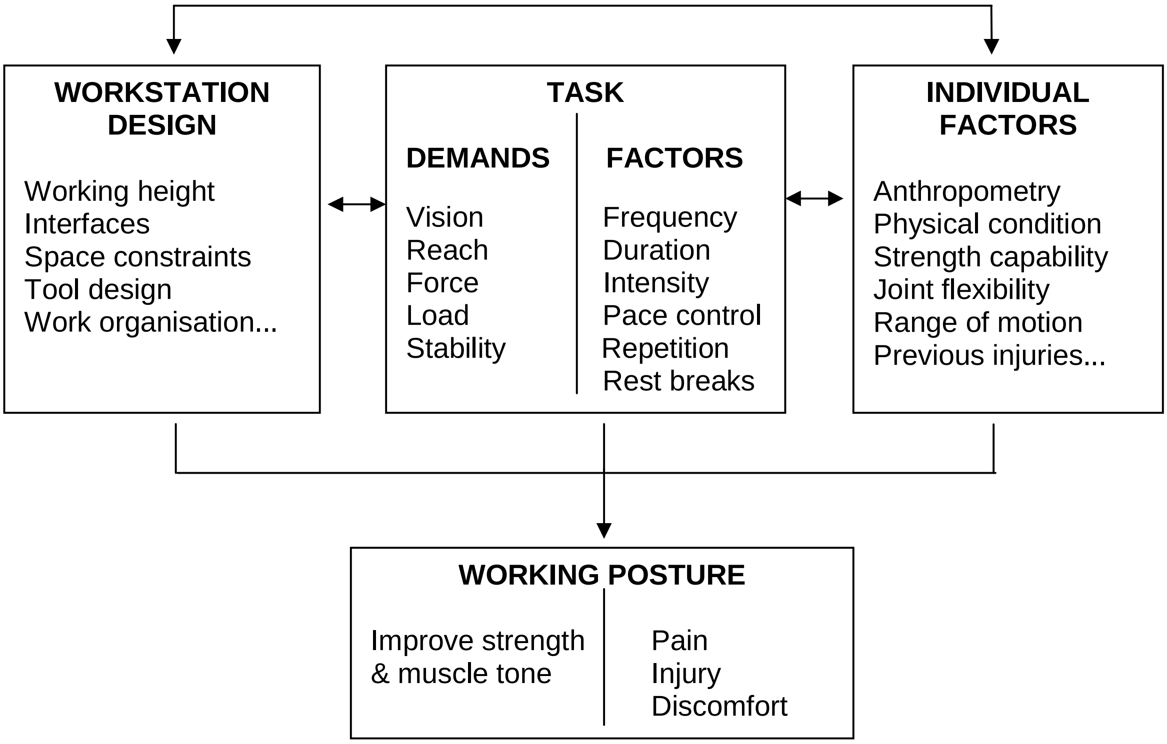


Figure 2.2: Factors affecting working posture. Adapted from Laville (1985), Haslegrave (1994) and Pheasant (1996).

Based on the procedure described by Laville (1985) and Haslegrave (1994), the working posture that is adopted can be understood by exploring the underlying roles played by the factors influencing posture. In this context, Haslegrave (1994) argues that within the existing workstation design parameters, individuals will adopt the posture(s) that allows them to execute the task in the most efficient and perceptually least taxing manner. That is to say, the individual will first prioritise task requirements and resolve which are most important for the outcome such that the posture adopted thereof will facilitate this goal, at least as far as the workstation will permit.

Thus, for a visually demanding precision task the individual will position the head and eyes first. In this regard, the head and eyes will be positioned at a distance that corresponds with the object's characteristics and the minimum required distance between the eyes and the object to be manipulated (Laville, 1985; Haslegrave, 1994).

This supposition was substantiated in a study by Wartenberg (2004) which illustrated that the distance between the head and hands was shorter and more immobile when high precision tasks are performed. Laville (1985) furthermore highlighted that head posture is critical because it serves as a reference point from which the rest of the body's segments align themselves. Reach and manipulation requirements determine the posture of the hand-arm system after which trunk and lower extremity posture follow in line with whole body stability demands. The degree to which these requirements can be met centres around workstation parameters and the worker's anthropometric disposition (Haslegrave, 1994; Pheasant, 1996).

Static and dynamic postures

In the quest to execute various tasks, the human body transitions from one posture to the next (Drury and Paquet, 2004). That is to say, movement of any kind is essentially an amalgamation of multiple postures that are sustained for varying periods of time. Rapid and frequent changes in posture result in dynamic movement of joints, achieved by regular contraction and relaxation of muscles. When postures are sustained for extended periods, continuous isometric contractions occur and certain joints and segments are held in fixed positions (Jonsson, 1988; Guastello, 2006). This leads to static muscular loading where muscles contract without relaxing sufficiently. Accordingly, postures are broadly classified as being either static or dynamic (Howorth, 1946). However, most tasks incorporate both static and dynamic components of posture, and thus muscle activity, at varying degrees (Jonsson, 1988). For example, a precision task would require static contraction of the major muscle groups in order to maintain postural control. However, the hand-arm system would be involved in movement and manipulation achieved through continuous contraction and relaxation of the relevant muscles.

When static postures are adopted blood flow to the contracting muscles is obstructed and nutrients, oxygen and metabolites cannot be transported efficiently (Keyserling **et al.**, 1992; Milerad and Ericson, 1994). A build up of toxic waste products and the deoxygenation of the muscles leads to discomfort and the premature development of fatigue and pain (Herberts **et al.,** 1980; Keyserling **et al.**, 1992; Magnusson and Pope, 1998; Vieira and Kumar, 2004). Executing tasks requiring force exertion or precision in static working postures augments the static loading on the muscles which in turn fatigue sooner (Sporrong **et al.**, 1998). Fatigued muscles and pain sensations evoked by static muscle loading compel workers to cease working until the affected soft tissues recover (Das and Sengupta, 1996). Soft tissue recovery only occurs if the damage is caused by short term reversible changes to the musculoskeletal framework (Herberts **et al.**, 1980). The time required for total recovery depends on the severity and recurrent nature of that damage. Highly repetitive tasks performed without the provision of sufficient rest-breaks are thus a concern as the residual strain would compound the muscular strain experienced. In order to promote optimal functioning of muscles and to reduce the risk of injury, static work should be kept to a minimum and where unavoidable, regular rest breaks and job rotation should be implemented (Jonsson, 1988; Keyserling **et al.**, 1992; Kuijer **et al.**, 1999; Frazer **et al.**, 2003).

AWKWARD WORKING POSTURES

It is not uncommon to find that the factors affecting posture are incompatible thus presenting workers with limited options to change posture (Bridger, 2003; Gallagher, 2005). This is worsened by workstations that are not adjustable. Therefore, many industrial workplaces are beset with inefficient and potentially harmful links with the environment (Pheasant, 1996).

It is important, at the outset, to distinguish between awkward working postures and restricted working postures. Awkward working postures are those involving extreme joint angles that subsequently require added effort to maintain (Keyserling **et al.**, 1992). This is usually caused by poorly designed workstations that are not compatible with worker characteristics. Restricted working postures, attributed primarily to “limitations in the workspace” (Gallagher, 2005 p51), are one of the many causes of awkward postures (Chung **et al.**, 2001). These limitations are related to and caused by insufficient provision of clearance, whole body and visual access, working heights and reach distances. These limitations in the work environment force the worker to adopt awkward postures (Pheasant, 1996). In such cases, the poorly designed workstations would have to be eliminated or their effect on the worker reduced through redesign to allow workers to adopt more appropriate working postures. However, it is possible that individuals may adopt incorrect postures in well designed workstations thereby necessitating worker education and awareness to address this issue.

Human adaptability

Despite the awkward postures, workers are still able to fulfil task requirements, albeit at potentially suboptimal levels, because the human body is highly adaptable (van Schalkwyk, 2001; Gallagher, 2005). This is made possible by the flexibility and adaptability offered by the structures of the human body which allow for an array of segment and joint arrangements that enable numerous postural configurations, within the body's biomechanical constraints (Haslegrave, 1994; Pheasant, 1996; Gallagher, 2005).

The human body's adaptability is highly advantageous as it allows people to work in a wide range of postures and environments. However, it can be potentially hazardous and uneconomical because poorly designed tasks and workstations force individuals to adopt postures that deviate greatly from 'neutral' postures; also referred to as awkward working postures (Gallagher, 2005). Although humans can potentially adopt an infinite number of postures in various environments, the extent to which each is effective, efficient and safe will vary substantially depending on the task parameters, the individual's capabilities and environmental variables.

Health related effects

Health effects associated with awkward working postures, although not directly analysed in this study, deserve some consideration because they are relevant for the performance of precision tasks which are customarily performed in awkward postures. Awkward working postures are hazardous for several reasons. The first pertains to the sustained static muscular contractions and the associated physiological consequences described above. These physiological changes caused by the strain on the musculoskeletal framework initially cause discomfort. One of the strategies employed by the human body in an attempt to relieve discomfort and stress imposed by working in awkward postures is to modify working posture and thus recruit alternative muscles (Graf **et al.**, 1995; Gallagher, 2005). Changing the working posture or the technique of task execution may potentially interfere with the output (Gallagher, 2005). In restricted workplaces however, there may not be an option to change working posture and the worker may have to continue working with fatigued muscles or cease working altogether.

If muscles are not afforded an opportunity to relax, local muscular fatigue eventually sets in. Local muscular fatigue emanates from sustained muscular work, the consequences of which evoke further discomfort which eventually manifests as pain concentrated in that specific muscle (Kumar 1996; McGill, 1997). These are overt reversible symptoms (Herberts **et al.**, 1980) caused by a decline in blood flow that restricts the elimination of waste products and the delivery of nutrients and oxygenation of the contracting muscles (Keyserling **et al.**, 1992; Herberts **et al.,** 1980; Magnusson and Pope, 1998; Vieira and Kumar, 2004). The reversible nature of fatigue means that the long term effects of local muscular fatigue do not necessarily cause direct damage to the fatigued muscle. Instead, the strain experienced may be transferred to support structures such as tendons and inter-vertebral discs and over time might cause damage to these structures (Herberts **et al.**, 1980).

Awkward postures involving the overloading of the shoulder joint and neck region cause upper limb work-related disorder (ULWRDs). Shoulder-neck pain and musculoskeletal disorders (MSDs) of this region are highly prevalent in industrial workers, particularly those involved in manipulative work with high precision requirements (Milerad and Ericson, 1994; Sood **et al.**, 2007). The causes of shoulder MSDs are complex involving a host of contributing factors including working with the neck flexed or twisted and the hand-arm system in an abducted and unsupported position while performing high precision tasks (Milerad and Ericson, 1994). Awkward displacement of the trunk has also been implicated in increasing trunk moments and causing compressive, shear, and torsion of the inter-vertebral discs and vertebra (Marras **et al.**, 1998; Frazer **et al.**, 2003). The cumulative effect of these loads acting on a very delicate spine all contribute to lower back pain (LBP). The residual strain from the cumulative stress on the musculoskeletal framework reduces the tolerance threshold of these structures making them more susceptible to injury.

MSDs continue to prevail as a major cost factor for organisations in terms of compensation claims, absenteeism and lost working hours (Herbert **et al.**, 1980). Moreover; these work-related disorders remain a crippling factor responsible for pain, discomfort and reduced working capacity in many industrial workers (Bridger, 2003). Although much research and effort has been invested in alleviating this challenge, the rate of occurrence and severity of MSDs is said to be on the rise (Visser **et al.**, 2004).

Performance related effects

The majority of research regarding the impact of awkward working postures has been related to strength producing capacity (Lee and Bruckner, 1991; Marras **et al.**, 1998). There is a paucity of research comparing performance outcomes of manipulative tasks in various postures, particularly precision tasks with their stringent accuracy requirements. This could be partly attributed to the fact that awkward postures have become accepted as an intrinsic part of the job and remain unquestioned (Haslegrave, 1994; Chung **et al.**, 2001; Gallagher, 2005). Furthermore, the lack of evidence showing clear relationships between the postures adopted and the performance of precision tasks poses a challenge for making recommendations to industry.

Given that precision tasks involve a substantial degree of postural stability, it may be likely that the muscles responsible for stabilising the body in the required position would fatigue over time. If postural muscles fatigue, stability of the hand-arm system may be jeopardised, thus also influencing the ability to aim accurately. A recent study by Schmid and colleagues (2006) demonstrated that fatigue in lower extremity postural muscles (rectus femoris muscle) did not affect whole body precision task execution.

This suggests that the body alters muscle recruitment patterns and engages in postural shifts to ensure that overall postural stability does not hamper performance. Alternatively it may be possible that muscles involved in stabilising general body posture, as opposed to those stabilising the segments directly involved in precision task execution, behave differently. Either way, if precision tasks are performed for a prolonged period, fatigue may surpass this adaptability and performance is likely to deteriorate.

DIFFERENT WORKING POSTURES IN INDUSTRY

Bearing in mind that over time, even ‘suitable’ working postures may have negative consequences, providing recommendations that favour both performance outcomes and worker well being often proves to be a complex issue (Helander, 1997). Identifying ‘poor’ working postures, however, seems to pose a lesser challenge. As such, there is no “perfect” working posture (Vieira and Kumar, 2004) because even “good” working postures may cause discomfort and injury when maintained for extended periods of time (Gross **et al.**, 1994; Magnusson and Pope, 1998). Nonetheless, some postures are still preferred over others.

The appropriateness of a given posture depends on the extent to which a balance is struck between the degree to which that posture efficiently and effectively facilitates task execution and the effect it may have on the worker’s physical reactions such as energy expenditure, muscular effort and spinal loading. Moreover, the points of contact provided by the workstation, as they relate to the human body’s capacity, will determine the appropriateness of the posture in terms of allowing for comfort, efficiency and acceptable safety limits (Pheasant, 1996).

This study will focus on seated, standing, stooping, overhead, supine and twisted postures although many other awkward working postures, such as squatting and kneeling, are prevalent in industry. In this regard, it is not uncommon to find workers adopting a combination of these postures. For example, workers may be observed to twist while they are in the stooping posture or working overhead while seated and so forth.

Seated Posture

Changes in the nature of work have led to a preponderance of work in seated postures compared to the more manual intensive work that predominated in the past (Bridger, 2003; Pheasant and Haslegrave, 2006). The issue of a ‘good’ or ‘optimal’ seating posture has been an issue of contention over decades with the focus first being on the appropriate seating behaviour (prescribed as an upright posture) to later being on providing a chair that will promote a good posture (Bendix, 1994; Graf **et al.**, 1995). Realising that even a good posture will eventually cause discomfort and fatigue in the muscles required to maintain that posture, the focus has changed yet again. A seat that allows for a variety of postures is recognised as being essential for alleviating the strain caused by postural immobility (Graf **et al.**, 1995; Bridger, 2003).

The seated posture has in the past been favoured because it is less energy consuming than other postures where the individual has to support their own body weight as is the case with standing and even stooping (Graf **et al.**, 1995). Working in the seated posture was preferred because it provides the stability required to facilitate the execution of tasks requiring high visual demands and motor control (such as precision tasks) (Magnusson and Pope, 1998). The chair cannot however be considered in isolation because its effectiveness in promoting appropriate postural configurations is dependent on other workstation design parameters and the individual’s anthropometric dimensions. Seated postures have been reported to increase the load on the neck because of individuals bending forward during high precision task performance. This may be a concern because increased neck flexion corresponds with increased tension and static contraction in the muscles in order to stabilise the head in the forward flexing posture (Bridger, 2003). Although leaning back may alleviate the strain temporarily, a preferred intervention would be to redesign the workstation in a manner that will keep the head in an upright forward facing position as the muscle electrical activity required to maintain the head in this position is minimal (Magnusson and Pope, 1998).

The seated posture is associated with an increased load on the back because the backward rotation of the pelvis is accompanied by flexion and decreased lordosis (flattening of lumbar spine) of the lumbar spine. This leads to compression of intervertebral discs which culminates in the development of lower back pain (Bendix, 1994; Pheasant, 1996). Floyd and Silver (1955) observed that erector spinae activity in the upright unsupported seated posture was higher than in the standing posture. These findings were later confirmed by Magnusson and Pope (1998) who reported that lumbar spine loading at the third lumbar vertebra was 40% greater when seated without the support of a back-rest than in the normal standing posture.

The benefits associated with working in a seated posture are nullified if the chair design does not match the workstation and the individual's anthropometric dimensions. Even with workstations that cannot be flawed in terms of ergonomics considerations, postural mobility is still a necessity and seated work is no exception.

Standing Posture

The standing posture closely resembles the reference anatomical posture and is usually recommended because it can allow for the maintenance of the neutral spine in the upright position (Pheasant and Haslegrave, 2006). This is favourable as it would minimise the shear forces and eliminates torsion especially at the vulnerable lumbar spine. In this posture humans are most mobile and strength producing capacity is optimal (Gallagher, 2005). However, this also depends on workstation parameters such as working surface height which is an important factor for work done in the standing posture. If the working surface is too low stooping and cervical and lumbar spine flexion may result, which would introduce risk for musculoskeletal disorders (Bridger, 2003; Pheasant and Haslegrave, 2006). Alternatively, if the surface height is too high work has to be performed with the arms raised and often abducted which is a threat for the development of shoulder disorders and injuries (Sood **et al.**, 2007).

Prolonged standing is associated with lower extremity oedema (swelling). This condition is a consequence of static leg muscle contraction which limits venous circulation (Cham and Redfern, 2004). Fatigue has also been reported to be an issue with standing postures. Soft flooring options and interventions such as anti-fatiguing mats are some of the interventions that have been proposed to alleviate fatigue induced by standing on hard surfaces for long periods (Cham and Redfern, 2004). Postural balance may be an issue in standing if the surface the worker is positioned on is uneven, or has a low coefficient of friction. This would not only be a concern for slip, trip and fall accidents, but may necessitate a reduction in force application in order to limit the effects of instability when performing tasks with high precision demands (Gallagher, 2005). Therefore stability in the upright stance, as in any other posture, is vital especially because the mere act of standing has been reported to impede mental task performance (Lajoie **et al.**, 1993). Further performance reductions can be expected if precision tasks are preformed in less stable postures involving stooping and twisting.

Stooping Postures

Stooping postures are those that involve trunk flexion usually from the lumbar spine. Increased trunk flexion has been found to lead to a corresponding increase in erector spinae muscle activity; a reaction required to counteract the downward pull of gravity on the head, upper extremities and the trunk. When the trunk is fully flexed erector spinae electrical activity is drastically reduced (Floyd and Silver, 1955). This has been attributed to a phenomenon referred to as the flexion relaxation process where muscle activity of lower back muscles is dramatically reduced at full flexion where the vertebral column is supported by passive tissues of back musculature (Gallagher, 2005). However, spinal shear forces increase with trunk flexion with the greatest shear forces occurring at the extreme range of flexion (Gallagher, 2005). As such, stooping postures are an aggravating factor in the development of lower back pain.

Overhead Working Posture

Performing a task with the hands raised above head level is a posture that is strongly advised against (Herberts **et al.**, 1980) yet is common in many assembly and maintenance tasks (Chung **et al.**, 2001). Magnusson and Pope (1998) reported that approximately 70% patients with shoulder pain were found to be involved in overhead work with the hand-arm system at or above shoulder level. Working with raised arms impairs vascular flow which leads to insufficient oxygenation of contracting muscles. Increased intramuscular pressure has also been reported to occur even in the absence of a load (Milerad and Ericson, 1994). The effect of these factors, with prolonged exposure and high external load handling, are key in causing discomfort, local muscular fatigue, pain, injury and MSDs of the shoulder (Sood **et al.**, 2007).

The impact of overhead work is determined by the degree of arm elevation and abduction (Herberts et al., 1980; Magnusson and Pope, 1998). Although any overhead work poses a risk, Sood **et al**. (2007) and Elliott (2007) have cautioned against overhead work done at extreme reaches. These authors recently documented increments in perceptions of discomfort and muscle activity with subsequent local muscular fatigue development during overhead work; a response that is exacerbated by increasing the height at which work is performed. The infraspinatus and anterior deltoid muscles were found to be the most susceptible to local muscle fatigue during overhead work (Herberts **et al.**, 1980).

Overhead work has been documented to cause fatigue in both experienced and inexperienced workers; in the former fatigue was reported only in the supraspinatus muscle while several muscles were fatigued in the latter (Herberts **et al.**, 1980). This suggests that overhead work is more of a risk in inexperienced workers. The functioning capacity of exteroreceptors and interoreceptors, both which are integral in posture control and movement, is said to diminish with age (Laville, 1985). In this regard, older workers experience higher levels of neck muscle activation when exposed to the same task demands as their younger counterparts (Laville, 1985). It is not clear how this age-dependant deterioration would be counteracted by the positive impact of experience on postural control and strain, particularly if the experienced worker is older.

Overhead work has not only been incriminated in negative health effects, but was demonstrated to be associated with increased error rates during the performance of a tapping task (Sood **et al.**, 2007). However, changes in movement time in overhead working postures have not been well documented.

Twisted Postures

Twisted postures involve axial rotation either at the neck, or the trunk, or as a result of concurrent rotation of both segments. The axial rotation increases the torsion forces and introduces an asymmetry in overall body posture (Pheasant, 1996). This has been shown to place additional strain on the passive structures of the spine and a concomitant increase in trunk muscle co-contraction; this places the spine at a risk for the development of lower back pain (Marras **et al.**, 1998; Van Dieen and Nussbaum, 2004). This not only causes discomfort and induces early onset of fatigue, but it has been reported to be a mechanical disadvantage for optimal force production (Lee and Bruckner, 1991; Gallagher, 2005). Furthermore, stability may be a concern in twisted postures, which may compromise performance of high precision tasks.

MEASURING POSTURAL LOAD WITH ELECTROMYOGRAPHY (EMG)

Electromyography (EMG) has been used extensively in ergonomics research (Kumar and Mital, 1996). Although this method has its limitations (Feldman, 1996; Goebel, 2005), it has been reported to be a valid indicator of the musculoskeletal load experienced (Herberts **et al.**, 1980). Normalising EMG signals such that the data is presented as a percentage of maximal exertion specific to each muscle has been used successfully by several authors (Soderberg, 1992; Marras **et al.**, 1998; Garg **et al.**, 2002; Iridiastadi and Nussbaum, 2006). This method of processing and interpreting EMG allows for intra-individual comparisons to be carried out, which is necessary given the high inter-individual variance in muscle responses. It also allows for comparisons between studies and criteria of acceptable limits.

The recommended activation levels for muscles vary considerably between studies. Moreover, recommended limits have been provided only for static tasks. This is relevant for tasks where postural control is a requisite and when isometric forces are applied.

However, as most tasks in industry involve dynamic movements, these criteria are not sufficient. Nonetheless, since the risks associated with static contractions are reduced in dynamic movements, it may be possible that higher levels of electrical activity may be permissible. Further research is required regarding the margins of the acceptable limits of muscle activation levels in dynamic tasks.

An overview of acceptable limits for static tasks reported in literature reveals gross inconsistencies. Rohmert (1973) proposed that at muscle activity levels below 15 to 20% MVC, one would be able to sustain an exertion indefinitely. Beyond this level of activation, it has been found that blood flow constriction occurs thus accelerating the rate of discomfort, fatigue and injury (Lindström **et al.**, 1977). Rohmert (1973) nonetheless acknowledged that this limit would need to be reduced to 8% MVC for exertions lasting longer than 60 minutes. However, Soderberg (1992) suggested that muscle activity at 10% MVC leads to local muscular fatigue. More conservative values have been reported by Jonsson (1988) and Sjøgaard **et al.** (1986). These authors advise that if exertions as low as 5% MVC are sustained for more than an hour, fatigue sets in.

These contradictions pose a challenge when interpreting results or making recommendations, especially as muscle responses are said to have high individual variability. As yet, an established classification system of acceptable limits for muscle response has not been constructed. Therefore, for the purposes of clarity and to contextualise the results from this study the available recommended limits (discussed above) were combined and classified into ‘low’, ‘moderate’ and ‘high risk’ categories (Table 2.I). These risks pertain to those associated with the early onset of fatigue which, with the complex involvement of cumulative exposure rates, is closely related to potential for the development of musculoskeletal disorders. Although fatigue results from factors considered to augment the risk of musculoskeletal disorders, this is not to say however, that fatigue will always necessarily precede injury (Sood **et al.**, 2007).

As local muscular fatigue can be a limiting factor even in light static tasks, identifying the onset of muscle fatigue has been suggested to be an important means of pain and injury prevention (Haslegrave, 1994; Magnusson and Pope, 1998; Carnide **et al.**, 2006). Electrical activity below the lowest proposed acceptable limits was considered as low risk (<5% MVC) where fatigue onset would be delayed. A moderate risk classification was assigned to the recommended limit for work not exceeding 60 minutes (5-8% MVC) while work done at muscle activity levels greater than the limit recommended for work done for more than an hour (>8% MVC)was classified as high risk.

Table 2.I: Level of risk for the early onset of fatigue assigned to different levels of electrical activity

LOW RISK	MODERATE RISK	HIGH RISK
<5% MVC	**5-8% MVC**	**>8% MVC**

It is important to highlight that this classification system is being used tentatively as epidemiological studies validating it have not been carried out. However, for the purposes of deciphering the results from this study, and in the absence of a validated system, this classification was deemed useful and will be referred to when discussing the results.

Although precision tasks are mostly manipulative and thus dynamic in nature, they also incorporate varying degrees of static muscular contractions; the posture of the hand-arm system or the trunk or whole body has to be maintained in order to facilitate the execution of the dynamic component of the task. As such, the classification outlined above will be used to interpret muscle activity responses from the movement and force application aspects of precision tasks

PRECISION TASKS

Definition of performance

Performance is a measurement of a combination of criteria relating to output and errors within the system; factors that are direct indicators of productivity, and quality. In this sense, the amount of time required to produce a certain outcome (performance time) and the number of errors incurred (accuracy and precision) while doing so are critical variables (Guastello, 2006). Although not traditionally viewed as a performance criterion, it can be argued that measurements of worker safety should also be incorporated into performance measurements as it features prominently in productivity and quality outcomes.

Performance time (also termed response time) relates to the combination of reaction time (central nervous system processing time that occurs before any movement takes place) and movement time (physical and overt movement behaviour manifesting the interpretation of received stimuli) (Schmidt and Lee, 2005). Reaction time is limited by the capacity of the central nervous system and is under the influence of task characteristics where, for example, reaction time is reduced if simple tasks, with sufficient warning and preparation, are performed (Lee **et al.**, 1991; Gordon **et al.**, 2004). Optimal performance does not solely rely on speedy movements (efficiency indicator), but also incorporates a measure of effectiveness in terms of achieving the goals set. This relates to accuracy which is interpreted differently depending on predetermined goals. The extent to which accuracy can be achieved is determined by the interaction of numerous factors relating to the task, workstation design and the physical and mental capability of the worker performing the task. Therefore, overall performance at the micro-ergonomics level is described by the ratio of the time taken to perform the task and the extent to which desired outcomes are attained; commonly known as the speed accuracy trade-off.

Precision and accuracy

Accuracy and precision are usually used interchangeably and thought to describe the same entity. However, although these terms are related, there are slight differences in the actual meanings of the words as they are used in the scientific context and, to a certain degree, in industry. Precision has been described to be synonymous with the ability to reproduce the desired action. This can also be interpreted as the degree to which certain tasks can be performed reliably to bring about the same or similar results (Schmidt and Lee, 2005). Accuracy on the other hand refers to the extent to which performance outcomes are similar to an expected and defined standard or result (Schmidt and Lee, 2005). Given these definitions, it is therefore possible to achieve accuracy without precision and vice versa.

A common example used by Schmidt and Lee (2005) to distinguish between the two is that of arrows hitting a target with the main aim being to hit the bull's-eye. If the arrows are interspersed on the board in a random fashion but clustered around the bull's-eye (variable error) then the performance can be described as that with high accuracy but with low precision. If on the other hand the arrows are clustered closely together but away from the bull's-eye (constant error), the performance is said to be low in accuracy but high in precision. The ideal situation however would be to attain high levels of accuracy simultaneously with precision as this would result in reliable performance that can be repeated over time to produce the desired outcomes.

When precision tasks have to be performed in industry they usually require workers to perform both precisely and accurately. Thus, for the purposes of this research, and based on the fact that these two terms are usually used to mean the same thing in industry, precision performance will be used to refer to the combination of both accuracy and precision demands. In industry the performance of precision tasks is measured in terms of how close to the prescribed standards the worker's output conforms (accuracy) and how often the predetermined and desired outcome is achieved (precision). In other words the best performance is that which incorporates aspects of both accuracy and precision. Products that fail to successfully integrate both accuracy and precision are characterised by non-conformance to criteria or errors and are regarded as being of poor quality. This of course will vary depending on how strict prescribed standards are and permissible error rates.

Speed-Accuracy Trade-Off

The manner in which precision performance changes when speed and accuracy requisites are manipulated is described by the speed accuracy trade-off (SATO) (Fitts, 1954; Winstein **et al.**, 1997; Guastello, 2006). This is one of the fundamental principles governing human movement, at least when speed and accuracy of movement are considered (Schmidt and Lee, 2005; Guastello, 2006). This concept proposes that increments in speed of task execution, after a critical point is reached, will compromise accuracy of movement thus increasing errors and causing deterioration in precision performance (Schmidt and Lee, 2005; Guastello, 2006). This concept was described by Fitts in the 1950s and incorporates target size and the distance that has to be moved to calculate the total movement time (MT). Reducing target size and/or increasing the distance to the target augment the effort required to achieve accurate movement and this in turn increases the amount of time required for the movement. Movement time is then said to be linearly related to the index of difficulty such that increasing the distance that has to be moved and/or reducing the size of the target amplifies the index of difficulty (Schmidt and Lee, 2005). Consequently, movement time would have to increase for accuracy of movement to be maintained.

Throughout task execution the individual obtains feedback about performance which allows for adjustments so that subsequent attempts will approach the target more precisely and accurately (Guastello, 2006). The extent to which these adjustments are effective depends on the appropriateness of the feedback and whether the individual can interpret the information meaningfully to correct the errors.

Speed-accuracy trade-off in awkward postures

The speed accuracy trade-off has been demonstrated to be applicable in a range of tasks although slight variations in the correlation between speed and accuracy do exist

(Plamondon, 1995). This behaviour can be described with an ‘s’-shaped curve where the number of errors start increasing once a certain speed has been reached (Guastello, 2006). Knowledge of this critical point would be instrumental in recommending the most optimal speeds at which tasks can be performed without the corresponding threats to accuracy. Research regarding the relationship between speed and accuracy in different postures is sparse and not well documented. Given that many precision tasks in industry are performed in awkward postures this relationship would be critical in optimising performance taking the effects of posture into consideration.

Performance time has been found to improve with practice and training as mental models are developed and movements become more coordinated and efficient (Lee **et al.**, 1991; Schmid **et al.**, 2006). Thus, with training tasks can be performed at the same speed but with fewer errors committed. It may also be possible that the critical point is reached at a much later stage where tasks can be executed at a faster speed with the same number of errors. It has been confirmed that improvements in performance can be attributed to faster reaction times that are caused by enhanced information processing capability (Bootsma **et al.**, 1994).

It is unclear however, how movement time as it relates to the displacement of body segments would be affected. Given the fact that motor task performance improves to a certain degree with repetition if the appropriate feedback is provided (Lee **et al.**, 1991; Guastello, 2006; Schmid **et al.**, 2006), it can also be hypothesised that habitual performance of a task in an awkward posture would lead to improvements in overall outcomes. Moreover, with respect to the effect of training on postural behaviour; it has been pointed out that extensive training and practice in performing a motor task may alter the manner in which visual input and information is utilised (Wartenberg **et al.**, 2004). Therefore it could be argued that the strain imposed by the segment posture configurations, as a result of the manner in which sensory information is utilised, may be tempered by the effect of training. Although performance in awkward postures may be improved with time, in theory it can be expected that because the human operator is already working at unfavourable and reduced physical capacity under awkward postures, it is likely that even if training induces improvements in performance, overall performance will not match that from less deviated postures. As such, it is likely that the critical point would be reached much sooner such that a greater number of errors would be committed and at slower speeds in awkward postures than when tasks are executed in more neutral postures.

Precision tasks in industry

While not detracting from manual materials handling (MMH), which remains a concern in industrially developing countries (IDCs), increased automation and new processes have resulted in a gradual transformation of the profile and nature of work in industry. This evolution has resulted in the high prevalence of more light fine manipulative tasks including precision tasks which are highly repetitive with a major focus on the upper extremity (Das and Sengupta, 1996; Wartenberg **et al.**, 2004; Sood **et al.**, 2007). These tasks are predominantly manipulative in nature, visually and cognitively demanding and furthermore characterised by quick, precise hand movements requiring high levels of skill (Wartenberg **et al.**, 2004). Nonetheless, precision tasks are commonly considered to be light manual tasks (Graf **et al.**, 1995), and have historically been perceived to be less of a risk than heavy manual materials handling tasks.

Precision tasks are comprised of movement (positional) precision and force precision (Sporrong et al., 1998; Visser et al., 2003), the requirements of which are different on the musculoskeletal framework (Buchanan and Lloyd, 1995). Applying a force while performing precision tasks intensifies muscular load (Sporrong **et al.**, 1998) and the direction of force mediates the strain on the shoulder musculature (Laursen **et al.**, 1998). As mentioned above, precision demands affect eye-hand distance (Haslegrave, 1994) such that high precision demands result in smaller hand-to-eye distances than low precision demands (Warternberg et al., 2004). Laville (1985) reports that this distance is affected by the frequency of task execution, precision demands, and the complexity of the data that has to be processed. Under the heightened influence of these factors, individuals tend to move closer to the task (thus reducing the distance between the eyes and the task) consequently increasing neck and lower back muscular strain and fatigue.

The time pressures imposed by standardised high machine paced cycle times compound musculoskeletal load (Laursen **et al**., 1998; Escorpizo and Moore, 2007). For example, high precision tasks have been reported to require smaller more precise and controlled movements which correspondingly elicit higher levels of muscle activation and result in increased shoulder muscle co-contraction (Sporrong **et al.**, 1998; Sood **et al.**, 2007). Furthermore, these tasks customarily are performed in awkward postures and incorporate substantial levels of static exertions on shoulder musculature; a consequence of the need to stabilise the frequent movements of the unsupported hand-arm system (Sporrong **et al**., 1998). These factors, coupled with increased exposure levels have been implicated in the development of MSDs (Wells **et al.**, 2004).

Workstation design has been proposed as a means of reducing the occurrence and severity of MSDs through the provision of workplaces that will limit work-related hazards while enhancing performance (Pheasant and Haslegrave, 2006). However, designing optimal workstations that will fit the needs of a user population is challenging because of human variability (Das and Sengupta, 1996). Furthermore, recommendations given for workspace dimensions for precision tasks blanket all types of precision task despite the suggestion that varied precision task demands affect the worker differently (Wartenberg **et al.**, 2004).

Performance of precision tasks under awkward postures therefore requires further attention and the simultaneous effects on both individual responses and performance outcomes need to be taken into cognisance. As task performance outcomes are an amalgamation of interactive processes involving the task, the worker and the environment, the role of awkward working postures in mediating precision task performance also has to be understood in this context (Chung **et al.**, 2001). Awkward postures are essentially the remnants of imbalances between these elements because they precipitate from suboptimal interactions. Thus it is important to understand the source of these awkward working postures and how they mediate performance outcomes and the health and well being of the worker (Wilson, 2000).

Effect of precision requirements on muscular loading

Precision requirements have been cited as a causal factor to increased postural strain because the visual and manipulative demands of precision tasks force workers into awkward working postures (Haslegrave, 1994) that have to be held in a fixed position for prolonged duration (Li and Haslegrave, 1999). Milerad and Ericson (1994) proposed that high precision demands augment the activity of muscles involved in stabilising the hand-arm system (such as infraspinatus, extensor carpi radialis). To this end, Visser **et al.**, (2004) reported a 21% increase in forearm extensor muscle activity attributable to higher precision demands. These authors concluded that the effects of precision demands occur mainly in the forearm region. This assertion is supported by Milerad and Ericson's (1994) findings where precision demands from a tracking task were observed to not differ significantly in arm and shoulder elevators (trapezius and supraspinatus and anterior deltoid). Findings from Escorpizo and Moore (2007) furthermore validated this supposition as they found that only distal muscles (extensor carpi radialis, extensor carpi ulnaris, extensor digitorium indicis and flexor digitorium superficialis) were influenced by precision requirements.

In contrast, Sporrong **et al.** (1998) found that supraspinatus activity (a shoulder muscle) increased when exposed to high precision demands. The same reason provided by Milerad and Ericson (1994), regarding the stabilising function of muscles, was cited. However, Escorpizo and Moore (2007) point out that forearm muscles were not analysed in the Sporrong **et al.** investigation thus it is not clear what transpired in the distal musculature. Moreover, there are apparent inconsistencies in the functions assigned to different muscles and hence their interaction with precision demands. Supraspinatus was given a predominant elevator function by Milerad and Ericson (1994), a reason for the low responsiveness of this muscle to precision demands. However, Sporrong **et al.** (1998) refer to this muscle as a stabiliser, hence its high responsiveness to precision demands. Methodological issues relating to the type of precision tasks that were measured can be attributed to these contradictions. This applies also to the inconsistencies of findings in this area of research that inhibit consensus regarding the effect of precision demands on muscle activity and pose a challenge in establishing recommendations regarding precision task recommendations for industry.

Several authors (Laursen **et al.**, 1998; Sporrong **et al.**, 1998; Visser **et al.**, 2004) alluded to the possibility that high precision tasks require increased stability of the hand-arm system which is achieved by co-contraction and increased tension in the muscles. This effect was evidenced even during light hand activity further highlighting the importance of hand-arm posture while performing these precision tasks (Sporrong **et al.**, 1998).

Laursen **et al.** (1998) and Sporrong **et al.** (1998) also suggested that the effect of precision demands on muscle activity can also be attributed to changes in movement patterns. They explained that for high precision tasks the hand accelerates to the target in order to allow a longer time to be dedicated to the accurate selection of the target. This acceleration (including the stabilisation of the hand-arm system) is thus reflected in higher muscle activity. Laursen **et al.** (1998) therefore proposed that speed and precision demands may have a similar effect on muscle activity. However, it was noted that at lower speeds this effect would diminish, as would be evidenced in the performance of high precision task at very high speeds. It was put forward that at a critical speed (not specified) the high precision demands cannot be sustained (Guastello, 2006). In accordance with this statement, the effect of high precision demands reportedly diminishes at low speeds (60 points/min) (Laursen **et al.**, 1998). As such a decrease in speed is necessary and would be followed by a corresponding reduction in EMG. Thus, it is possible that the effects of precision demands on the muscular load are closely related to the relationship between precision requirements and the speed of task execution.

CONCLUSION

Ergonomics as a discipline is founded on the principle and the need to reduce incompatibility of system elements with the aim of improving worker well-being, productivity and quality (Pheasant, 1996; Wilson, 2000; Guastello, 2006; Wells **et al.**, 2007). Accordingly, ergonomics research is driven by ongoing efforts to limit the deleterious effects of ergonomics deficits, such as awkward working postures, in order to preserve worker performance and health (Bridger, 2003; Gallagher, 2005; Pheasant, 1996). Much research has been conducted on the effects of awkward postures on worker health. For instance, it has even been suggested that the combined effect of precision tasks performed in awkward working postures may accentuate the risk of developing work related upper limb disorders (Huysman **et al.**, 2006). While Haslegrave (1994) alluded to the fact that awkward postures caused by poor workstation design may be responsible for suboptimal performance in industry, conflicting evidence emerged from other research in this area. This necessitates further studies that will focus particularly on elucidating the performance related effects of awkward postures. Moreover, the impact of precision task demands on postural strain deserves further research attention as the relationship between these variables is not clear. Research in this area is also a necessity because the survey conducted on manager perceptions regarding quality and ergonomics (referred to in Section 1) demonstrated that managers and organisations are not aware of the impact ergonomics deficits may have on organisational objectives.

SECTION 2

CHAPTER III
METHODOLOGY

INTRODUCTION

Ergonomics purports to have a positive influence on worker health and output and is recommended as an effective tool for the alleviation of ergonomics deficits such as awkward working postures in industry (Wilson, 2002; Bridger, 2003; Pheasant and Haslegrave, 2006). However, there are relatively few studies providing conclusive and tangible evidence of the performance effects associated with awkward working postures (Eklund, 1995; Dul and Neumann, 2008). This pertains particularly to precision tasks which, although are characteristically light tasks, inherently impose awkward postures on the human operator. Therefore, further research into these areas is required; this formed the basis for this study.

RESEARCH CONCEPT

The aim of this study was two-pronged. The first objective was to assess the effect of working postures on precision task performance (Figure 2.3 (a)). This was necessary because precision demands have been shown to contribute to the adoption of awkward working postures by workers (Laville, 1985; Haslegrave, 1994; Wartenberg **et al.**, 2004) yet their effect on performance is not fully understood. It was hypothesised that if task demands were kept the same, any differences in performance could then be attributed to the effect of posture.

The second aim was to investigate the impact of precision demands on postural strain experienced by individuals (Figure 2.3(b)). It was theorised that exposing individuals to varied precision demands (high and low precision tasks) within the same posture would allow for the determination of the manner in which varying precision requirements influence the postural load experienced by the human operator.

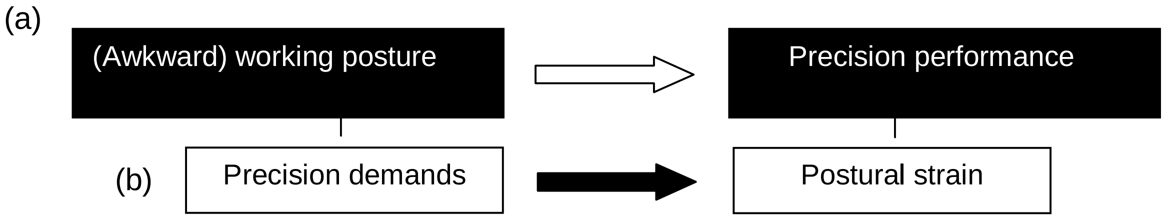


Figure 2.3: Premise of the current research study

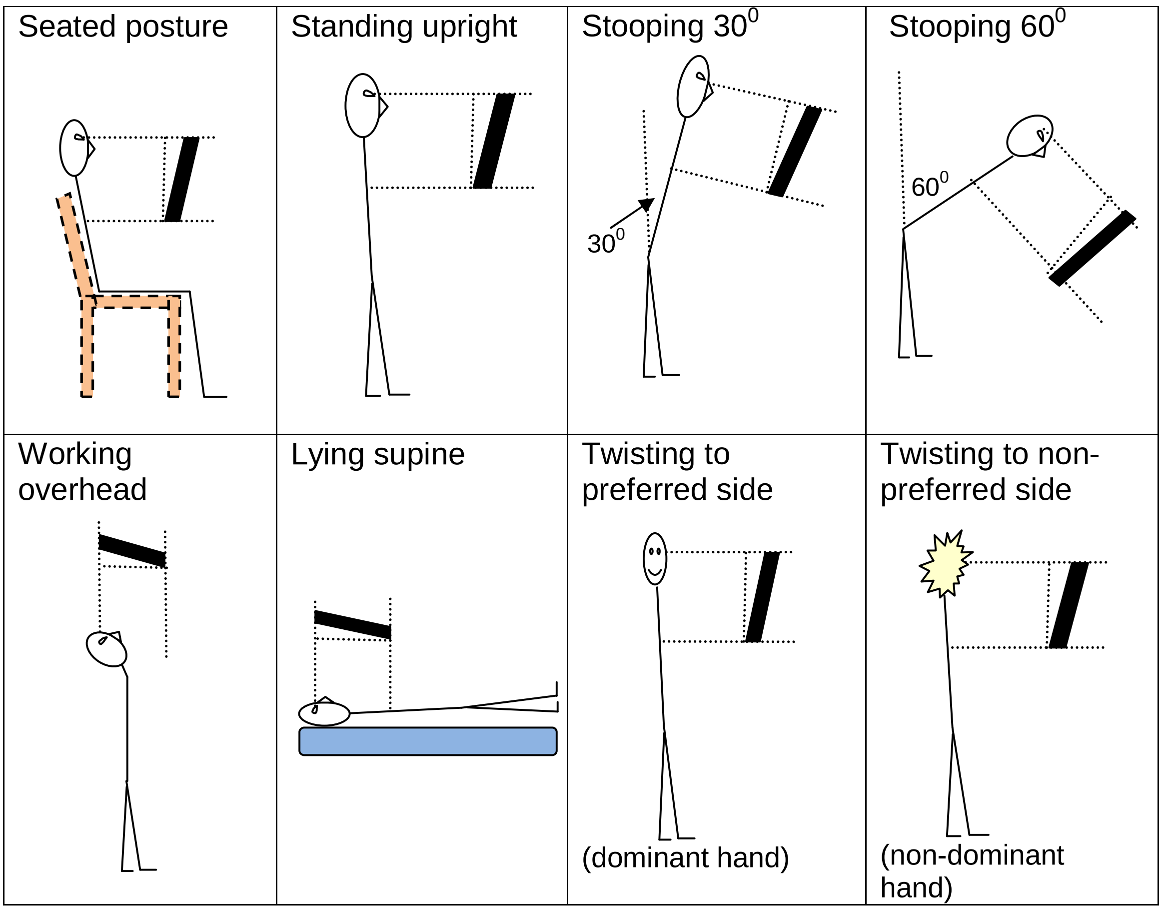


Figure 2.4: Postures tested in the current study

This concept was tested on a single sample group performing identical precision tasks under several different postures. Eight different postures commonly found in industry were selected. These included the seated, standing, stooping 30^0 and 60^0, lying supine, working overhead, and twisting to either side postures. Diagrams depicting the postures adopted appear in Figure 2.4. Since all participants were right hand dominant, twisting to the preferred side refers to twisting to the right while twisting left means twisting to the non-preferred side.

Two precision tasks were analysed. The first was a modified Fitts tapping task performed on a touch screen monitor. The second task measured precision of force application; which is an indication of the ability to maintain constant pushing and pulling forces over time. The performance related dependent variables included movement time, deviation from the centre of the target, and precision of force application. In addition, worker responses were examined using muscle activity, heart rate, and ratings of perceived exertion.

STATISTICAL HYPOTHESES

Based on the research concept discussed above, two hypotheses were devised. These are presented in table 2.II and 2.III.

Null Hypothesis 1

Precision performance (precision of movement, movement time, and precision of force application) and individual responses (biomechanical, physiological and psychophysical) will remain unchanged in all postures.

Table 2.II: Null and Alternate hypotheses for the first hypotheses

Dependent Variables	Null & Alternate hypotheses
Movement time: Speed (MT)	Ho: $\mu MT_{(Posture1)} = \mu MT_{(Posture2)} = \dots\dots\dots \mu MT_{(Posture8)}$
	Ha: $\mu MT_{(Posture1)} \neq \mu MT_{(Posture2)} \neq \dots\dots\dots \mu MT_{(Posture8)}$
Deviations: Accuracy (D)	Ho: $\mu D_{(Posture1)} = \mu D_{(Posture2)} = \dots\dots\dots \mu D_{(Posture8)}$
	Ha: $\mu D_{(Posture1)} \neq \mu D_{(Posture2)} \neq \dots\dots\dots \mu D_{(Posture8)}$
Precision of force application (PF)	Ho: $\mu PF_{(Posture1)} = \mu PF_{(Posture2)} = \dots\dots\dots \mu PF_{(Posture8)}$
	Ha: $\mu PF_{(Posture1)} \neq \mu PF_{(Posture2)} \neq \dots\dots\dots \mu PF_{(Posture8)}$
Biomechanical responses (BM)	Ho: $\mu BM_{(Posture1)} = \mu BM_{(Posture2)} = \dots\dots\dots \mu BM_{(Posture8)}$
	Ha: $\mu BM_{(Posture1)} \neq \mu BM_{(Posture2)} \neq \dots\dots\dots \mu BM_{(Posture8)}$
Physiological responses (PS)	Ho: $\mu PS_{(Posture1)} = \mu PS_{(Posture2)} = \dots\dots\dots \mu PS_{(Posture8)}$
	Ha: $\mu PS_{(Posture1)} \neq \mu PS_{(Posture2)} \neq \dots\dots\dots \mu PS_{(Posture8)}$
Psychophysical responses (PP)	Ho: $\mu PP_{(Posture1)} = \mu PP_{(Posture2)} = \dots\dots\dots \mu PP_{(Posture8)}$
	Ha: $\mu PP_{(Posture1)} \neq \mu PP_{(Posture2)} \neq \dots\dots\dots \mu PP_{(Posture8)}$

Null Hypothesis 2

High and low precision demands will elicit the same biomechanical, physiological and psychophysical responses in all postures.

Table 2.III: Null and Alternate hypotheses for the second hypotheses

Dependent Variables	Null & Alternate hypotheses
Biomechanical responses (BM)	Ho: µBM High$_{(Posture1……Posture\ 8)}$ = µBM Low$_{(Posture1……Posture\ 8)}$
	Ha: µBM High$_{(Posture1……Posture\ 8)}$ ≠ µBM Low$_{(Posture1……Posture\ 8)}$
Physiological responses (PS)	Ho: µPS High$_{(Posture1……Posture\ 8)}$ = µPS Low$_{(Posture1……Posture\ 8)}$
	Ha: µPS High$_{(Posture1……Posture\ 8)}$ ≠ µPS Low$_{(Posture1……Posture\ 8)}$
Psychophysical responses (PP)	Ho: µPP High$_{(Posture1……Posture\ 8)}$ = µPP Low$_{(Posture1……Posture\ 8)}$
	Ha: µPP High$_{(Posture1……Posture\ 8)}$ ≠ µPP Low$_{(Posture1……Posture\ 8)}$

High: High precision demands Low: Low precision demands

PILOT RESEARCH

A series of pilot studies were conducted prior to testing. Factors that had to be considered centred on postural dimensions of the selected eight postures, task specifications and determining the most suitable equipment to be used.

Postures adopted

The selection criteria for the chosen postures were based on their common occurrence in industry, and the ability of recruited subjects to adopt these novel postures for the required period. The appropriateness of the postures in terms of these selection criteria was piloted at length. To ensure that all subjects adopted the same postures, each posture was defined in relation to anatomical landmarks, anthropometric dimensions and objects within the height adjustable workstation (Appendix B.1A). In this regard, careful consideration was taken in constructing a workstation that would be adjustable enough to accommodate all the subjects' varied anthropometric dimensions in all postures. Mathematical equations that would provide exact dimensions for the workstation and the subject's position within that workstation were then created to ensure that each posture was standardised and replicated correctly (Appendix B.1B).

These equations were also piloted on several volunteers to ensure that all the dimensions were calculated appropriately.

Every attempt was made to keep the hand-arm position constant so that any effects of posture on precision performance could be isolated from those caused by different hand-arm trajectories under the varying postures. Subjects were also required to keep the head and neck alignment constant throughout all the conditions so as not to change the line of sight. The position of the monitor was therefore standardised and relativised to each individual such that it was the same distance away from the subject and at the same height in relation to the eyes in every posture. This was not entirely possible for the overhead working posture where subjects had to tilt the head back in order to reach the working surface and view the screen, a distinct characteristic of overhead work in industry (Sood **et al.**, 2007). Despite this, the position of the monitor was comparable to the other postures and the line of sight did not change although neck posture inevitably did.

The distance of the monitor from the individual was utilised to control finger reach and thus arm posture. It could be argued that eyesight and comfortable viewing distance (factors that would not necessarily be accommodated in the arm posture dimensions in the current study) would differ between individuals and may influence the performance of a precision task. However, the effects of these factors were deemed minimal since all participants of the study were not visually impaired. Moreover, if these factors were influential in any way, this effect would be the same in all postures and would not affect the comparison between them.

The change in direction of gravity on the hand-arm system was also unavoidable in certain postures and was acknowledged as having a potential influence on performance. For example, gravity would be acting in the same direction as that of task performance in the postures requiring stooping. In contrast, working overhead or lying supine would require subjects to work against gravity when stabilising the hand-arm system in the appropriate position to execute the task. In such cases, providing arm support could be beneficial in reducing the additional load emanating from the effect of counteracting gravity (Helander, 1997). However, the effect of gravity was beyond the scope of this study thus, this variable was not controlled in this study.

Precision tasks

Precision tasks are characterised by a movement component (where the aim is to reach the prescribed target) as well as a force application component (a force has to be applied to either counteract the weight of a load being handled or once the target is reached). Correspondingly, the tasks selected had to reflect these inherent precision demands.

Precision of movement

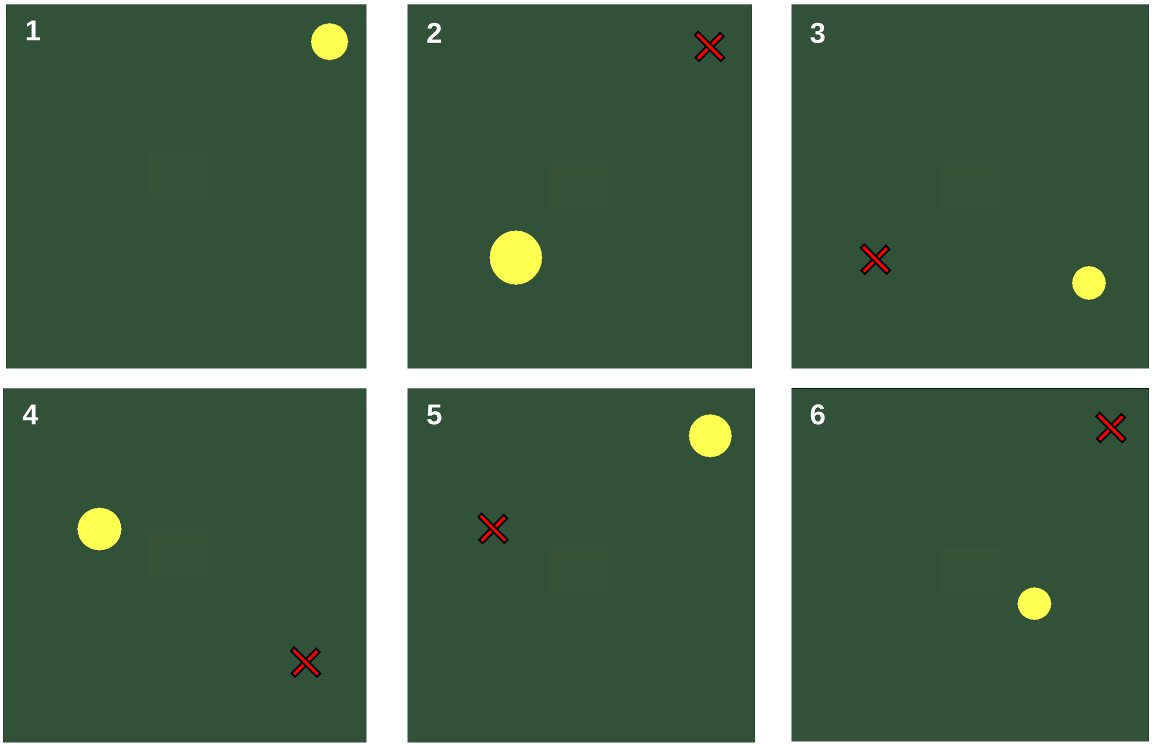
The precision task that was to be investigated had to be selected taking into cognisance several issues. A decision had to be made regarding the type of task to be analysed as precision tasks can either be discreet (tapping task) or cyclic (continuous task). The movement phase of both these precision tasks is governed by Fitts' law, which describes the trade-off between speed (movement time) and accuracy (deviation from the target) in regulating precision performance (Fitts, 1954; Winstein **et al.**, 1997; Schmidt and Lee, 2005). In this context, performance is mediated by the index of difficulty (ID) which is determined by the ratio between movement distance and target size (Schmidt and Lee, 2005; Guastello, 2006). Manipulating and managing the ID poses less of a challenge for a tapping task and this option offered a task that was easy to perform with minimal training. Moreover, using a continuous tracking task would have been difficult given the changes in the impact of gravity acting on the hand-held device that would have had to be utilised in this task. Therefore this component of precision performance was evaluated by means of a discreet tapping task.

The use of tools in task performance requires controlled and skilled movements. It was therefore necessary to find an interface where a discreet task could be performed without having to utilise any tools besides the hand-arm segments. In line with this, a touch screen monitor was selected because it eliminated the need to use a tool to select the targets. Thus the participants had to directly select the targets on the screen using the index finger.

A high and low precision task had to be included in the experimental design in order to ascertain the influence precision demands had on the strain experienced. Pilot studies were carried out to establish the appropriate ID for these tasks. Ultimately, IDs of 5.66 and 3.44 were selected for the high and low precision tasks respectively. This was resolved by working with different combinations of target size and distance between targets yet still ensuring that the targets appeared in a random fashion within the area provided on the screen interface that was utilised. The targets appeared in a random sequence to prevent participants from predicting target location before the targets appeared. This was essential as it ensured that the responses obtained were attributable to the stimulus (Schmidt and Lee, 2005).

A consequence of having the targets appear in a random order was a continual change in the distance between targets and thus the ID. To circumvent this effect, yet still keep the ID constant, the distance between targets was changed simultaneously with the size of the targets such that the average ID was the same at the end of each trial for all conditions. That is, if the distance between targets had to be increased, there would automatically be a corresponding increment in the target size such that the ratio between the two measures would still have the same index of difficulty (see Figure 2.5). For the high precision task, it was also imperative that the size of the smallest target was big enough to be detected easily.

Further pilot studies were performed on these tasks to determine the appropriate duration. In this regard the duration had to be sufficient to collect sufficient data yet not too long that performance was compromised, not because of individual capacity but because of the monotonous nature of the task. The results from the pilot studies indicated that these criteria were fulfilled when 25 targets were selected as thereafter performance decreased; a response attributed to reduced concentration levels attributable to the mundane nature of the tasks. These attention influences were reported by Sood **et al.** (2007) to be a confounding variable that impedes performance.



Yellow dot is the target point. Red cross is the position of the previous target

Figure 2.5: Example of target size and position changes for the low precision task

In order to isolate the effects of task difficulty on the level of strain experienced by the individual, the pace of task execution had to be standardised to limit the effects of speed of movement. Since the index of difficulty is linearly related to movement time, lowering the index of difficulty leads to a reduction in movement time due to increased speed of task execution. More rapid movements generally have a greater effect on muscle activation and are more physiologically taxing; imposing an additional load on the human compared to slower movements. It was therefore important to reduce the effect of speed of movement while not tampering with speed accuracy trade-off responses. This was done by ensuring that after a target was selected, the same amount of time (1.5 seconds) elapsed before the next target appeared for both high and low precision tasks. Thus, movement time was essentially the time lapsed from when the target was presented until the subject responded by touching the screen. An auditory signal was included to alert the participants that the next target had appeared on the screen. This was necessary because during pilot studies it was realised that individuals missed some targets if they appeared directly in line with the hand-arm system which obstructed the view. Therefore the auditory signal notified the individual that the next target had appeared.

As the interface used was a computer monitor, several factors relating to the graphics used and lighting were considered. After sampling different colours, a dark background was used for the screen and a bright yellow colour was used for the targets (see Figure 2.5). This contrasting colour scheme ensured visibility of the targets and follows guidelines set for computer work (Bridger, 2003). Lights used in the laboratory were fluorescent; these spread the light equally throughout the room. They were positioned at right angles to the monitor but not directly above the workstation. The curtains were drawn to reduce glare from sunlight coming in through the windows.

Precision of force application

As most precision tasks require force application during precision task performance, it was necessary to also consider an individual's ability to maintain a constant force over time. Precision of force application cannot however be understood under the framework of Fitts' law as this concept focuses only on the movement component of precision tasks. In terms of the force component of precision tasks, equipment that could simultaneously measure speed, accuracy and force application was not easily obtainable and could not be built. Consequently, the movement and force aspects were investigated separately in order to identify the individual effects of each.

Precision performance in the context of force application related to the ability to exert a constant force over time. Due to the fact that force feedback is mostly proprioceptive and kinaesthetic in nature, as opposed to predominantly visual as evidenced in aiming tasks, the force component of the precision task had to be executed with closed eyes. It was, imperative to allow participants time to adapt and stabilise the force exertion first with their eyes open before the eyes were closed and recording began. As such, participants were initially able to visually monitor fluctuations in force application on a computer screen between two defined targets. Once a constant force, (as constant as the subject could maintain) was attained, participants were then required to close their eyes while attempting to maintain the same force as before. The fluctuations measured were used as an indicator of the individual's ability to maintain a given force over time. This was ability was quantified using the trend/slope of force application.

After a series of available load cells were examined in pilot studies, one that measured uniaxial pushing and pulling forces was selected. The forces that were applied had to be uniaxial because this part of the study was concerned with the degree to which individuals could maintain a constant force. Thus, any 'off-axis' forces that would be observed would be an indication of the inability to maintain a constant force. The chosen load cell was also favoured because it permitted different forces (pushing and pulling) to be exerted and both hands were used to perform the task as is characteristic of many industrial tasks. Handles were attached on opposite ends of the hand-held load cell to allow for comfort and ease of use (see figure 2.6).

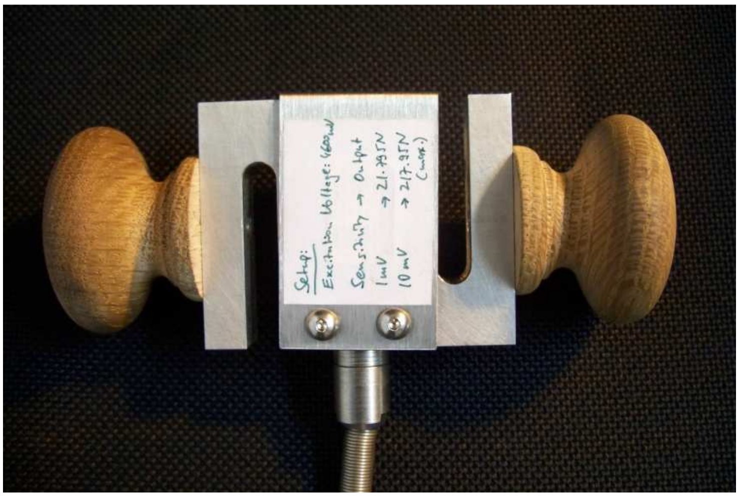


Figure 2.6: Load cell with handles

Further pilot studies were performed to determine the amount of force that all the subjects could exert over this period and the time required to get sufficient data. It was resolved that the force that had to be applied should be kept within two demarcated areas marked on the screen which corresponded with 50N (+50N for pushing and -50N for pulling). The participants were instructed to exert a constant force, below 50N, that they perceived to be able to sustain for 20 seconds while holding the load cell at the base of the monitor that was positioned at a distance of 75% of arm length. The deviations from the chosen constant force were measured as the trend followed by the force exerted. This force was considered to be low given that the weight of the load cell was negligible. Further piloting deemed a period of 20 seconds to be sufficient to obtain sufficient data. The load cell had to be stabilised at the same reference point (in front of the monitor) for all the participants.

EXPERIMENTAL DESIGN

In effect, the research design consisted of 24 conditions. That is, 3 tasks (high precision, low precision and a precision of force task consisting of two nested sub-conditions; namely pushing and pulling force tasks) were tested while subjects adopted eight different postures (seated, standing, stooping 30^0 and 60^0, working overhead, lying supine, and twisting to the preferred (dominant right hand) and non-preferred (non-dominant left hand) sides). The design matrix for this study is illustrated in Table 2.IV.

Table 2.IV: Experimental design matrix illustrating the conditions tested in this study

	TASKS		
POSTURES	**High precision (a)**	**Low precision (b)**	**Push & pull (c)**
1. Seated	1a	1b	1c
2. Standing	2a	2b	2c
3. Stoop 30	3a	3b	3c
4. Stoop 60	4a	4b	4c
5. Overhead work	5a	5b	5c
6. Lying supine	6a	6b	6c
7. Twist preferred side	7a	7b	7c
8. Twist non-preferred side	8a	8b	8c

For the precision tasks a total of 25 yellow spherical targets, accompanied by an auditory signal, appeared individually in a consecutive manner on the screen. The participants were instructed to select the target (as soon as it appeared on the touch-screen interface) as rapidly and accurately as possible using the index finger. Each task lasted approximately 40 seconds (25 targets × 1.5 seconds). Pushing and pulling were performed consecutively and lasted 20 seconds each amounting to 40 seconds for the force application task. When changing between pushing and pulling, participants had to once again visually monitor force output on the computer screen before closing their eyes. The order of the 24 conditions was randomised. This was done by permutation of the eight postures and alternating the high and low precision demands and the pushing and pulling force tasks. Rest breaks were given to subjects after all 3 tasks had been completed for each posture and approximately 30 seconds elapsed after each task was performed.

It was imperative to ensure that, in line with the holistic approach advocated for ergonomics research (Dempsey, 1998), a broad spectrum of individual responses representing all major approaches were analysed. Thus, in ascertaining the postural load experienced, biomechanical (muscle activity), physiological (heart rate), and psychophysical (ratings of perceived exertion) responses to the precision tasks were analysed.

DEPENDANT VARIABLES

In the study posture and the precision tasks were identified as independent variables while precision performance, as it applies to precision of movement and precision in force application, were the dependant variables. Posture was varied to ascertain how it would affect performance as it translates to movement time (speed of task execution), distance from the centre of the target (accuracy), and consistency of force application (trend for pushing and pulling).

The current study acknowledged the human-centred approach by not only investigating performance variables (speed, accuracy and force), but also considering the effect of the different conditions on the physical and psychophysical responses of the human. Posture has a direct relationship with the resulting muscle activity. Although the whole body is involved in any task execution, some muscles make a greater contribution to overall task performance than others. In the case of a precision task the hands are involved in the actual execution of the task. This includes moving the hand to the target, manipulating the hand and/or tool used and making the appropriate corrective hand postural adjustments based on the feedback received. Furthermore, several other muscles are involved in stabilising the hand-arm system while executing the task as well as the muscles that stabilise whole body posture. Leg muscles (such as quadriceps and hamstrings) were not directly analysed in this study. Although they assist in maintaining whole body posture especially during stooped postures, this was not the case in all of the postures that were investigated in this study.

From pilot studies of muscle activity, it was established that one representative muscle from the hand-arm system involved in task execution would be investigated; brachioradialis was chosen. Other muscles that predominated in all the postures for hand-arm system movement and stabilisation (biceps brachii, triceps brachii, anterior deltoid, posterior deltoid and trapezius), and trunk stabilisation (left and right erector spinae) were also included.

The nature of the tasks that were investigated could be classified as light tasks as they were not excessively physiologically taxing (Jonsson, 1988). The duration of each condition was limited to less than 60 seconds, and frequent rest breaks were provided. In order to get a reliable measurement of heart rate (HR) responses, HR is traditionally taken once a steady state has been reached which is normally three to four minutes after exercise (McArdle **et al.**, 2001). Given that the tasks performed in this study were less than 60 seconds in duration, HR could not have stabilised in that time and it could be argued that the individual would still be adapting to the task requirements. However, these tasks were performed under postures that deviated from the neutral posture (such as stooping and twisting). Although pilot studies revealed that HR had not completely stabilised in the set time, the differences in HR responses when postures are compared can still be evaluated although the absolute values cannot be interpreted in terms of established steady state norms. Therefore, and due to the known significant effect of posture on heart rate (HR) responses (McArdle **et al.**, 2001 and Pheasant, 1996), this variable was also incorporated into this study, albeit as a secondary measure.

Subjective recounts of the manner in which the tasks affected the subjects are important as they give an indication of the perceptual balance between the task demands and the individual's capabilities. The final dependant variable was the ratings of perceived exertion (RPE) in terms of whole body muscular contribution to the task. These ratings were obtained by utilising the Ratings of Perceived Exertion (RPE) scale.

MEASUREMENTS AND EQUIPMENT

Anthropometric parameters

Obtaining anthropometric measurements was of importance in this study. These measurements provided a quantitative means of describing the sample that was investigated. More importantly however, by making use of anatomical landmarks, these measurements served as reference points for defining the postures that were tested, and aided in translating these into tangible dimensions for the workstation. Standardisation of posture was a necessity and would allow for comparisons of responses to be made between the different postures and subjects. With the exception of stature, all other anthropometric measurements were taken from the right hand side using an Anthropometer held perpendicular to the floor. For all these measurements (except the seated positions) subjects had to stand in the anatomical position looking straight ahead and where appropriate measurements were taken from the right hand side. Arm length of the dominant (right) arm was measured using a retractable measuring tape. A description of each anthropometric measurement used in this study is provided in Table 2.V.

Table 2.V: Anthropometric measurements

MEASUREMENT	DESCRIPTION
Stature	Stature (mm) was measured using a Harpenden stadiometer. The reading was taken from the base of the stadiometer to the vertex in the sagittal plane while the subject stood upright with the head in the Frankfurt plane.
Body Mass	Body mass was measured, to the nearest 0.1kg, on a Toledo scale. Subjects were required to stand upright in the middle of the scale dressed in light clothing and without shoes.
Standing eye height	Distance measured from the soles of the feet to eye level (in mm).
Shoulder height (Acromiale height)	Distance measured from the soles of the feet to acromion process of the scapula (in mm).
Hip height (iliospinale height)	Distance measured from the soles of the feet to the iliac crest (in mm).
Standing eye to hip height	Distance measured from the iliac crest to eye level (in mm).
Sitting eye height	Distance measured from the surface of the seat pan of the chair the subject was seated on to eye level (in mm).
Arm length	Distance measured from the acromion process to the styloid process while subject was standing in the anatomical position (in mm).

Biomechanical parameters

Precision tasks not only require individuals to make the appropriate limb movements to the target, but whole body postural adjustments are also necessary to continually stabilise and maintain the body in the posture(s) that facilitates task execution. As muscles are integral to the above, electromyography (EMG) was used to analyse muscle electrical activity during different postures for the different precision tasks that were analysed.

Electromyography

Electromyography is a biomechanical analysis tool that indirectly measures muscle electrical activity (Stokes **et al.**, 2003). The Muscle Tester ME6000 Biomonitor System (Mega Electronics Ltd) makes use of disposable silver chloride surface electrodes adhered to the skin overlying the muscle(s) being investigated. The skin over which the electrodes were placed was shaved where necessary. A description of electrode placement is provided in the Appendix B.1C. For each muscle that was tested, two electrodes were utilised and only one representative ground electrode (adhered on the forearm wrist flexors) was used to reduce cross talk. This device can measure sixteen muscles although eight were used in the current study. The device was placed in a pouch and strapped around the subject's waist so that movement could not be inhibited by the wires. Testing was performed online at a sampling rate of 1000Hz for each muscle and the signals were automatically filtered and recorded by the Muscle Tester ME6000 Biomonitor System.

Maximal voluntary contractions (MVCs) have been cited as a valid means of normalising electromyography (EMG) data thus allowing for changes in relative effort from the muscles to be monitored and comparisons between different postures and individuals to be drawn. Two maximal exertions lasting three seconds each were performed for each of the muscles that were to be tested. Participants were encouraged and motivated to exert maximal forces while caution was taken to prevent pain and injury. Table 2.VI provides a summary of the procedure followed to obtain MVCs.

Table 2.VI: Description of maximal voluntary contraction (MVC) tests (adapted from Kendell **et al.**, 1993)

MUSCLE	MAXIMAL TEST DESCRIPTION
Brachioradialis	• Subject seated with elbow flexed and forearm in neutral position between pronation and supination • Pressure applied against forearm in the direction of extension while subject flexes elbow further
Biceps brachii	• Subject seated with elbow flexed greater than 90^0 while forearm is supine • Pressure applied against forearm in the direction of extension while subject flexes elbow further
Triceps brachii	• Subject lying supine with elbow raised from surface and flexed slightly more than 90^0 while forearm is in neutral position between pronation and supination • Pressure applied against forearm in the direction of flexion while subject extends elbow further
Anterior Deltoid	• Subject seated with elbow raised (through abduction) and flexed slightly less than 90^0 while forearm is pronated • Pressure applied in the direction of adduction against the elbow while subject exerts force in the direction of abduction
Posterior Deltoid	• Subject seated with elbow raised (through abduction) and flexed slightly less than 90^0 while forearm is pronated • Pressure applied anteriorly against the elbow while subject exerts force in posterior direction without twisting the upper body
Trapezius	• Subject seated with both arms resting on thighs • Subject elevates the acromial end of the clavicle and scapula (shrugging action bringing shoulder towards the ears) while the researcher exerts an opposing force in the direction of depression
Erector Spinae (right and left)	• Subject lying prone with hands clasped behind the head while lifting the head and trunk off the surface as far as possible thus extending the trunk to its full range of motion • Researcher holds subject's legs down to stabilise movement

Force Sensor

The Biometrics Ltd DataLOG W4X8 has eight channels that allow for a series of different data to be collected. For this study, a single analogue channel was used to measure pushing and pulling forces (N) using a load cell. The load cell, built with handles on either side, was connected to the Biometrics Ltd DataLOG W4X8 and calibrated accordingly. The data logger software was loaded onto a laptop which was also connected to the touch screen monitor that was used by subjects for the precision tasks. When the subjects exerted a pushing or pulling force, the changes in force production generated in the load cell were displayed on the touch screen monitor providing subjects with visual feedback about their force production.

Physiological parameters

Heart Rate online tracking device

Heart rate (HR) was recorded using a Suunto HR online tracking device consisting of a HR strap that was fastened around the subject's chest and a USB attachment that telemetrically transmitted recorded data to the PC. This system made it possible to track HR changes in real time. The tasks that were investigated lasted a short period of time (approximately 40 seconds each) thus making it imperative to ensure that HR was recorded continually. The online HR tracking device facilitated this as it was possible to view HR changes in real time thus allowing for timeous detection of any breaks in signal transmission.

Psychophysical parameters

Some precision tasks in industry are performed under awkward postures which have been found to be key in the development of discomfort and fatigue (Magnusson and Pope, 1988; Sood **et al.**, 2007). Precision tasks for the most part are usually not considered to be physiologically demanding although the cumulative muscular effort required for performing the task and posture stabilisation may be significant. As such, the perceptions of muscular effort, as opposed to physiological input, were thus of interest.

Ratings of Perceived Exertion (RPE) scale

The Ratings of Perceived Exertion (RPE) scale (Appendix B.1D; Borg, 1982) is designed to obtain a quantitative measure of workers' perceptions about the task they are performing. This scale has numeric values corresponding to verbal anchors that give an indication of the perception of effort an individual invests in a task. The RPE scale is used to distinguish effort that is centrally (from the heart and lungs) or locally derived (from muscles and joints). In this study subjects were asked to report on their perception of muscular effort. These ratings pertained to whole body muscular effort and not a specific region and were taken after each task was completed. 'Central' RPE was not considered as the task was not expected to impose excessive physiological stress on the participants as it was a light task requiring minimal movement over short periods of time.

EXPERIMENTAL PROCEDURE

The experimental procedure of the current study consisted of two sessions, namely the habituation session followed by the testing session both of which were approved by the Ethics Committee. Informed consent was obtained before commencing with the habituation session. There was thus an understanding that partaking in the study was completely voluntary and that participants had the option to withdraw from the study whenever they felt the need to do so. The habituation session was designed to acquaint the participants with the experimental protocol, procedures and the equipment that was to be utilised. Additionally, they were introduced to, and given a chance to practice the tasks that were to be performed. Each task was performed until the subject felt comfortable with executing it thus the time varied between subjects. Participants' anthropometric data was measured and entered into equations that determined the dimensions to which the workstation would be adjusted. During this session informed consent was obtained.

Upon arrival for the experimental session, the subjects were once again reminded of the details of the experimental procedure and the equipment that would be used. The HR strap was then attached around the chest and electrodes were adhered to the skin over the relevant muscles. Maximal voluntary contractions (MVCs) were then performed with the aid of the assistant researcher after which subjects had to rest for approximately 5 minutes while lying in the supine position in order to return HR to resting levels; the 'reference' HR was then recorded. The workstation was adjusted to the appropriate dimensions depending on the condition that would be performed (Figure 2.7). All of the equipment (HR tracking device, electromyography and the force sensor) was then started.

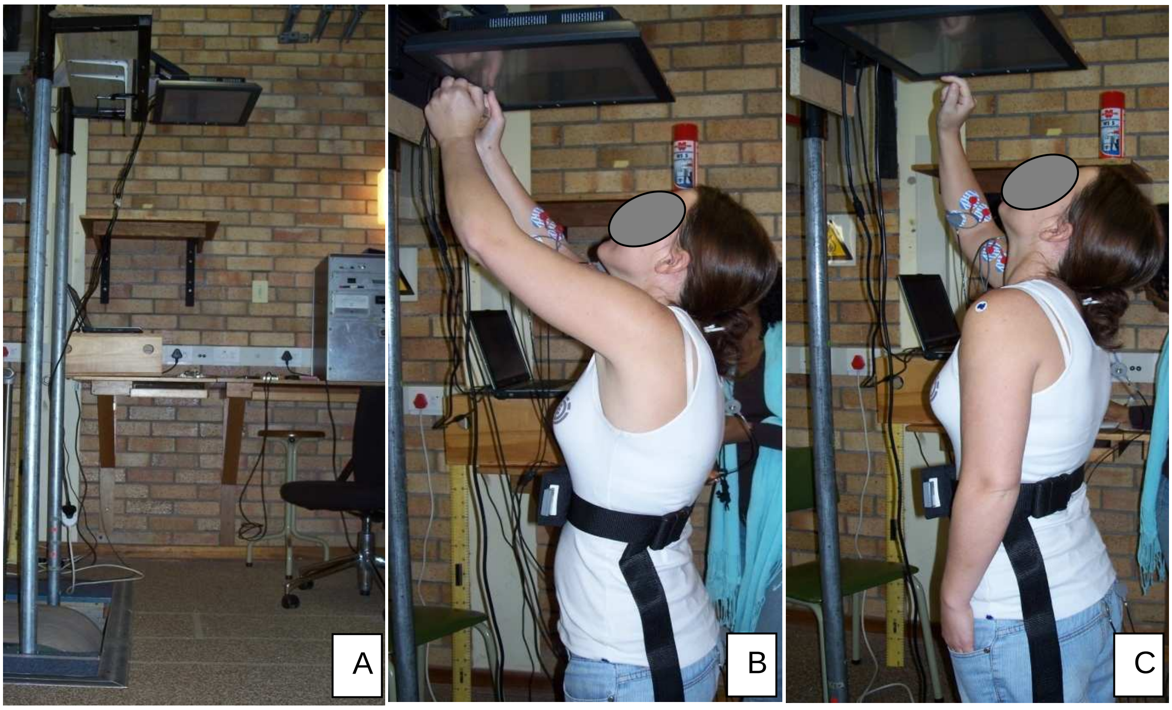


Figure 2.7: Experimental set-up for overhead work (A); with participant performing the force (B) and precision (C) tasks.

Following this the subject was given a brief description of the conditions they were to perform (ie: the posture and the different tasks to be performed under that posture) and instructions on how to perform the tasks were repeated. After all 3 tasks had been performed for each posture, RPE ratings were taken. The participant was then given a rest break of approximately 2 minutes while the workstation was adjusted for the following condition. Between tasks performed in the same posture, approximately a 30 second break was taken by the participants while the next task was being set up. Therefore, the rest breaks given for each posture totalled approximately 210 seconds (120 seconds rest in addition to 30 seconds after each of the three tasks). Given that the tasks were light and total working time for each posture was 120 seconds, the work to rest ratio was deemed sufficient to ensure that fatigue did not become a confounding variable thus reducing the validity of the measurements over the full testing session.

It was imperative that all the postures under investigation were replicated accurately so that all subjects would be exposed to the same postural demands. Due to the variable demands of the postures, the order in which the postures and the tasks were performed was permutated in order to prevent any order effects. This was achieved by randomising the order in which the postures were tested in addition to alternating the order in which the pushing and pulling force were executed.

SUBJECT CHARACTERISTICS

In accordance with the twenty four conditions that were tested (8 postures × 3 tasks), an equal sample of right hand dominant females (24) and males (24) between the ages of 18 and 26 years were selected. Thus, forty eight subjects were recruited from the student population at Rhodes University to participate in this study. The number of subjects in the sample was dictated by the number of postures and tasks tested (8*3=24) and the fact that a balance of male and female (24+24=48) subjects had to be used. With the exception of one subject that worked briefly as a cashier at a bar, all subjects had no prior experience using a touch screen. However, the tasks were simple and easy to execute and subjects were able to perform them after practice trials. All subjects signed an informed consent form that assured confidentiality of their identity and results. A synopsis of the anthropometric characteristics of the sample is provided in Table 2.VII.

Table 2.VII: Subject anthropometric data (n=24 males and 24 females) (SD denotes standard deviation

Measurement	Males		Females	
	Mean	SD	Mean	SD
Stature (mm)	1749	94	1648	54
Mass (kg)	76.30	11.92	61.28	9.38
Standing eye height (mm)	1650	70	1526	58
Shoulder height (mm)	1459	59	1353	56
Arm length (mm)	577	29	538	25
Sitting eye height (mm)	1224	53	1161	48
Hip height (mm)	993	69	945	45

STATISTICAL ANALYSIS

The movement time, deviation from the target, force, muscle activity, heart rate, and ratings of perceived exertion values were averaged and are thus a reflection of the mean of the data obtained while the subject was performing a specific task. With reference to the force data, the coefficient of variation (CV) was calculated to verify if subjects were able to adhere to the instructions given. Thereafter, the trend (slope) of the pushing or pulling force over the 20 second period was calculated to determine the general changes in force output. The muscle activity data is the average value for the interval that was processed for each condition. This data was also normalised using the maximal voluntary contractions (MVC) for each muscle. As such, the data that was analysed appears as a percentage of the MVC. The reduced data was then exported to Statistica version 8 (2008) where descriptive statistics, normality and tests of homogeneity of the variables were carried out. Repeated Measures ANOVAS were utilised to test the overall effects of posture and varying precision demands on the dependent variables. The Tukey HSD test (MANOVA/ series of t-tests) was conducted to determine pair-wise differences in the dependent variables between the different postures. Throughout these analyses the level of significance was set at 95% ($p<0.05$) to reduce the likelihood of committing a Type I error.

SECTION 2

CHAPTER IV
RESULTS

INTRODUCTION

Awkward postures are known to cause strain on the human operator and lead to fatigue, injury and the development of musculoskeletal diseases (Herberts **et al.**, 1980; Bridger, 2003; Carnide **et al.**, 2006). Unlike the effects of awkward working postures on the individual, their influence on task performance is little understood and marred by conflicting evidence. In this light, this research project attempted to elucidate the effects of awkward working postures on the performance of a precision task. The postures in question included a seated, standing, stooping 30^0 and 60^0, working overhead, lying supine and twisting to either side. Precision performance was measured by movement time (speed), deviation from the centre of the target (accuracy), and precision of force application (degree to which a pushing and pulling force could be sustained over time). Precision demands were differentiated by setting two different indexes of difficulty (ID); 5.66 and 3.44 for the high and low precision tasks respectively. The ID was moderated by the relationship between target size and the distance between subsequent targets. Although the focus of the current study was on the effects of posture on precision performance, it was essential to describe how the different postures affected the individual and how this then translated to performance outcomes. Muscle activity of eight muscles, heart rate, and ratings of perceived exertion were utilised as indicators of the postural strain on the individual.

The confidence level was set at 95% ($p<0.05$) for all of the results that will be presented. The error bars that appear in all figures represent standard deviations

PERFORMANCE VARIABLES

Movement time has a direct influence on task completion time and productivity and is thus an efficiency indicator (Gunasekaran **et al.**, 1994). Efficiency cannot however be considered in isolation to effective task completion which is closely related to the quality of output. Therefore, and in accordance with Drury and Paquet (2004), performance in this study was considered as a combination of movement time and deviation from the centre of the target. As force is an integral component in task execution the change in force application was also monitored by processing the trend of the force.

Before proceeding to the results pertaining to the effect of posture on speed of task execution, it must be noted that measures were taken to minimise the effect of speed on performance outcomes and individual responses. This was accomplished by standardising the time that lapsed between the targets appearing on the screen for both high and low precision tasks. In other words, the overall time it took to complete both tasks was identical and response differences could not be attributed to differences in the speed of task execution.

Effect of precision demands and posture on movement time

Task difficulty (precision demands) had a significant effect on movement time (Table 2.VIII), with the high precision task taking a significantly longer time to complete than the low precision task in all the postures that were examined (Figure 2.7).

Table 2.VIII: Effect of posture on movement time

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	272.6057	1	272.6057	4229.122	p< 0.05
POSTURE	0.2814	7	0.0402	24.350	p< 0.05
DIFFICUL	2.5245	1	2.5245	266.755	p< 0.05
POSTURE*DIFFICUL	0.0322	7	0.0046	4.339	0.000129

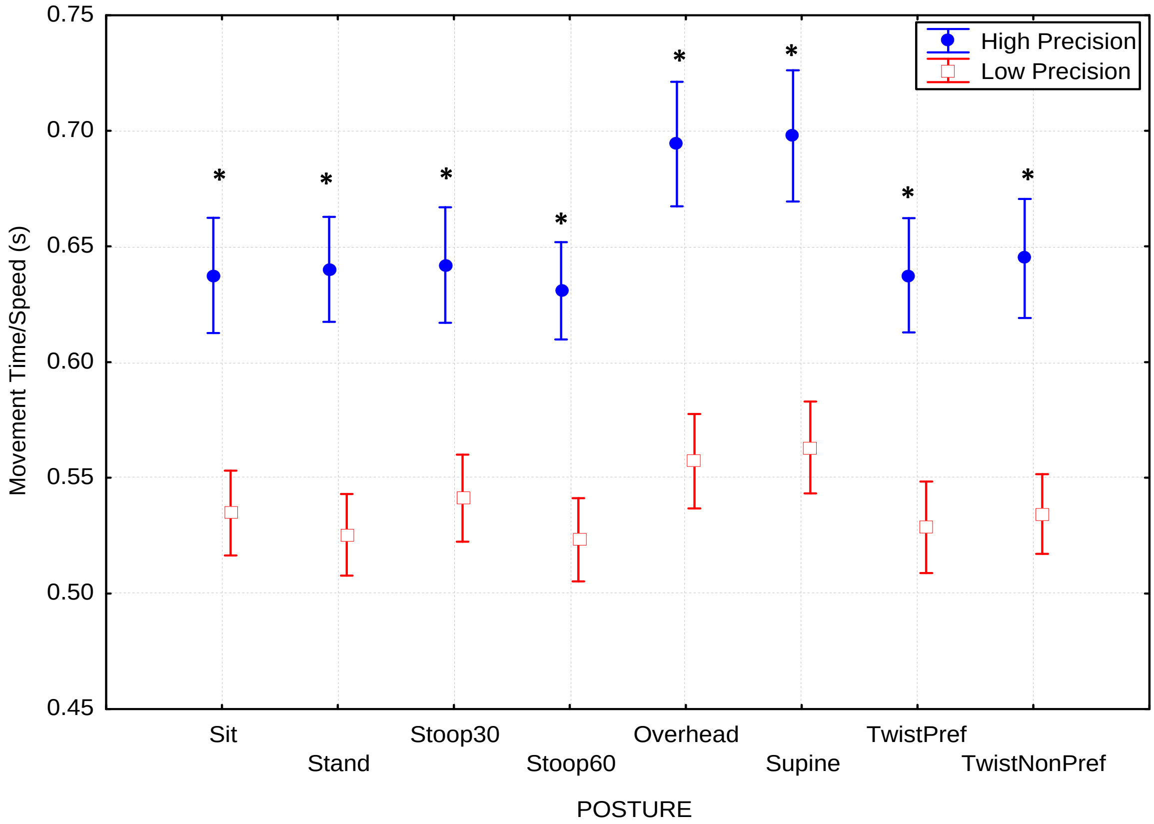


Figure 2.8: Movement time differences between the high and the low precision tasks under different postures. * denotes significant difference between low and high precision demands.

Overall, posture was found to have a significant effect on movement time and is thus likely to have important ramifications for performance outcomes (Table 2.VII). The fastest average reaction times were achieved for the stooping 60^0 posture for high (0.63s) and low (0.52s) precision demands. However, movement time in the stooping 60^0 posture did not differ statistically when compared to all the other postures except the overhead and lying supine postures (Figure 2.8). Pair wise comparison of the postures showed that movement time while in the seated posture, a commonly prescribed posture for workers performing precision tasks (Helander, 1997), was comparable to that from the standing, stooping 30^0 and 60^0 and the twisted postures. These postures all had faster movement times when compared to working overhead or lying supine.

Lying supine caused the slowest average movement times with a mean of 0.68s and 0.56s for the high and low precision tasks, respectively (Figure 2.8). However, movement time in the lying supine posture was statistically similar to that obtained while working overhead thus suggesting that both these postures compromise overall speed of task execution.

The interaction of posture and task difficulty (high or low precision tasks) was highly significant (Table 2.VII). This means that movement time is affected in a different manner by posture and task difficulty. Hence, the influence of posture on movement time may change depending on whether a high or low precision task is performed.

These results suggest that the postural strain caused by increased trunk flexion and axial twisting was not excessive enough to cause decrements to movement time. Alternatively, it may be possible that individuals were able to adapt to the postural demands within the time provided thus preventing any negative effects on movement time. Probably the combination of working with the hand-arm system stabilised above the head or shoulders and working against the direction in which gravity is acting does not favour optimal movement times.

Effect of precision demands and posture on deviation from target

Accuracy can be regarded as the ability to consistently adhere to predefined tolerance limits (Schmidt and Lee, 2005; Guastello, 2006) and this can be quantified by analysing the deviations from the target. In this study these deviations were measured from the centre of the target. Since low precision demands allow for greater tolerance, it was expected that participants would be able to approach the centre of the target less closely than when a high precision task with stricter tolerances was performed. Accordingly, task difficulty had a significant effect on the degree to which individuals deviated from the centre of the target (Table 2.IX). In this regard, participants approached the target centre closer when performing the high precision task. However, this effect was not significant for the standing upright posture (Figure 2.9). This implies that in the standing posture varying precision demands had no effect on the deviation from the centre of the target. However, the wide range in terms of deviations from the target for high precision demands in the standing posture suggests that there was a larger degree of individual variation in these responses.

Table 2.IX: Effect of posture on deviation from the centre of the target

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	10151.32	1	10151.32	2490.868	$p < 0.05$
POSTURE	44.58	7	6.37	9.529	$p < 0.05$
DIFFICUL	123.34	1	123.34	143.075	$p < 0.05$
POSTURE*DIFFICUL	5.87	7	0.84	1.288	0.255548

Due to the fact that precision demands will inherently lead to varied deviations, the following results will compare deviations observed when equal precision demands were imposed. Thus, posture effects during high precision task will be presented separately to those obtained while performing low precision tasks.

Deviations from the centre of the target were significantly affected by the posture that was adopted (Table 2.IX). Consequently some postures facilitated the individual's ability to make more accurate movements while others made the individual more susceptible to deviating from the target. This could have important implications for industries where tolerance limits and quality specifications are high yet the manner in which the workstations are designed force workers to adopt awkward postures. The postures that would be a concern in this regard when considering high precision tasks would be the overhead, lying supine and standing postures, all of which led to significantly higher deviations than the other postures.

In terms of low precision tasks, the only significant difference in deviation from the target was evidenced between the lying supine and stooping 60^0 postures where the latter was significantly lower than the former. The overhead working posture led to similar deviations to those from all the other postures with the exception of stooping 60^0 which was significantly lower.

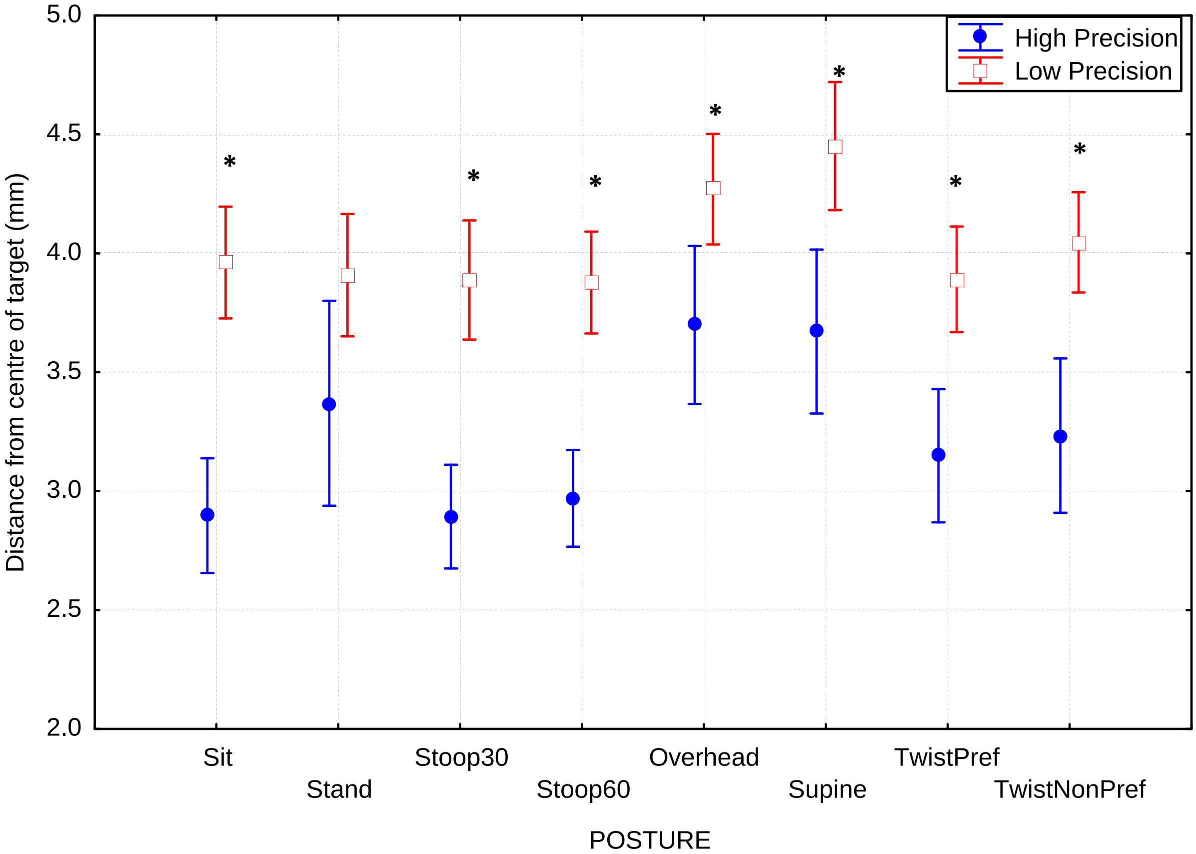


Figure 2.9: Deviation from target between the high precision (ID = 5.66) and low precision (ID = 3.44) tasks under different postures. * denotes significant difference between low and high precision demands.

The interaction effect of posture and task difficulty on deviations from the target was not significant ($p = 0.255$; Table 2.IX). This means that the effect of posture does not differ significantly for varying precision demands as far as deviations from the target are concerned.

Effect of pushing/pulling and posture on precision of force output

Precision of force application was measured by the degree to which subjects could maintain a constant force over a period of time. This was determined by calculating the trend each force exertion followed over time which was either a decrement or increment in applied force over the twenty second duration for pushing and pulling. A positive trend would be a consequence of an increase in force output over time. This would be an indication of the individual over-compensating by exerting more force than is required. Alternatively, a negative slope would coincide with reduced force output over time, which can be interpreted as an under-compensation reaction. If force output remains stable, this would represent the ability to sustain a constant force over time.

Neither posture (p = 0.058), the force applied (p = 0.47), nor the interaction of both (p= 0.72) varied significantly with the calculated trend/slope for precision of force application (Table 2.X). The evinced trends in precision of force application could thus not be solely attributed to posture, force, or the interaction of both. Through pair wise analysis the only significant difference evidenced during force production was between overhead work and stooping 60^0 (p = 0.02067) when a pushing force was applied.

Table 2.X: Force trend results

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	155731	1	155731.3	5.652322	0.021553
POSTURE	195502	7	27928.9	1.977164	0.057582
FORCE	8319	1	8319.1	0.532837	0.469039
POSTURE*FORCE	63484	7	9069.1	0.637823	0.724528

Figure 2.10 depicts a high standard deviation for the pushing force in the overhead working posture. After inspecting the normality of the data regarding overhead pushing it was seen that the data was likely to have been skewed by one outlier. Removing this participant's results revealed a difference response pattern as illustrated in Table 2.XI and Figure 2.11.

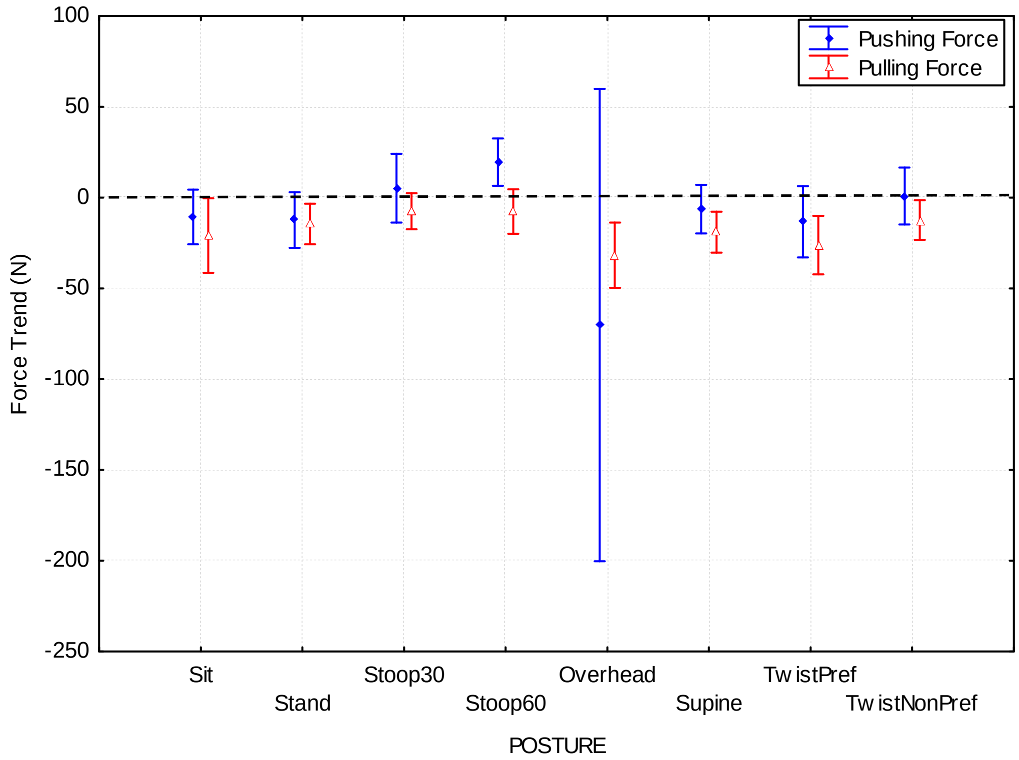


Figure 2.10: Trend for precision of pushing and pulling force application. Dotted line highlights differences in positive (increase) and negative (decrease) force output

Table 2.XI: Force trend results excluding outlier.

Repeated Measures Analysis of Variance (Spreadsheet6) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	75297.1	1	75297.14	5.34505	0.025311
POSTURE	54909.9	7	7844.28	3.16981	0.002950
FORCES	40798.5	1	40798.49	13.94697	0.000517
POSTURE*FORCES	9440.2	7	1348.60	0.68890	0.681486

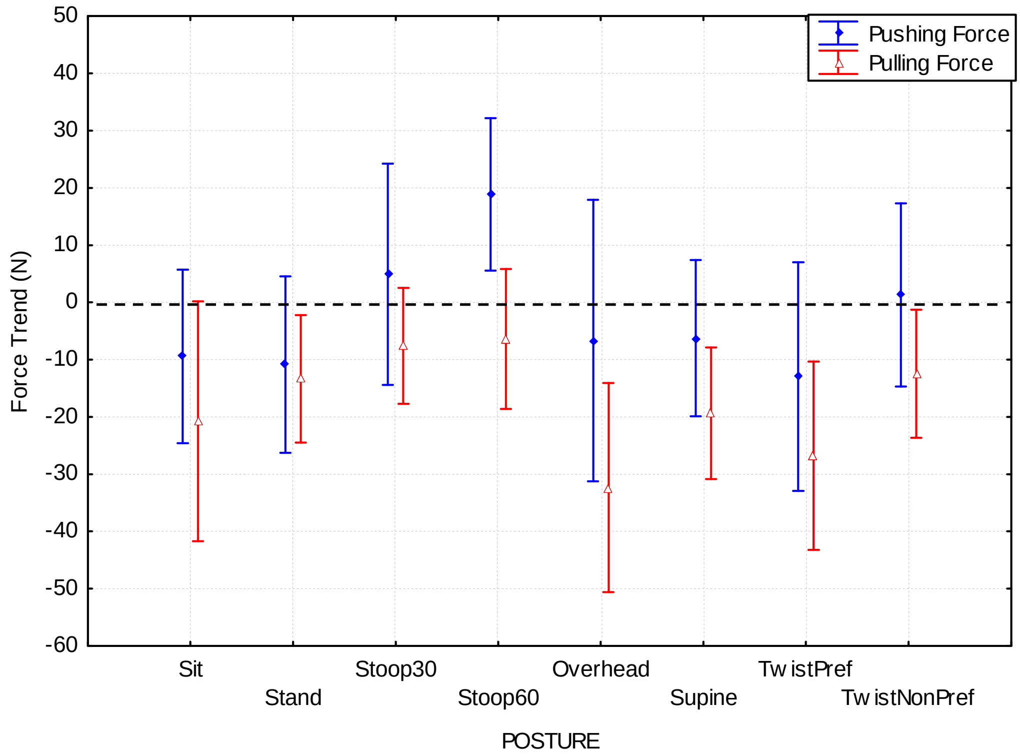


Figure 2.11: Trend for precision of pushing and pulling force application excluding outlier. Dotted line highlights differences in positive (increase) and negative (decrease) force output

The direction of force applications (pushing or pulling) significantly affected the evidenced trend (Table 2.XI). This means that the trend of force exertion was dependant on whether a pushing or pulling force was exerted. In this regard, pulling force output followed a negative trend indicative of a reduction in force output over time for all the postures (Figure 2.11). The pushing force also followed a general negative trend for all the postures except the stooped postures and twisting to the non-preferred side (Figure 2.11).

Posture was also found to have a significant effect on the trend of force application. Force output increased for the stooped postures suggesting that participants were overcompensating force production and were pushing harder than necessary. While twisting to the non-preferred side participants were able to maintain a constant force more so than during the remaining postures. The only significant difference was found between pushing while stooping at 60^0 and twisting to the preferred side. The interaction of posture and force was not significant (Table 2.XI) suggesting that the effect of posture on the trend is the same regardless of whether a pushing or pulling force is exerted.

Summary: performance outcomes

In accordance with Fitts' Law, movement time was significantly different when high and low precision tasks were compared. In each posture high precision demands resulted in slower movement times, a necessary adjustment to meet precision requirements, whereas low precision demands allowed for quicker movements. The fastest movement times were achieved while subjects were stooping at a 60^0 angle for both high and low precision tasks but this was statistically similar to all other postures with the exception of working overhead and supine. Working overhead and while lying supine resulted in the slowest movement times.

Higher precision requirements made it imperative that participants approach the target centre closer. As such, deviations from the centre of the target were greater for the low precision demands reflecting the bigger tolerance allowed while the opposite held true for high precision demands. Posture had a strong influence on deviation from the target when tasks with the same precision requirements were compared. High precision requirements brought about the greatest deviations in the overhead, supine and standing postures. For low precision demands lying supine elicited significantly greater deviations when compared to stooping 60^0.

Posture and the direction of force application (push or pull) both had a significant effect on force output over time as indicated by the trend/slope. Pulling force output diminished over time for all the postures as indicated by a negative trend. Pushing force output also diminished with time but to a lesser degree than pulling for all postures except the stooping (where pushing force output increased over time) and twisting to the non-preferred side (pushing force output was more or less constant over time).The high standard deviations for all the trend results suggest that individual variation affects the extent to which constant pushing and pulling forces can be exerted over time in the different postures.

Table 2.XII: Summary of performance outcomes.
n.s = not significant; High = High precision demands; Low = Low precision demands

Performance variable	p	Comment
Movement time	$p<0.05$ High>Low	Fastest = Stoop60 similar to all other postures except overhead and lying supine (high and low precision) Slowest = overhead and lying supine (high and low)
Deviation from target	$p<0.05$	Greatest deviations in overhead posture (high precision demands) and lying supine (low precision)
Precision of push/pull force application	$p<0.05$ Push>Pull	Overcompensation (increase force)= Pushing at stoop30^0 & 60^0 Under-compensation (decrease force) = all (except pushing stooped postures). Greatest reduction in force for overhead (pulling) and twisting to preferred side (pushing)

BIOMECHANICAL REPONSES

Muscle activity responses were normalised using the maximal voluntary contractions (MVC) that were performed for each muscle. As such, muscle activity results are presented as a percentage of MVC to allow for inter-individual comparison to be carried out. The effects of precision tasks and force tasks on the different muscles are reported separately.

PRECISION TASKS

Effect of precision demands on muscle activity

The effect of precision demands was found to be significant for 3 of the 8 muscles that were tested; namely brachioradialis (Table 2.XIII), trapezius (Table 2.XIV), and posterior deltoid muscles (Table 2.XV). In these muscles, electrical activity was significantly amplified by high precision demands while this was not the case in the remaining muscles (refer to Appendix B.3C for the statistics analysis of these muscles)

Table 2.XIII: Brachioradialis muscle responses for high and low precision tasks.

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	15314.54	1	15314.54	101.2331	$p < 0.05$
POSTURE	122.55	7	17.51	5.6032	0.000004
DIFFICUL	20.76	1	20.76	25.6790	0.000007
POSTURE*DIFFICUL	3.31	7	0.47	1.6612	0.117714

Table 2.XIV: Trapezius muscle responses for high and low precision tasks.

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	63343.78	1	63343.78	211.3107	$p < 0.05$
POSTURE	16355.35	7	2336.48	100.1736	$p < 0.05$
DIFFICUL	34.93	1	34.93	12.7093	0.000848
POSTURE*DIFFICUL	15.16	7	2.17	1.8773	0.072532

Table 2.XV: Posterior deltoid muscle responses for high and low precision tasks.

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	7829.370	1	7829.370	121.1359	$p < 0.05$
POSTURE	2837.982	7	405.426	51.1176	$p < 0.05$
DIFFICUL	3.618	1	3.618	12.7673	0.000828
POSTURE*DIFFICUL	1.035	7	0.148	0.6866	0.683444

Although the above statistics indicate that higher precision demands are more taxing on the selected muscles, this was not the case in all the postures. Brachioradialis muscle activity levels were significantly greater for the high precision task only in the seated, overhead and twisting to the non-preferred side postures (Figure 2.12).

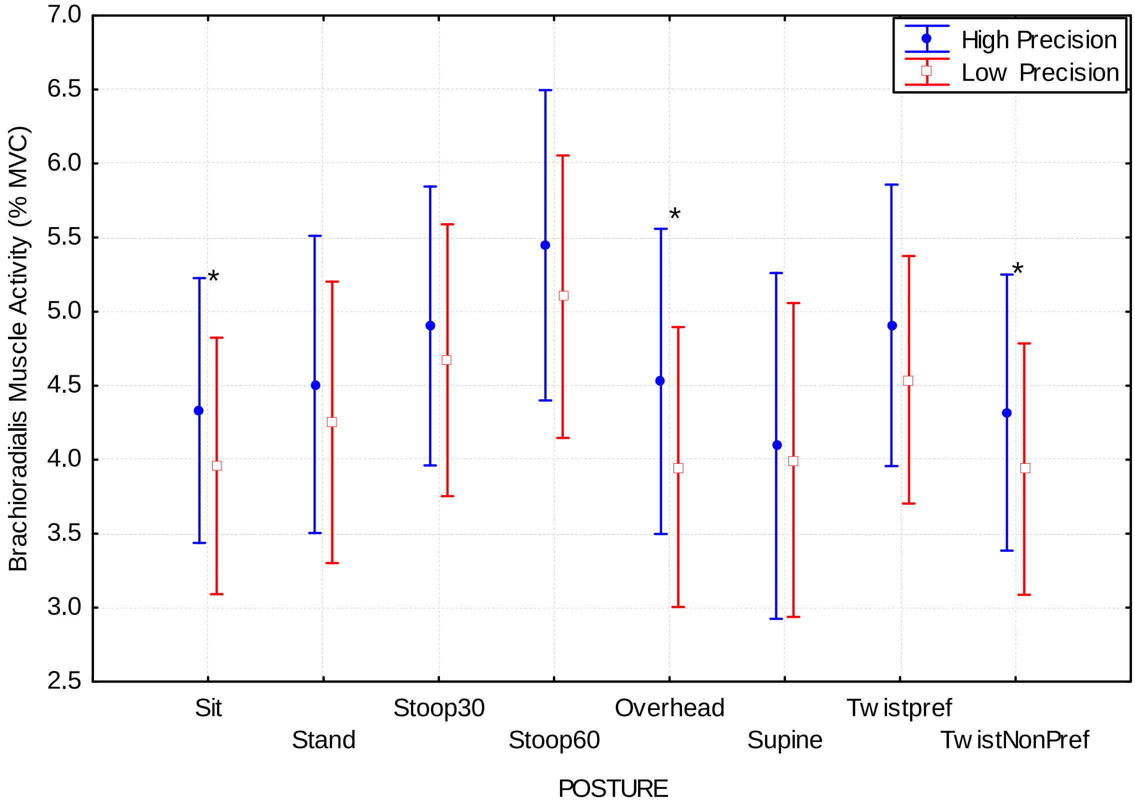


Figure 2.12: Brachioradialis muscle activity for precision tasks. * denotes significant difference between low and high precision demands.

When all postures were considered, precision demands were found to have a significant effect on trapezius muscle activity (Table 2.XIV). However, this difference (muscle activity augmented for higher precision demands) was only observed in the overhead working posture when the postures were considered individually (Figure 2.13).

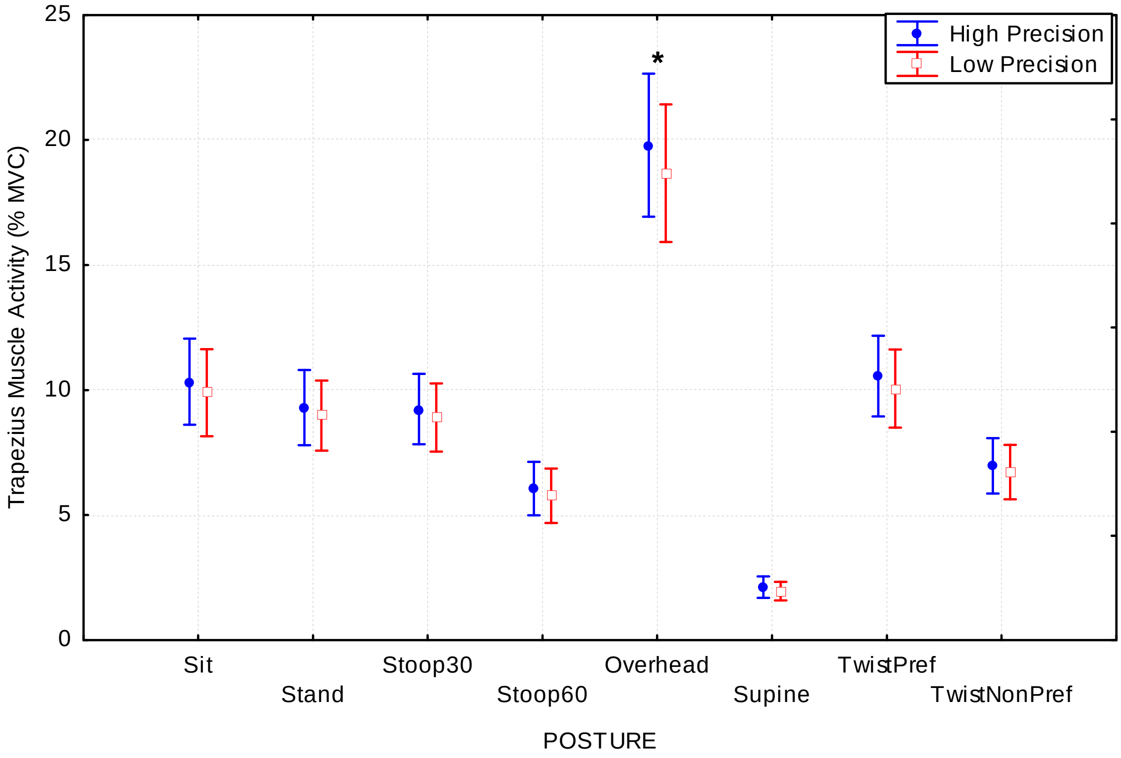


Figure 2.13: Trapezius muscle activity during precision tasks * denotes significant difference between low and high precision demands.

On consideration of all postures together, high precision demands led to significantly higher posterior deltoid electrical activity (Table XV). This however was not the case when individual postures were considered in isolation as the high precision task elicited similar muscle activity to that of low precision tasks (Figure, 2.14).

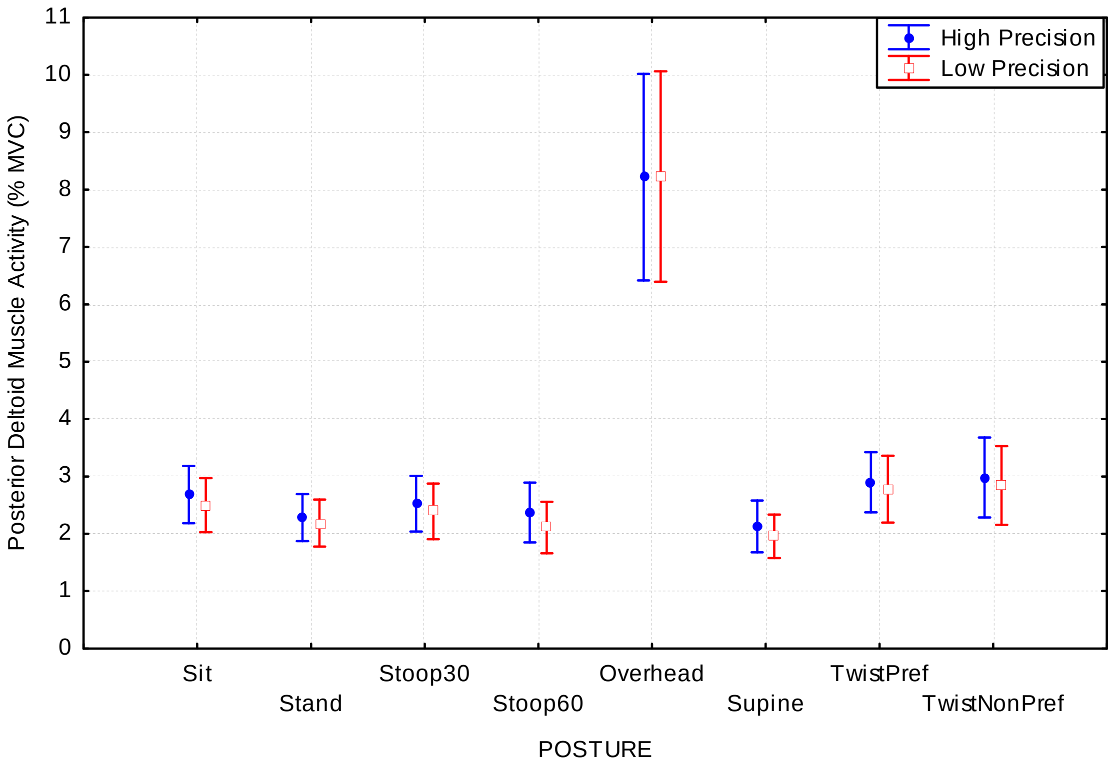


Figure 2.14: Posterior deltoid muscle activity during precision tasks.

The percentage increase of muscle activity from low precision demands to high precision demands varied between the postures (Table 2.XVI). Brachioradialis in the overhead posture showed the greatest increase (15%) between high and low precision demands as opposed to a lower 6% in the trapezius muscle. It was interesting to note that even in the seated posture, a posture that is regarded as more appropriate for performing precision tasks (Graf **et al.**, 1995; Helander, 1997); precision demands had an influence on muscle activity (9% difference between high and low). This further supports the supposition that precision demands, coupled with the working posture may be important determinants of performance outcomes.

Table 2.XVI: Significant results for effect of precision on muscle activity.

High = High Precision; Low = Low Precision

Muscles	p	Posture(s)	% increase between high & low
Brachioradialis	p< 0.05 High>Low	Seated Overhead Twist Non-Preferred side	9% 15% 10%
Trapezius	p< 0.05 High>Low	Overhead	6%
Posterior Deltoid	p< 0.05	Combined effect of all postures	Range 4% (stand, twist preferred) -12% (Stoop60)

Effect of posture on muscle activity: precision demands

It has been proposed that individuals adopt postures based on the extent to which that particular orientation can facilitate task execution within the existing workstation parameters and anthropometric dimensions (Haslegrave, 1994; Laville, 1985). Since different segments, joints and muscles of the body are responsible for different components of overall performance, the effect of posture on muscles will be considered in terms of the function of the muscle. As such, muscles involved in moving the hand-arm system (brachioradialis, biceps brachii and triceps) will be presented separately to those involved in stabilisation of hand-arm system (trapezius and anterior and posterior deltoid) and the trunk posture (right and left erector spinae).

Posture had a significant influence ($p<0.05$) on muscle activity ensuing from the performance of precision tasks for all the muscles that were tested (refer to Appendix B.3C for the statistics for these muscles). This influence was altered under different postures, a reflection of the postural strain experienced. The following results present the significant findings as well as those that were found to be similar. This was important because it highlighted similarities in postures that are purportedly different.

Movement component of precision performance

Brachioradialis muscle activity elicited the lowest activation levels when a low precision task was performed in the seated, overhead, lying supine, and twisting to the non-preferred side postures, which were all statistically similar. Stooping 60^0 was the most taxing on the brachioradialis muscle for both high (5.5% of MVC) and low (5% of MVC) precision tasks (Figure 2.12).

While lying supine, individuals utilised less than 2% of biceps brachii MVC, which was significantly lower than occurred during any of the other postures for both high and low precision demands. Working overhead resulted in individuals working at approximately 6% MVC, almost 3 times more than the supine posture (Figure 2.15).

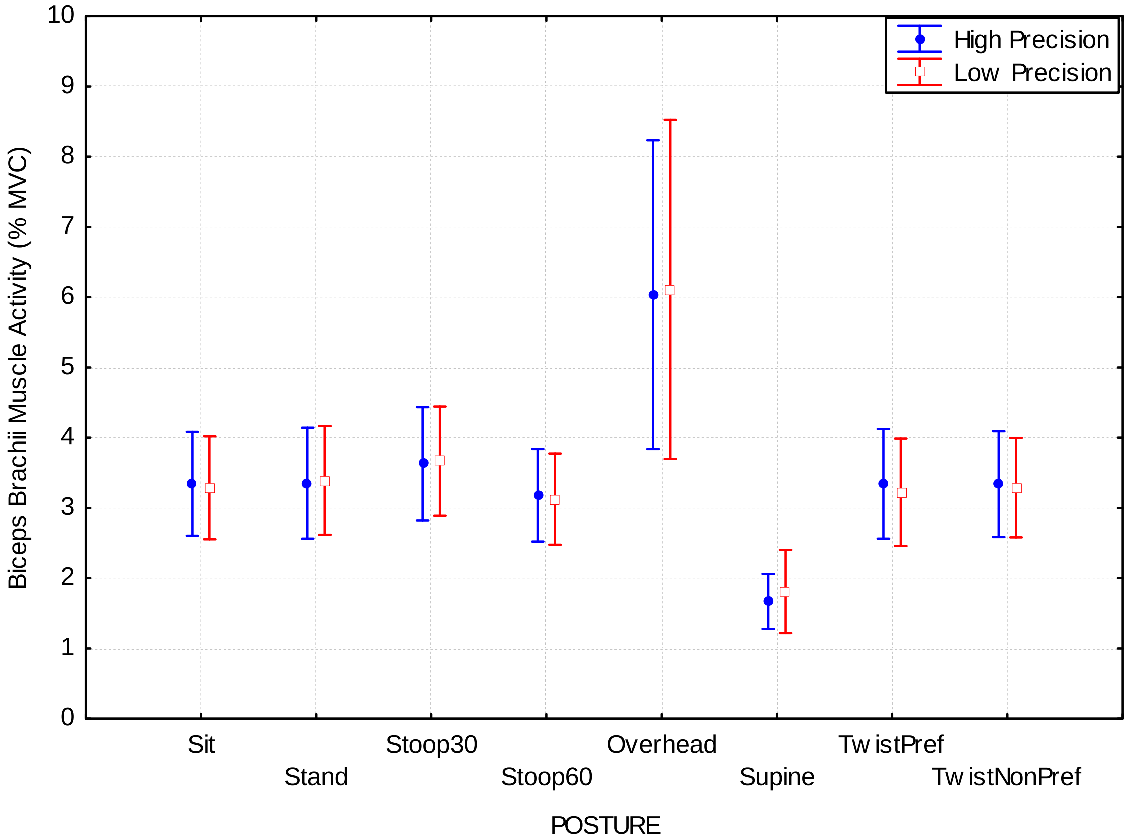


Figure 2.15: Biceps brachii activation during precision tasks.

Biceps brachii muscle activity during overhead work was significantly higher compared to the other postures. It can thus be postulated that overhead work was the most biomechanically taxing on biceps brachii. This posture also evidenced the greatest standard deviation (Figure 2.15), which may be a reflection of individual response variability in coping with the strain imposed by this extreme posture. Additionally, biceps brachii recruitment was significantly greater for stooping 30^0 than stooping 60^0.

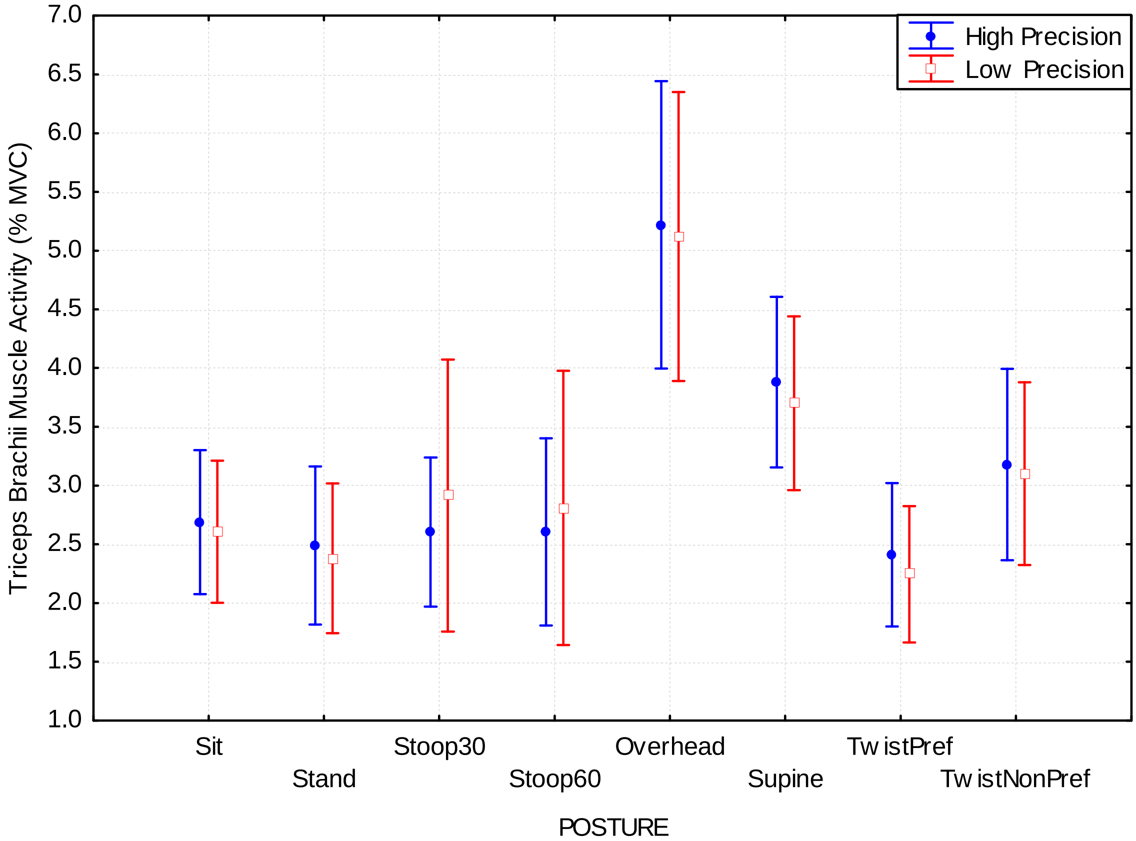


Figure 2.16: Triceps brachii muscle activity during precision tasks.

The overhead working posture required the greatest muscle activation (approximately 5% MVC) for triceps brachii and this was significantly higher than the other postures. Electrical activity for the lying supine posture was also significantly higher than all other postures except the overhead working posture. Sitting, standing, stooping 30 and 60^0 and twisting to the non-preferred side elicited similar muscular activity responses. While lying supine caused lowest biceps brachii electrical activity, this posture caused the second highest activation levels in triceps brachii suggesting antagonistic function for both these muscles. Although high variability is recognised as typical in electromyography, a consequence of individual variability (Herberts **et al.**, 1980), it was interesting to note that the standard deviations were particularly high in the overhead working posture (Figure 2.16).

Stabilisation component of precision performance

The anterior deltoid, muscle activity responses evidenced significant differences between all the postures except stoop 600 and twisting to the preferred side; these were the least strenuous postures eliciting approximately 6 to 7% MVC (Figure 2.17).

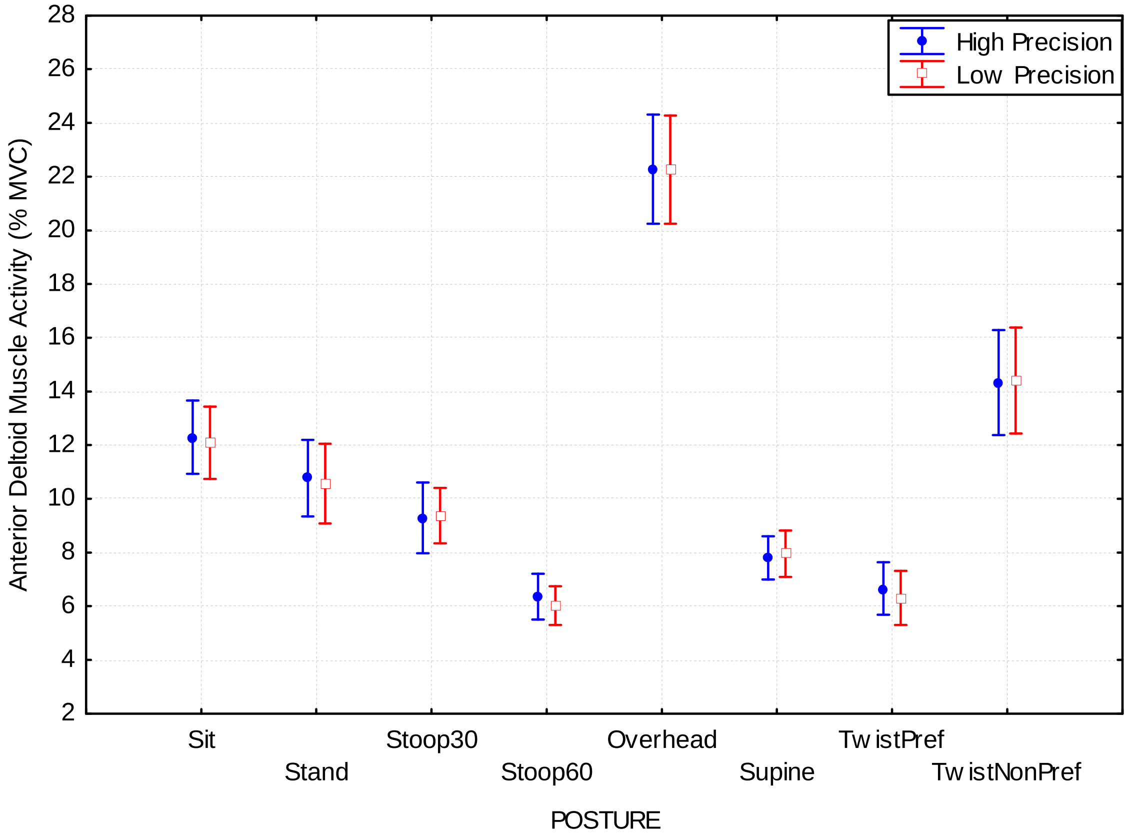


Figure 2.17: Anterior Deltoid muscle activity during precision tasks.

Overhead work caused the greatest strain on the anterior deltoid. At 22% MVC, it was 3 times that elicited while stooping 60^0, lying supine and twisting to the preferred side.

The seated, standing, and twisting to the non-preferred side postures all elicited activity of more than 10% MVC (Figure 2.17). This is an indication that the stabilisation required in maintaining arm posture is significant even in less straining postures such as standing and sitting.

With the exception of the overhead posture which exhibited just higher than 8% MVC activation, the posterior deltoid elicited no more than 3% MVC responses (Figure 2.14). Electrical activity for standing, stooping 60^0, and lying supine did not differ significantly. Similarly, posterior deltoid activity while seated was comparable to twisting to the preferred side but not to twisting to the non-preferred side posture. Working in the overhead working posture caused much higher levels of electrical activation in anterior deltoid (22% MVC) than posterior deltoid muscles (8% MVC) (Figure 2.14).

Although the twisted postures elicited similar posterior deltoid activity (3% MVC), these postures were significantly different for anterior deltoid. In this regard, twisting to the non-preferred side (14% MVC) caused significantly greater strain than twisting to the preferred side (6% MVC). In all the postures, anterior deltoid exhibited higher levels of activation than posterior deltoid thus alluding to the possibility that this muscle plays an important role in stabilising the hand-arm system when performing precision tasks. However, the interference from MVC normalisation cannot be completely ruled out ruled out in this interpretation.

Trapezius muscle activity in the overhead posture showed higher levels of electrical activity for high and low precision demands, 20% and 18% of MVC respectively than during other postures (Figure 2.13). These values seem elevated considering that the lowest muscle activation (3% MVC) was evinced for the lying supine posture. The standard deviation was once again greatest in the overhead posture an expected result when utilising electromyography (Herberts **et al.**, 1980). However, it is also likely that the higher standard deviations in the overhead working posture may be a consequence of individual variability in adapting to the excessive postural demands. An inspection of the coefficient of variation (CV) revealed otherwise as the CV was lowest in the overhead working posture when compared to the other postures. It was interesting to note that trapezius muscle activity obtained while standing and stooping 30^0 was comparable (9-10% MVC), as were the seated and twisting to the preferred side postures (both above 10% of MVC) (Figure 2.13).

The stooping postures caused the greatest strain on left and right erector spinae compared to the remaining postures with the latter working at a slightly higher level. Left erector spinae was activated to approximately 18% of MVC for both stooped postures (Figure 2.19). In contrast right erector spinae while stooping 30^0 (22% of MVC) caused significantly higher muscle activity than stooping 60^0 (19% of MVC) (Figure 2.18). Left erector spinae activity while lying supine (lowest level of activation, 3% MVC) was comparable to the seated and standing postures, which were in turn similar to the twisting to the preferred side posture. The seated, standing and overhead postures caused similar right erector spinae responses (approximately 5% MVC), whereas the seated and twisting to the preferred side postures were similar only when a high precision task was performed. Twisting to either side made no difference to the level of activation of left erector spinae (Figure 2.19). In contrast, twisting to the non-preferred side (9% MVC) caused significantly greater muscular strain on right erector spinae than twisting to the preferred side (7% MVC) (Figure 2.18).

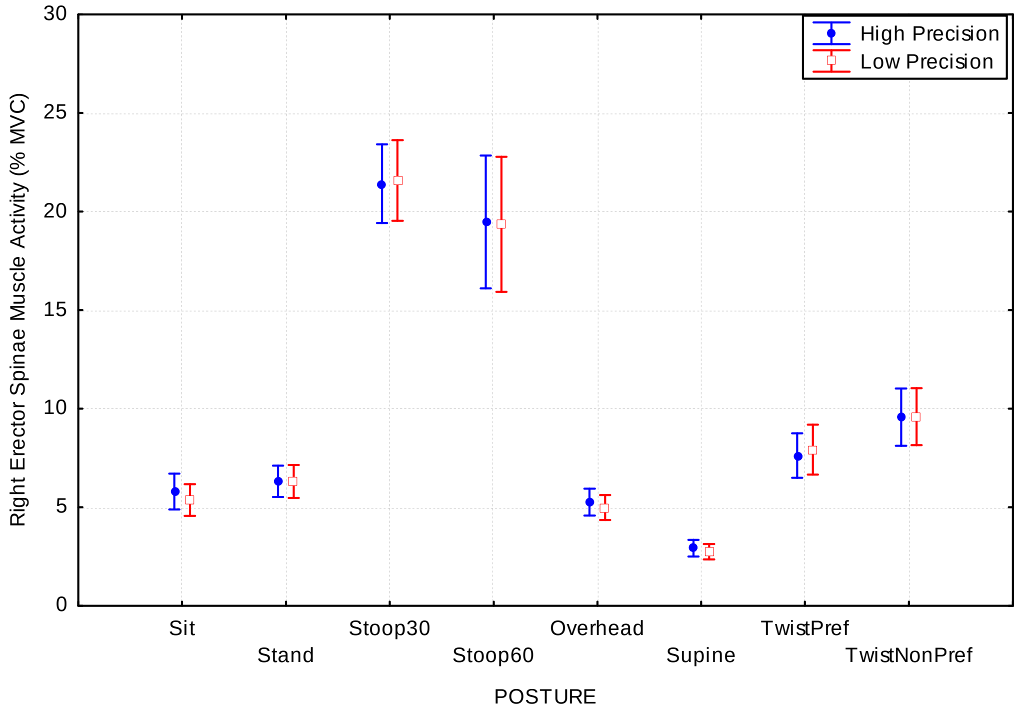


Figure 2.18: Right Erector Spinae muscle activity during precision tasks.

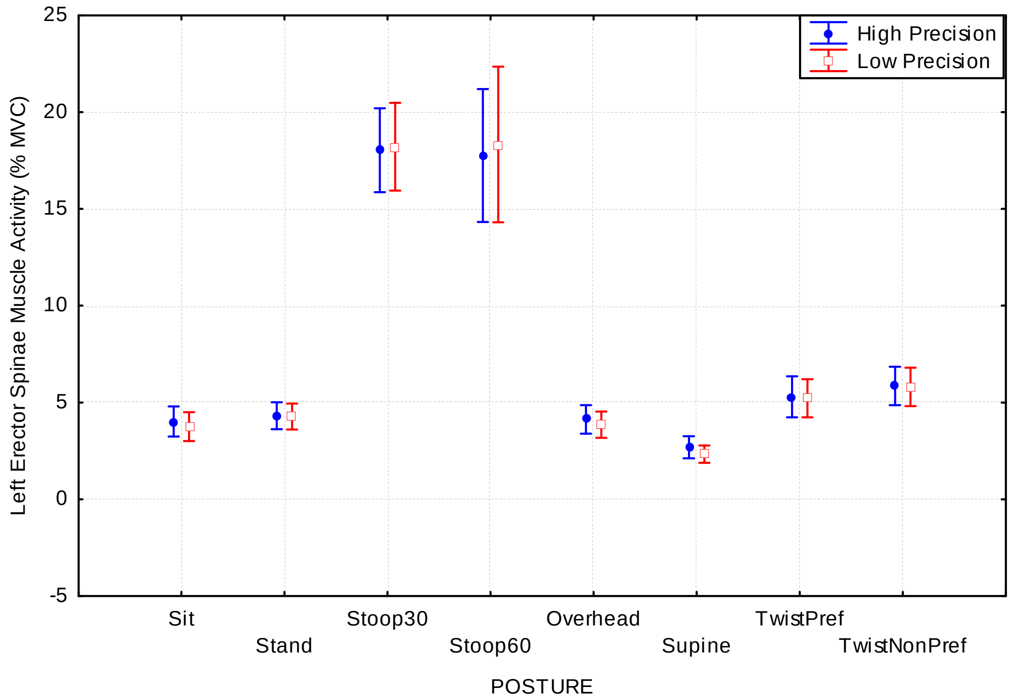


Figure 2.19: Left Erector Spinae muscle activity during precision tasks.

Summary: biomechanical responses to precision tasks in different postures

Muscle activity responses were significantly affected by precision demands for brachioradialis, trapezius, and posterior deltoid muscles (Table 2.XVII). Performing a high precision task while working in the seated, overhead, and twisting to the preferred side postures lead to increased brachioradialis activity. Higher precision demands also lead to increased trapezius electrical activity for the overhead posture. The effects of precision demands on posterior deltoid were only significant ($p < 0.05$) when all the postures were considered in the calculation. This however was not the case when individual postures were considered in isolation.

Table 2.XVII: Summary results of biomechanical responses to precision tasks.

(Min = minimum; Max = maximum; %MVC = percentage of maximal voluntary contraction; n.s = not significant; TwistPref = Twisting to the preferred side)

Muscles	p	Posture(s)	Min and Max (%MVC)
Brachioradialis	p< 0.05	Seated Overhead Twist Preferred side	Min=Seated, Overhead (4%) Max=Stoop60 (5%)
Biceps brachii	n.s		Min=Supine (2%) Max=Overhead (6%)
Anterior Deltoid	n.s		Min=Stoop60, TwistPref (6%) Max=Overhead (22%)
Trapezius	p< 0.05	Overhead	Min=Supine (3%) Max=Overhead (18-20%)
Triceps brachii	n.s		Min=Stand, TwistPref (2%) Max=Overhead (5%)
Posterior Deltoid	p< 0.05	Combined effect of all postures	Min=TwistPref (2%) Max=Overhead (5-7%)
Erector spinae (Left)	n.s		Min=Supine (3%) Max=Stoop30 + 60 (18%)
Erector spinae (Right)	n.s		Min=Supine (3%) Max=Stoop30 (22%)

Muscle activity was affected by the posture in which the tasks were performed. This was true for all the muscles that were examined and it was apparent that some were more integral in certain postures than others. The overhead working posture stood out as the most taxing posture, causing the highest levels of muscular activation in 5 of the 8 muscles that were tested. With a range between 5% and 22% of MVC for these muscles (Table 2.XVII), the overhead working posture was a concern given the static nature of the stabilising requirements of the hand-arm system on the shoulder and upper back musculature. In contrast the lying supine posture placed least demand, for example, where the erector spinae muscle accounted for the lowest levels of activation (3% MVC).

The stooped postures elicited electrical activity responses of up to 22% MVC for erector spinae muscles (Table 2.XVII), the cumulative effect of which would be a catalyst for the development of lower back pain and injury. It was surprising to find that brachioradialis was the most strained muscle under the stooping 60^0 posture (Table 2.XVII). Possible reasons for this and the effects of precision demands on muscle responses will be explored further in the discussion (Chapter V).

PUSH/PULL FORCE TASKS

The direction in which force was applied had some bearing on muscle activity responses of the majority of the muscles that were tested (refer to Appendix B.3C for the statistics for these muscles). This was related to a combination of the posture that was adopted and the specific function of each muscle.

Effect of pushing/pulling: hand-arm and shoulder muscles

The ability to maintain a constant force over time relied on the direction of the force being applied, which ultimately affected brachioradialis recruitment. In this regard, brachioradialis functioned at a significantly higher percentage of maximal voluntary contraction (MVC) for the pulling force than the pushing force under all the postures (Figure 2.20).

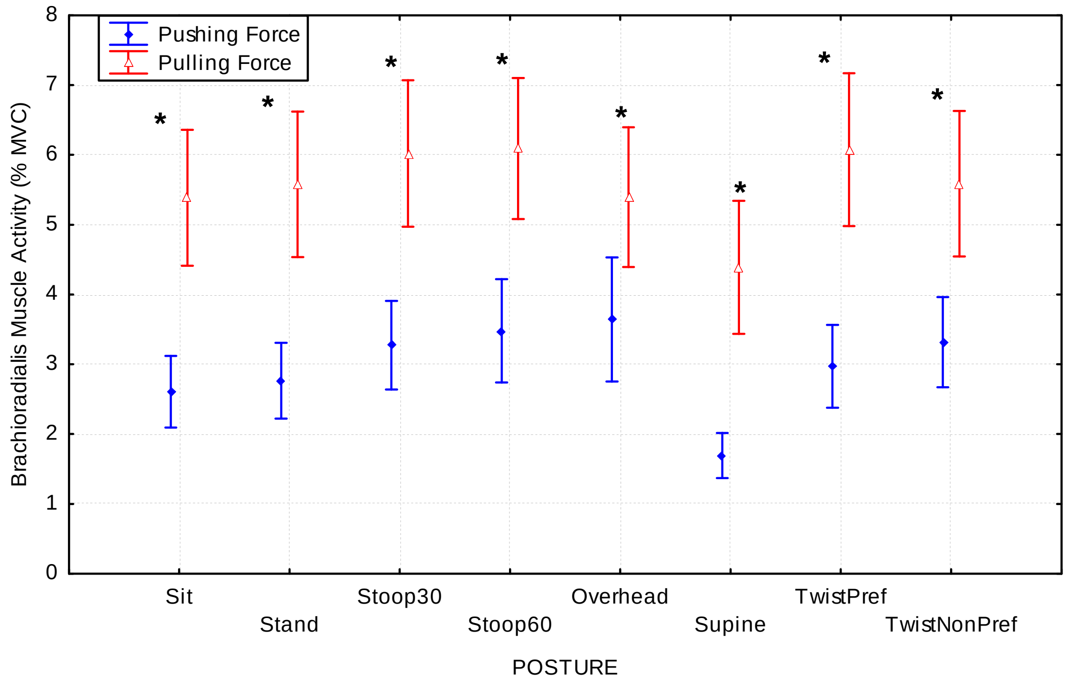


Figure 2.20: Brachioradialis activation during force tasks. * denotes significant difference between pushing and pulling forces.

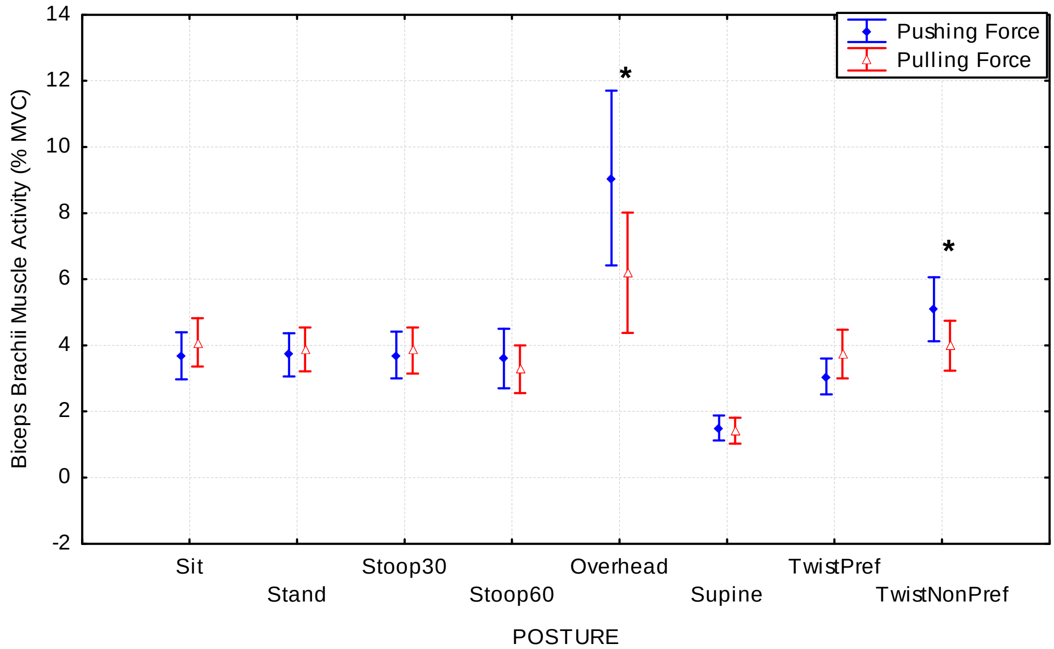


Figure 2.21: Biceps brachii activation during force tasks. * denotes significant difference between pushing and pulling forces.

For pushing and pulling force application, biceps brachii muscle activation was also strongly associated with the direction of force being applied ($p < 0.05$). Pushing elicited significantly higher muscle activity than pulling only in the overhead and twisting to the non-preferred side postures (Figure 2.21).

On consideration of all postures together, the direction of force application led to similar triceps brachii electrical activity. However, when the postures were considered individually, triceps brachii activity in the overhead posture brought about significantly higher muscle activity for pulling (7% MVC) than pushing (6% MVC) (Figure 2.22). As such, the antagonists; biceps brachii and triceps brachii complimented each other with pushing having a greater effect on biceps while pulling was more taxing on triceps brachii.

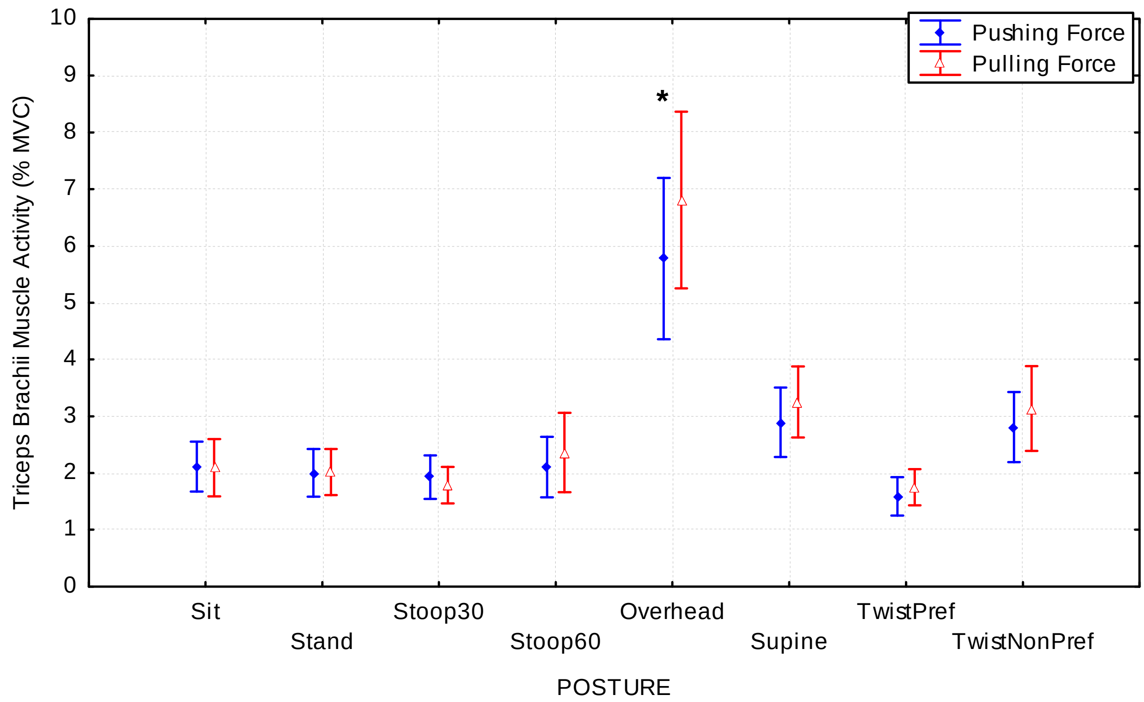


Figure 2.22: Triceps brachii muscle activity during force tasks. * denotes significant difference between pushing and pulling forces.

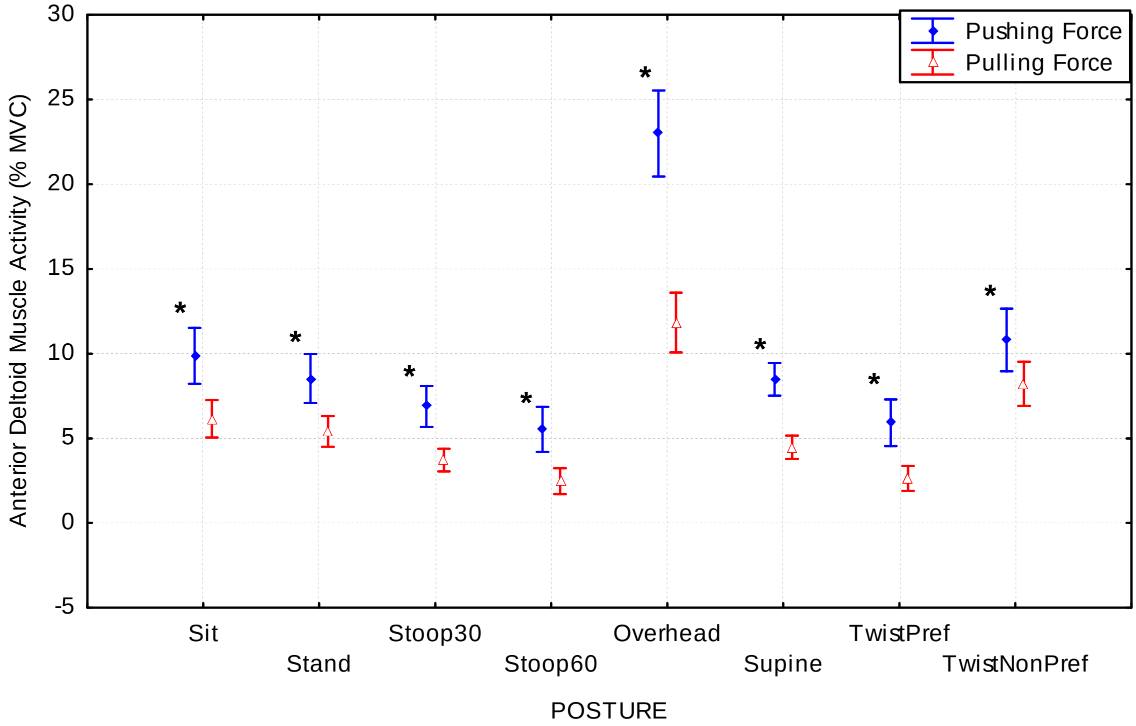


Figure 2.23: Anterior Deltoid muscle activity during force tasks. * denotes significant difference between pushing and pulling forces.

The direction of force application had a significant influence on anterior deltoid electrical activity when pushing and pulling forces were executed in all the postures. In each posture, anterior deltoid muscle activity elicited during pushing was significantly higher than that obtained while pulling (Figure 2.23). In contrast, applying a pushing force led to significantly lower posterior deltoid electrical activity for all postures than when a pulling force was applied (Figure 2.24). In this regard, pushing for all postures, excluding the overhead working posture, required less than 2% of MVC while pulling elicited levels of MVCs between 2 and 5%. Pushing and pulling in the overhead working posture led to posterior deltoid activation of between 8 and 10% of MVC respectively (Figure 2.24).

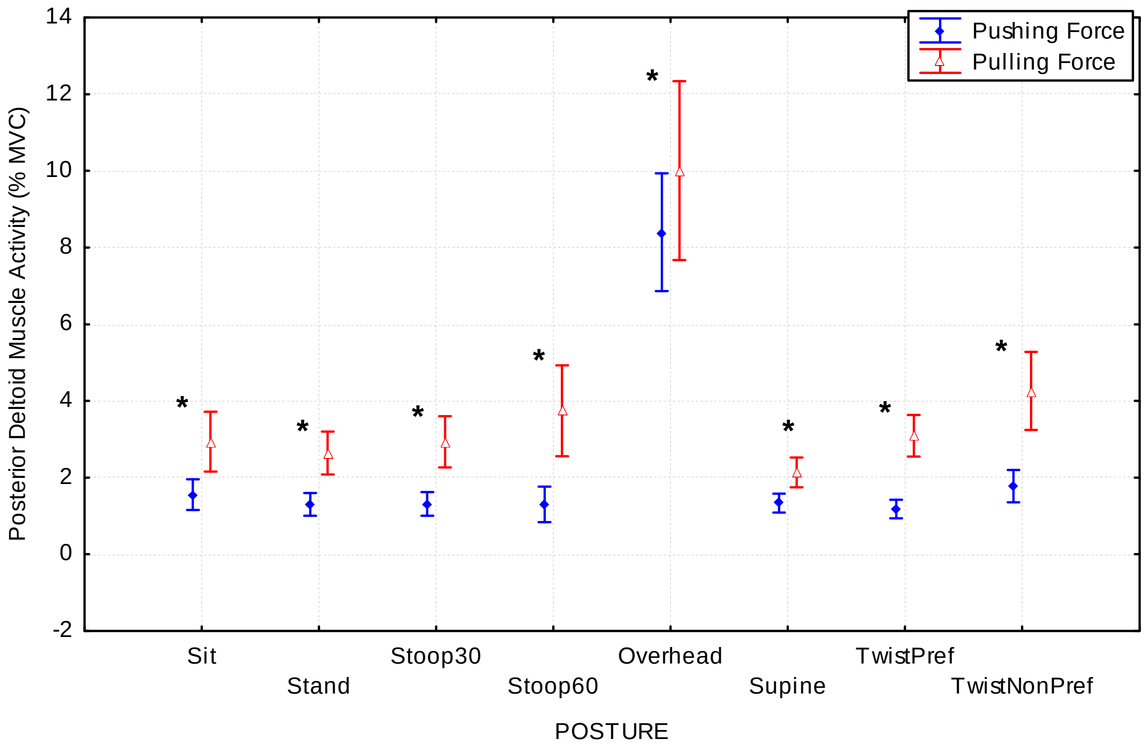


Figure 2.24: Posterior deltoid muscle activity during force tasks. * denotes significant difference between pushing and pulling forces.

Effect of pushing/pulling: Back & trunk muscles

Trapezius muscle activity differed significantly when pushing and pulling forces were exerted in all postures with the exception of stooping 60^0 and lying supine. In Figure 2.25 it is clear that pulling forces were more taxing on the trapezius muscle as they elicited significantly higher levels of electrical activity for sitting, standing, stooping 30^0 and twisting to either side. In contrast, pushing (18% MVC) caused significantly greater electrical activity than pulling (15% MVC) in the overhead posture.

The direction of force application had no bearing on left erector spinae muscle activation. Similarly, right erector spinae responses were comparable for pushing and pulling tasks.

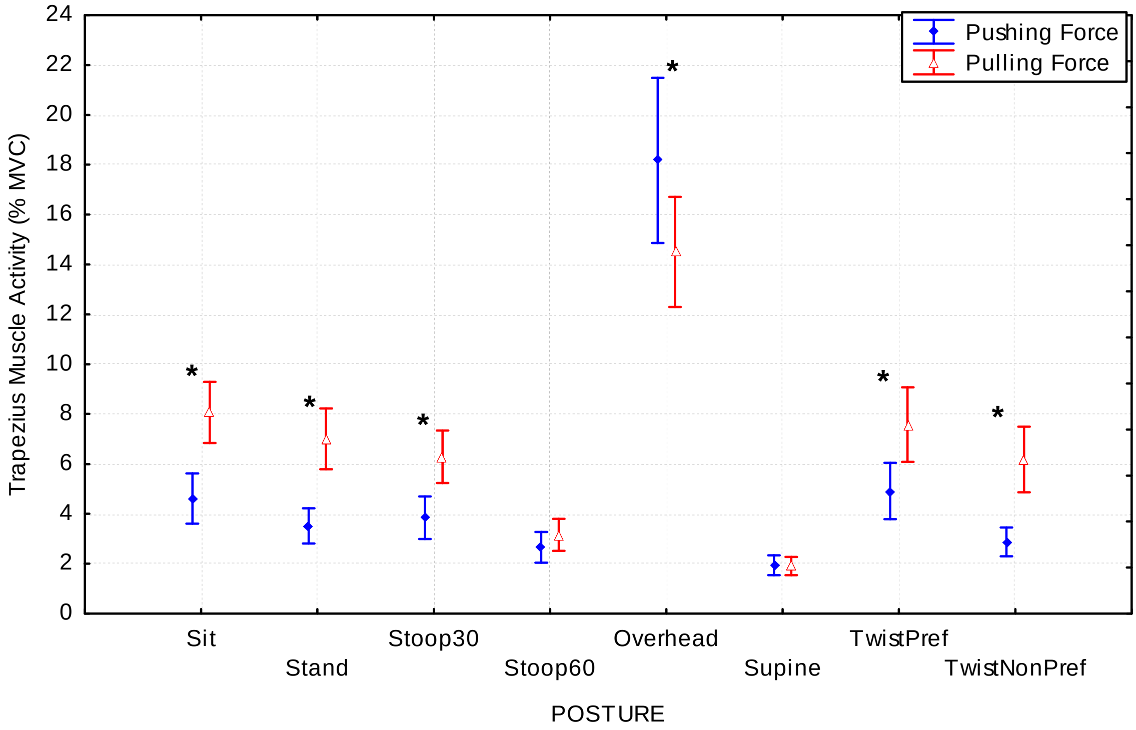


Figure 2.25: Trapezius muscle activity during force tasks. * denotes significant difference between pushing and pulling forces.

Effects of posture: Hand-arm and shoulder stabilising muscles

Posture had a significant effect on muscle activity responses when pushing and pulling forces were exerted. This was true for all of the muscles that were tested and implies that the ability to apply a precise force over time is determined by the posture in which one performs the task.

Brachioradialis activation during precision of force application varied significantly depending on the posture adopted. This meant that the posture adopted was instrumental in determining brachioradialis activity and thus the extent to which a constant force could be applied. Lying supine caused the least strain on brachioradialis for both pushing (<2% MVC) and pulling (<5% MVC) when compared to all the other postures (Figure 2.20). The seated posture required significantly lower brachioradialis muscle activity than stooping 60^0 and working overhead. Likewise, in the standing posture electrical activity was significantly lower than in the overhead working posture.

The twisted postures elicited significantly different electrical activation; brachioradialis worked at a significantly higher level of MVC when pushing while twisting to the non-preferred side. However, pulling was more taxing when twisting to the preferred side (Figure 2.20).

For pushing and pulling force application, biceps brachii muscle activation was strongly associated with the posture assumed. The overall percentage of MVC for the overhead working posture was significantly higher than the other postures (Figure 2.21). This indicated that this posture was the most taxing on the biceps brachii muscle (9% MVC for pushing and 6% MVC for pulling) as opposed to lying supine which was seemingly the least taxing (<2% of MVC) (Figure 2.21). The seated, standing, stooping and twisting to the preferred side postures were all comparable in terms of biceps brachii electrical activity during pushing and pulling. Only the pushing force was significantly different when the twisted postures were compared. In this regard, and similarly to brachioradialis, muscle activity derived during pushing was significantly higher in the twisting to the non-preferred side posture.

The overhead working posture caused the highest levels of triceps brachii muscle activity for both pushing (5.5% MVC) and pulling (6.5% MVC) (Figure 2.22). Although the triceps were more strained under this posture than any other, this was at relatively low levels when compared to the other muscles. Triceps electrical activity was comparable for sitting, standing and stooping at 30^0 and 60^0. Similarly, muscle responses in the supine and twisting to the non preferred side postures were comparable. Twisting to the non-preferred side once again caused high electrical activity for both pushing and pulling forces when compared to twisting to the preferred side (Figure 2.22).

The overhead posture brought about the highest anterior deltoid muscle activation for both pushing (23% MVC) and pulling (12% MVC) although the former was almost double that of the latter (Figure 2.23). Anterior deltoid responses to pushing and pulling in the seated, standing, stooping 30^0 and lying supine postures were comparable.

Pushing while seated and in the twisting to the non preferred side postures both caused similar levels of activation approximately 10% MVC (Figure 2.23). Twisting to the non-preferred side was more strenuous on anterior deltoid than twisting to the non-preferred side for both pushing and pulling.

Posterior deltoid activity was highest in the overhead working posture during pushing (8% MVC) and pulling (10% MVC) as compared to the other postures; these elicited less than 5% MVC for pulling and 2% for pushing (Figure 2.24). The lying supine posture elicited electrical activity that was similar to that obtained while in the seated, standing, and stooping 30^0 postures. In the same way, twisting to the preferred side was comparable to the seated, standing and stooping 30^0 postures. However, only the muscle activity from the pushing force application during the lying supine and twisting to the preferred side postures were similar. The twisted postures once again caused varied electrical activity with twisting to the preferred side causing less strain than twisting to the non-preferred side (Figure 2.24). In this case, pulling caused greater posterior deltoid activation levels than pushing, an opposite reaction to that of anterior deltoid.

Effects of posture: Back/Trunk stabilisation muscles

The overhead working posture was the most taxing in terms of trapezius muscle activity for both pushing (18% MVC) and pulling (15% MVC) which were significantly higher than all other postures. Electrical activity during all the other postures did not exceed 8% MVC (Figure 2.24). Trapezius performed in a similar manner for pushing and pulling when seated, standing, stooping 30^0, and twisting to the preferred sides. Likewise, trapezius muscle activity for pushing and pulling in the stooping 60^0 posture was comparable to lying supine. The twisted postures were only different as far as electrical activity for the pushing force was concerned.

The stooped postures were the most straining on left erector spinae. Functioning at 21% MVC, stooping 30^0 which was significantly higher than the 17% obtained during the stooping 60^0 posture (Figure 2.26). The twisting postures were significantly different with twisting to the preferred side causing greater electrical activity (9% MVC) than twisting to the non-preferred side (6% MVC). The overhead posture brought about similar electrical activity to the seated and standing postures (5% MVC). Additionally, standing was comparable to twisting to the non-preferred side in terms of left erector spinae responses.

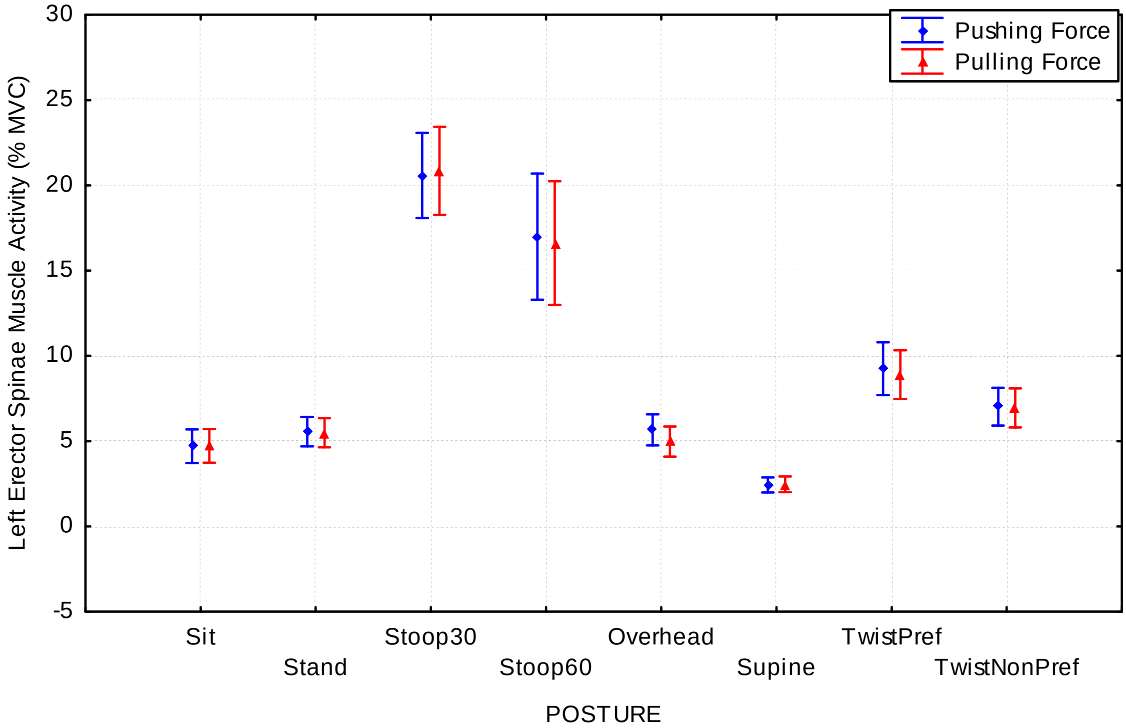


Figure 2.26: Left Erector Spinae muscle activity during force tasks

Stooping 30^0 (22% of MVC) elicited significantly higher right erector spinae than stooping 60^0 (18% MVC) (Figure 2.27). Similar levels of (between 6 and 8% of MVC) electrical activity were attained while in the seated, standing, overhead, and twisting to the preferred side postures. Right erector spinae experienced less strain for the twisting to the preferred side posture (9% MVC) than while twisting to the non-preferred side (11% MVC), thus compensating the responses of left erector spinae. As with left erector spinae, the overhead working posture elicited similar electrical activity to that of the seated and standing postures. However, and in contrast to left erector spinae, right erector spinae muscle responses to standing were comparable with those from twisting to the preferred side, which was also similar to the seated posture.

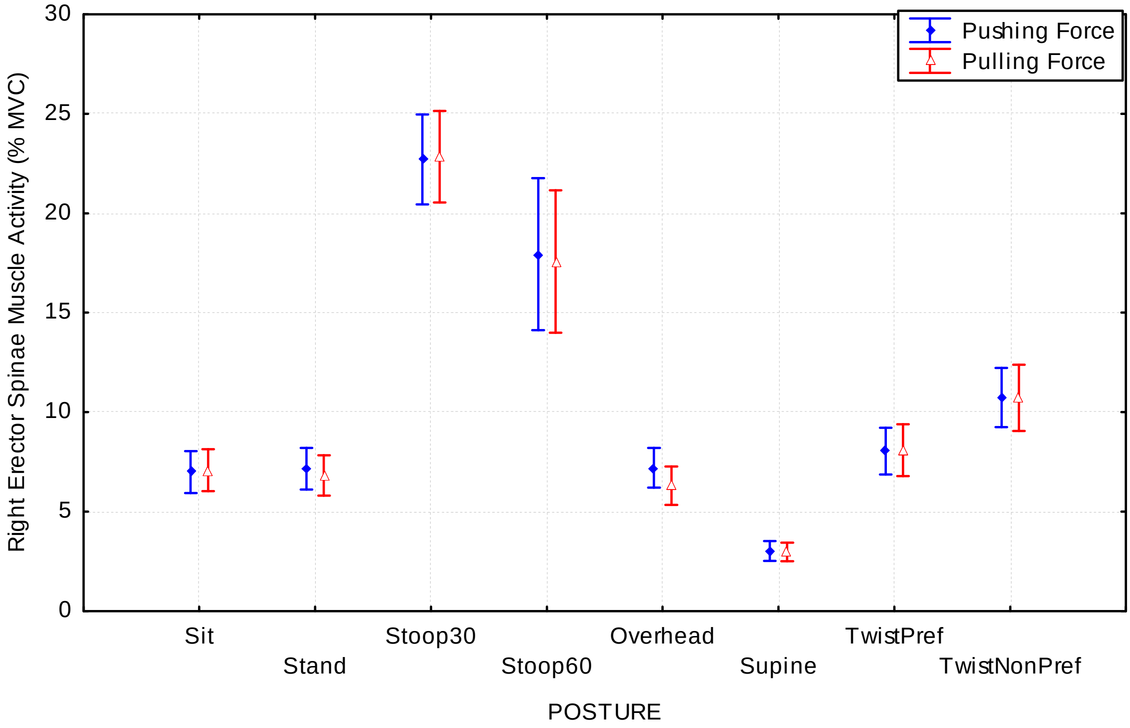


Figure 2.27: Right Erector Spinae muscle activity during force tasks

Summary: biomechanical responses to force tasks under different postures

Electrical activity of the brachioradialis, biceps brachii, anterior deltoid, trapezius, and posterior deltoid muscles was significantly different when pushing and pulling forces were exerted under different postures (Table 2.XVIII). Thus, the ability to maintain a constant pushing or pulling force over time was different for different muscles and was highly influenced by the posture that was adopted. The differences in the muscle responses can be attributed partly to agonist and antagonist roles played by different muscles. An example of this is biceps brachii and the triceps brachii where pushing caused greater electrical activity in the biceps during overhead work while the opposite was true for the triceps.

Table 2.XVIII: Summary results of muscle responses to pushing and pulling tasks

Min = minimum; Max = maximum; %MVC = percentage of maximal voluntary contraction
n.s = Not significant; TwistPref = Twisting to the preferred side, TwistNonPref = Twisting to the non-preferred side

Muscles	p	Posture(s)	Min and Max (%MVC)
Brachioradialis	$p < 0.05$ Push<Pull	All	Min=Supine 2% push, 4% pull Max= Stoop30 & 60, TwistPref (<4% push, 6% pull)
Biceps brachii	$p < 0.05$ Push>Pull	Overhead Twist Non Pref	Min=Supine (1.5% push & pull) Max=Overhead (9% push, 6% pull)
Anterior Deltoid	$p < 0.05$ Push>pull	All	Min=Stoop60, TwistPref (3-5% push and pull) Max=Overhead (23% push; 12% pull)
Trapezius	$p < 0.05$	All Push < Pull Overhead Push>pull	Min=Supine, stoop60 (2-4% push & pull) Max=Overhead (18% push, 14% pull)
Triceps brachii	n.s	**But** pair wise analysis: Overhead $p<0.05$ Push<Pull	Min=TwistPref (<2% push and pull) Max=Overhead (6% push, 7% pull)
Posterior Deltoid	$p < 0.05$	All Push<Pull Supine Push>pull	Min=Sit, Stand, Stoop30 & 60 (<2% push, <4% pull) Max=Overhead (8% push, 10% pull)
Erector spinae (Left)	n.s		Min=Supine (3% push & pull) Max=Stoop30 (20% push and pull)
Erector spinae (Right)	n.s		Min=Supine (3% push & pull) Max=Stoop30 (23% push and pull)

Muscles have different strength producing capabilities in various positions as a result of having different levels of mechanical advantage through the range of motion (Chang **et al.**, 1999). This consequently directly impacts force output and the relative contribution of muscles under different postures, as was the case in this study. In the stooped postures, for example, erector spinae, and other trunk musculature, was therefore pivotal in maintaining trunk flexion, reflected in the high levels of activation (up to 23% MVC). While lying supine, however maintain postural stability was not a concern and erector spinae was activated to only 3% of MVC (Table 2.XVIII).

PHYSIOLOGICAL RESPONSES

The heart rate (HR) responses provided in these results are the average values recorded over the duration of each task while adopting the different postures. As the duration of each task did not exceed 60 seconds, a steady state in HR could not be reached. Throughout all the postures average heart rate did not escalate to greater than 90bt.min^{-1} further confirming that the tasks that were performed could be regarded as light manual tasks.

Heart rate (HR) responses: precision tasks

Precision demands did not have an influence on heart rate (HR) responses as no significant differences were found ($p = 0.36$; refer to Appendix B.3C) between low and high precision task responses in all the postures. However, and in line with assertions made in industry, heart rate (HR) responses were affected by the working posture in a significant manner.

Lying supine elicited the lowest HR responses, followed by the seated posture, indicating that these postures were the least physiologically taxing on the individual (Figure 2.28). The greatest physiological strain was experienced while working in the overhead posture and while twisting to the non-preferred side (left hand side for right hand dominant individuals) (Figure 2.28). It was interesting to note that HR responses for the seated and stooping 30^0 postures did not vary significantly despite the alleged increase in physiological stress in stooped postures (McArdle **et al.**, 2001). Even more surprising was the fact that stooping 60^0 brought about HR values that were significantly lower, for high and low precision demands, when compared to the standing posture (Figure 2.28).

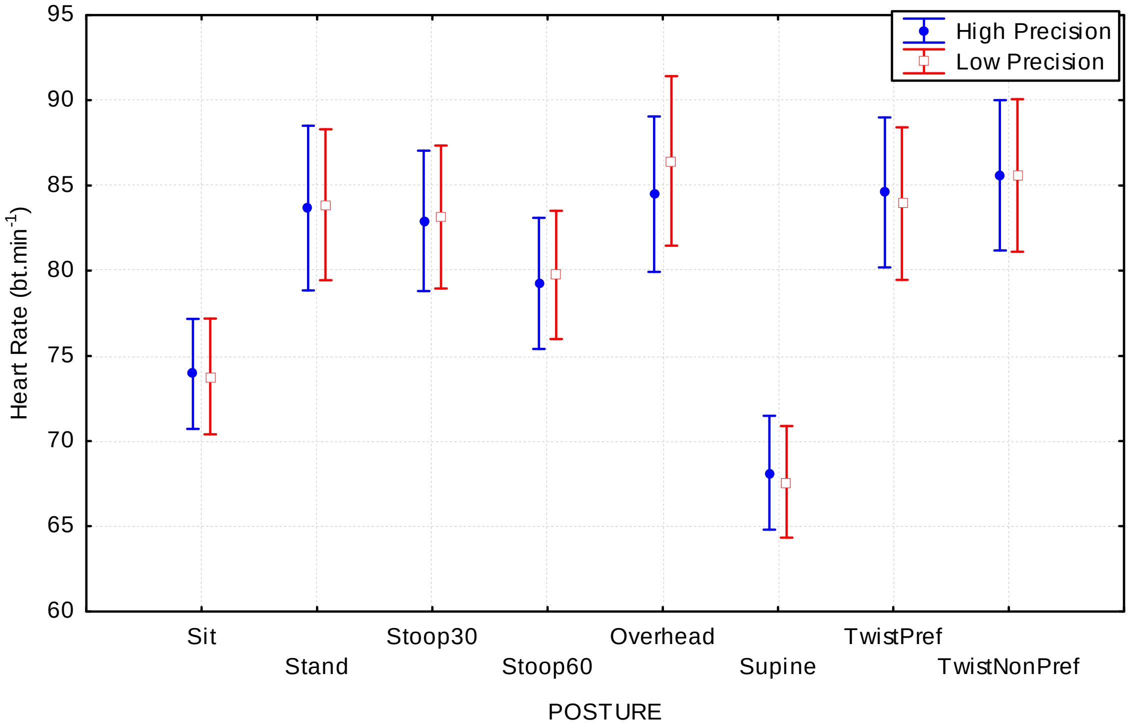


Figure 2.28: Heart rate (HR) responses for the low and high precision tasks

Heart rate (HR) responses: force tasks

The direction of force application had an overall significant effect ($p < 0.05$) on heart rate responses (Table 2.XIX). However, pair wise comparisons of the individual postures did not reveal the same effect. The effect of posture on HR responses was found to be significant in the context of force task performance (Table 2.XIX).

Table 2.XIX: Effect of posture and precision of force application on HR responses

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	5121354	1	5121354	1582.399	$p < 0.05$
POSTURE	31726	7	4532	55.625	$p < 0.05$
FORCE	284	1	284	10.091	0.002632
POSTURE*FORCE	254	7	36	1.670	0.115414

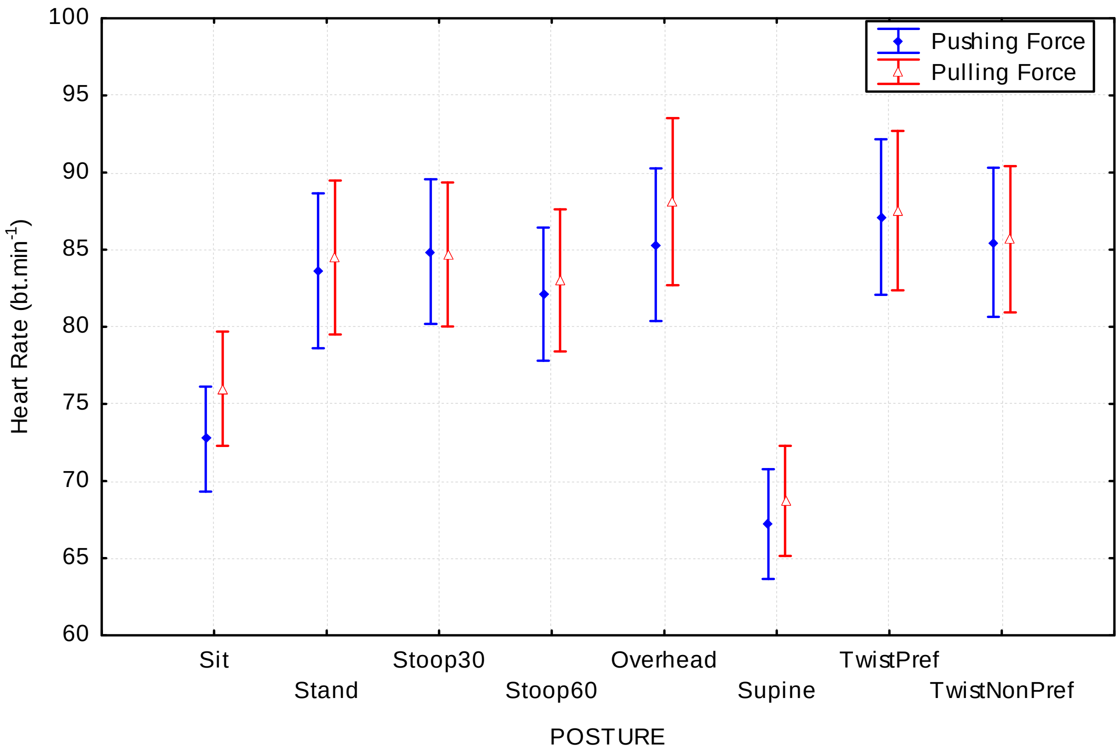


Figure 2.29: Heart rate (HR) responses for pushing and pulling tasks.

HR responses while seated and lying supine exhibited the lowest values for both force and precision tasks. HR was significantly lower in the supine position than while seated when a pushing force was applied (Figure 2.29). This implies that from a physiological viewpoint lying supine and working in the seated posture are preferable especially because the HR responses from these postures were significantly lower than all of the remaining postures that were examined for pushing and pulling forces alike. Exerting a pushing force in the overhead posture elicited HR values that were significantly higher than in the standing, stooping 30^0 and 60^0 postures. The interaction effect between posture and the direction of force application was not significant (Table 2.XIX). That is, force application under different postures alters HR in a significant manner regardless of the direction of the force being applied.

PSYCHOPHYSICAL RESPONSES

The ratings of perceived exertion (RPE) results are ‘local’ RPE ratings and refer to individuals’ perceptions of the muscular effort invested in performing the tasks under the different postures.

Rating of perceived exertion (RPE) responses: precision tasks

Precision demands had no apparent effect on the ratings of perceived exertion (RPE) as no significant differences were found when high and low precision tasks were performed. RPE was significantly related to the posture under which the precision tasks were performed. The seated and standing postures were perceived to be equally the least taxing of all postures (Figure, 2.29). The highest ratings of perceived muscular effort were ascribed to the overhead posture followed by the stooping 60^0 and stooping 30^0 postures (Figure 2.30). These postures were furthermore significantly different to each other.

The effort required for the supine posture was perceived to be similar to that of twisting to the preferred side for both high and low precision demands, but only with the high precision task in the twisting to the non-preferred side. While performing the low precision task, the same amount of muscular effort was perceived to have been invested in the supine and standing postures.

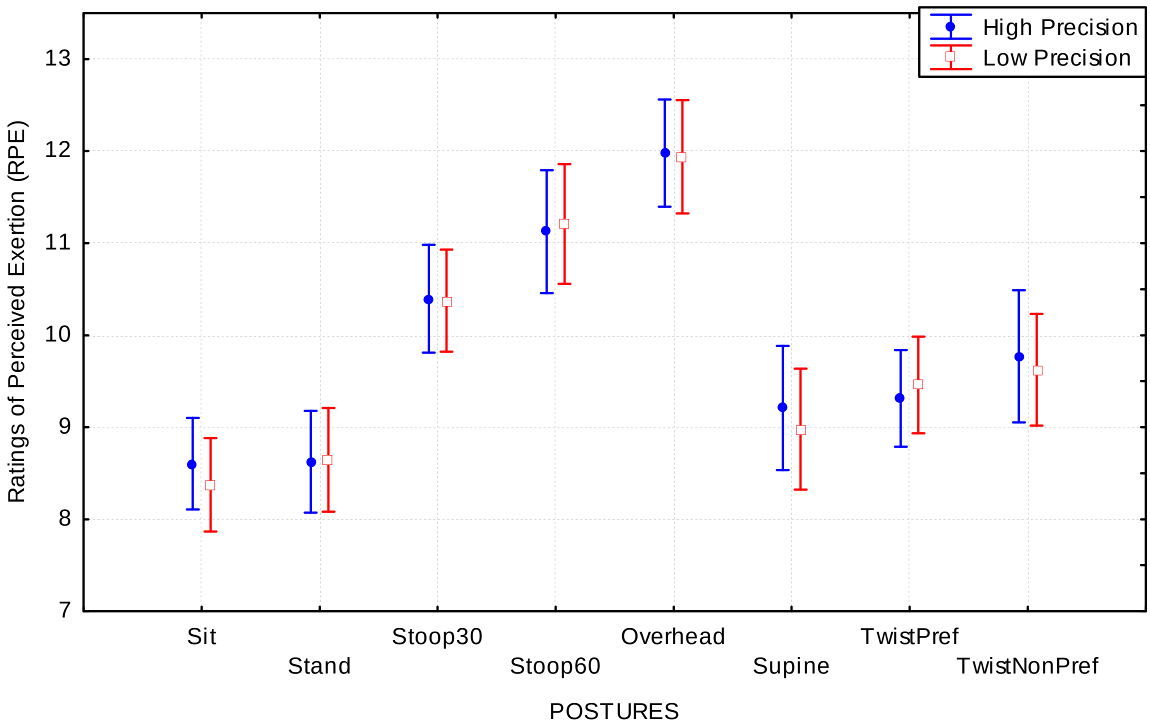


Figure 2.30: Rating of perceived exertion for high and low precision tasks

Rating of perceived exertion (RPE) responses: force tasks

Overall, the muscular effort required to maintain pushing and pulling forces was perceived to be the same as force did not vary significantly with RPE when all the postures were considered together. However, when the postures were considered separately, RPE was significantly different for pushing and pulling in the standing posture (Figure 2.31). In this regard, the pulling force was perceived to be slightly more demanding in terms of muscular contribution than during pushing ($p < 0.05$).

The effect of the different postures in which the force had to be applied was perceived to be significant. Similarly to the high and low precision demands, the overhead, stooping 60^0 and stooping 30^0 were perceived to have been the most strenuous in terms of muscular effort (Figure 2.31). However, unlike the precision task responses, local muscular contribution in the supine and twisted postures was perceived to be significantly different. In this regard, the twisting to the non-preferred side was perceived to be most taxing followed by twisting to the preferred side and lying supine (Figure

2.31). The only postures that were perceived to be comparable in terms of the contribution of local factors were the standing and sitting postures when a pushing force was applied.

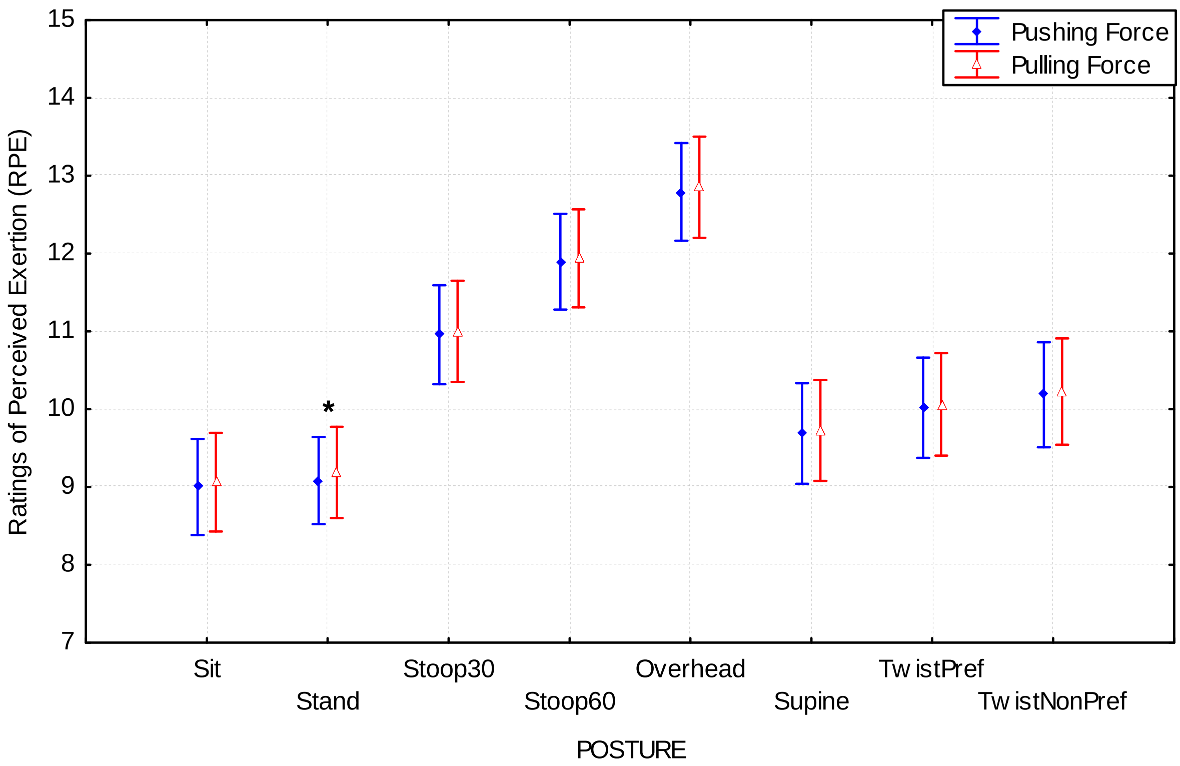


Figure 2.31: Rating of perceived exertion for force tasks. * denotes significant difference between pushing and pulling forces.

CONCLUSION

In order to fully appreciate the concurrent influences of awkward working postures on resulting performance outcomes and the strain experienced by the individual it is important to consider all the results in a holistic manner. The results presented suggest that awkward postures have an influence on performance variables and individual responses. The results also allude to the possibility that precision demands may affect postural strain.

SECTION 2

CHAPTER V
DISCUSSION

INTRODUCTION

Gunasekaran **et al.** (1994) and Guastello (2006) pointed out that overall performance is determined by the speed and accuracy with which it is performed, both of which have a direct influence on productivity and quality of product output. However, as the human operator is considered a central component in task performance, individual responses ought to be incorporated into any efforts aimed at improving organisational performance. This study therefore investigated the simultaneous effects of awkward working postures on performance outcomes and individual responses to varying precision demands. The results presented in the previous chapter allude to the possibility that awkward working postures and varying precision demands are key in mediating performance.

TASK PERFORMANCE

Effect of precision demands and posture on movement time

High precision tasks took a significantly longer time to complete than low precision tasks. This was an expected finding as, according to Fitts' Law, high precision demands require a longer time for the target to be reached accurately (Fitts 1954; Schmidt and Lee, 2005). Although these results are not a key finding, they confirm that the performance of the tasks carried out in this study is in line with the well established motor control laws.

Posture was found to have a significant effect on movement time. This means that the postures adopted by workers have an influence on efficiency of task performance. The movement time observed in the seated posture was comparable to that during standing and stooping postures. This indicates that although the seated posture is one that is recommended for precision tasks, movement time is not compromised when standing or stooping. The overhead and lying supine postures significantly increased movement time. When compared to the seated posture, working overhead and lying supine both augmented movement time by 9%. While in these terms this may appear without consequence, a 9% increase is equivalent to approximately 6 extra minutes for every hour worked. This translates to approximately 48 minutes for an 8 hour shift. This suggests that these postures should be avoided if efficiency is to be maintained because these are significant time losses, particularly given time constraints in industry. A common feature in overhead work and supine postures is working with the hand-arm system raised. In these positions, movement was against the direction of gravity and the arm had to be stabilised with limited respite for the contracting muscles. This, coupled with the fact that individuals were not accustomed to working in such postures, was likely to have increased the prospects of the early onset of fatigue with subsequent decrements in performance.

These findings are important because they provide quantitative evidence of the effect of awkward postures on a critical performance variable. Given that many tasks in industry are performed in awkward postures, it is conceivable that reducing exposure to these awkward postures may have a positive impact on movement time and overall performance outcomes. However, other factors such as learning would have to be considered. It must be pointed out that differences in movement time evidenced in the current study cannot be attributed to a learning effect in task performance between different postures because permutation of all conditions was carried out.

Nonetheless, as a generalisation, reaction time has been reported to decrease with practice where greater improvements (within physiological and biological limits) are observed if learning takes place over prolonged duration (Schmidt and Lee, 2005; Guastello, 2006). It can be assumed that this effect would occur regardless of the posture in which one performs. However, overall performance time (speed of task execution) is a combination of reaction time (central nervous system processing and interpretation of stimuli) and movement time (overt behaviour achieved by moving the relevant limbs to the target) (Gordon **et al.**, 2004; Schmidt and Lee, 2005). As such, it is hypothesised that posture would have an effect on the time taken to move the limbs to the desired position and movements performed in awkward postures would take a longer time due to the delay caused by excessive muscular loading. Therefore, the speed of task execution would improve with practice in all postures; however, these improvements would be lower in awkward postures such as overhead and supine. Further research that will quantify the performance gap in terms of differences in movement time in different postures is required particularly given that negative health related factors ensuing from awkward postures remain a challenge.

Effect of precision demands and posture on deviation from target

Since the target size is larger in low than high precision tasks, a greater surface area is available for selection of targets and the permissible restrictions are lower (greater tolerance). As expected, deviations from the centre of the target were observed to be greater in low than for high precision demands. The high precision requirements inherent in high precision tasks forced individuals to approach the centre of the target with more care. This generalisation did not apply for the standing posture as no significant differences were found in deviation from the target when high and low precision demands were compared. The average coefficient of variation (CV) for deviation from the centre of the target in the standing posture was 44%, thus indicating that there was large variation in individual performance. Observed differences cannot therefore be assigned to postural changes alone as individual variation could have played an integral role in this regard.

Posture was observed to have a significant effect on deviation from the centre of the target when results from similar precision demands were compared. During high precision demands deviations were greatest in the overhead, supine and standing postures. When compared to the seated posture, there was a 28% and 27% increase in the deviation from the centre of the target in the overhead and lying supine postures, respectively. Therefore, it can be deduced that if tasks with low tolerance limits (high quality requirements) are performed, overhead and lying supine postures should be avoided as in these postures individuals are less able to perform the tasks as precisely as observed during the other postures. Workstations in industries force workers into awkward postures that not only compromise musculoskeletal integrity but as seen in this study, may cause quality related problems. Both of these challenges can be alleviated by implementing ergonomics interventions that will simultaneously improve worker well-being and performance.

During low precision demands posture affected deviation from the centre of the target to a lesser extent. Individuals deviated in a similar manner for all postures with the exception of stooping 60^0 and the overhead working postures. In this regard, deviations from the centre of the target were significantly higher by 10% while working overhead than in the stooping 60^0 posture. It may be possible that the effect of posture was more dominant than the influence of low precision demands because the high tolerance limits (greater surface area) offered by low precision demands require less effort from the individual to overcome even with the high postural demands. However, this effect diminishes as the postures become more extreme and more taxing on the individual, as was the case with working overhead.

Relationship between movement time and deviations from the target

On consideration of both performance variables during high precision task execution, it was clear that the overhead and lying supine postures were the least favourable. Figure 2.32 illustrates how these two postures took the longest time to perform yet were evidenced to have the highest deviations from the target. As movement time and deviations from the target can be translated to quality and productivity, it can be inferred that high precision tasks performed while working overhead or supine will compromise these performance variables. Even if more time was allocated to such tasks (a move that would jeopardise efficiency) in order to retain high quality standards, product output would still be susceptible to quality deficits if workers are working overhead or supine.

Movement time and deviations from the centre of the target while performing a high precision task in the remaining postures were comparable to each other. This suggests that the performance outcomes, in terms of product quality and efficiency, during high precision tasks were similar. Caution must however be exercised in the application of these results into industry as the tasks in analysed in this study were of short duration and conclusions cannot be drawn as to the long term effects of these postures on performance. Furthermore comparisons to other studies cannot be carried out as, to the knowledge of the author; no other studies have investigated the comparative effects of different postures on performance.

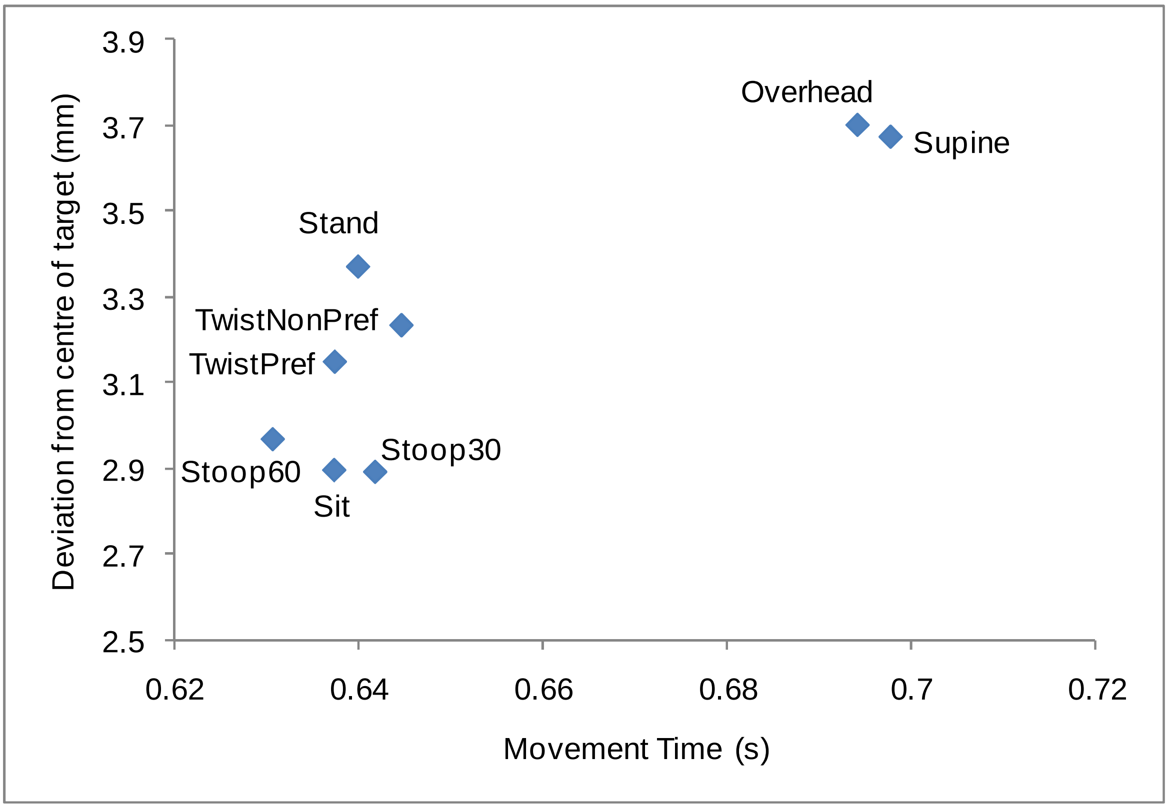


Figure 2.32: Performance of high precision tasks in different postures. (TwistPref: Twisting to the preferred side; TwistNonPref: Twisting to the non-preferred side).

Performance of a low precision task while working overhead and lying supine resulted in the longest movement times (Figure 2.33), which is indicative of reduced efficiency in these postures. However, the overhead posture resulted in similar deviations from the target when compared to the seated, standing and stooping postures. Lying supine led to similar responses but unlike the overhead posture, deviations when lying supine were significantly higher than stooping 60^0. This suggests that when performing a low precision task in the overhead and supine postures, participants had to reduce movement time in order to approach the centre of the target closely. Therefore, quality requirements under these postures would be fulfilled at the expense of productivity. Moreover, in a time-pressured environment where speed of task execution is high, workers would encounter problems with regards to preserving quality, especially if they do not have control over the pace of task performance.

Although the deviations from the centre of the target were similar for low precision demands in the standing and stooping 30^0 postures, movement time was significantly higher in the latter. Therefore, it would be advisable to rather perform low precision tasks when standing rather than stooping.

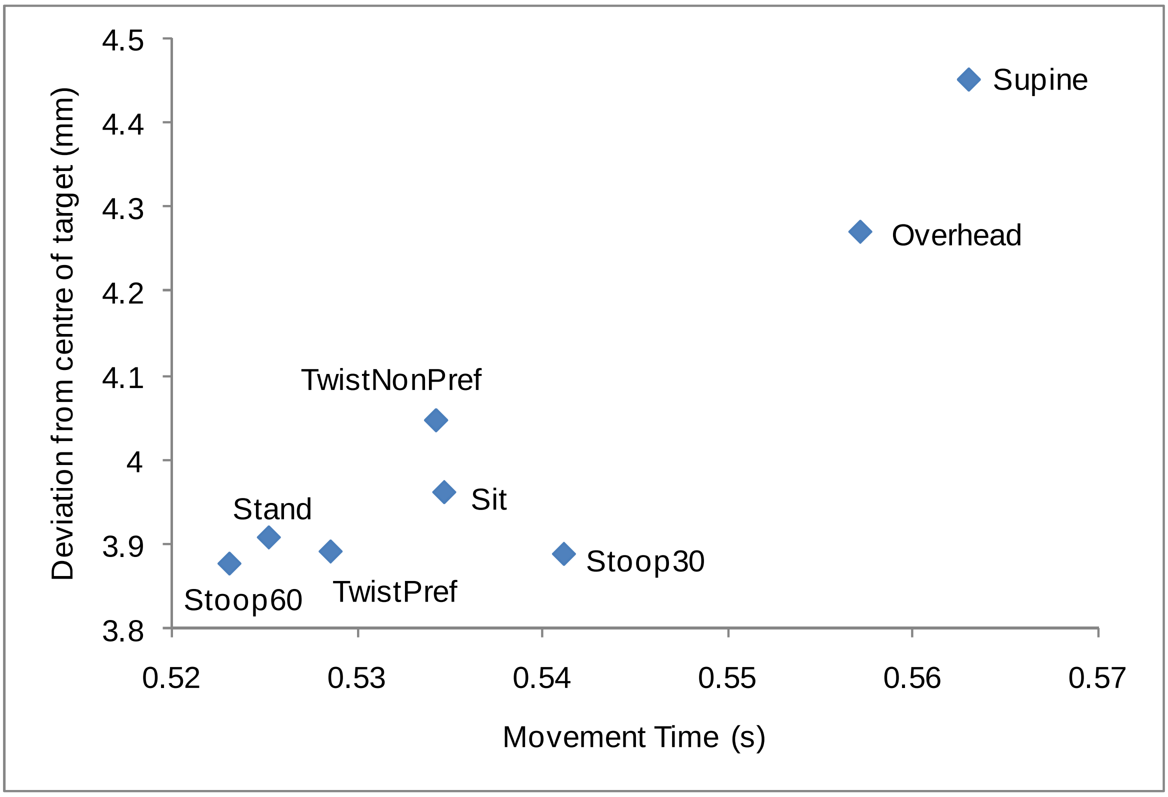


Figure 2.33: Performance of low precision tasks in different postures. (TwistPref: Twisting to the preferred side; TwistNonPref: Twisting to the non-preferred side).

Effect of pushing/pulling and posture on precision of force output

Precision tasks in industry commonly incorporate a movement aspect simultaneous to force production to move the hand-arm system to the target and to apply a force once the target is reached. In accordance with the assertion that strength output changes in different postures (Lee and Bruckner, 1991), force output was observed to vary under the different postures ($p<0.05$). Force also differed between pushing and pulling force exertion ($p<0.05$) where pulling force output declined more than pushing force thus indicating that individuals had more difficulty maintaining pulling forces.

As visual feedback was eliminated, individuals were forced to rely on kinaesthetic and proprioceptive feedback in order to maintain the required force. During the stooped postures force production was observed to increase over time; an over-compensation reaction where individuals exerted more force than was required. It is possible that force could not be maintained at a constant level because insufficient feedback hindered participants from tracking performance. When visual feedback is limited, other forms of feedback (such a vibration, or a clicking sound heard only once the appropriate force has been exerted) should be incorporated into tasks and working parts to guide workers. Another possible explanation for the observed over-compensation of force in the stooped postures is related to trunk flexion. Only in the stooped postures, characterised by trunk flexion, was the over-compensation of force observed. This suggests that with increased flexion of the trunk, the postural strain experienced subjectively augmented pushing force requirements thus leading to over-compensation of force output. The fact that force output was greater while stooping 60^0 than 30^0 supports this supposition. It would be interesting to investigate how this response would change over time. As high force production cannot be maintained indefinitely, it can be expected that over time the increased force exertions witnessed in the stooped postures would eventually decrease.

Only while twisting to the non-preferred side were participants able to maintain a constant force. The reasons for this, however, are not clear because feedback was limited as during all other postures. In the remaining postures force output diminished over time, indicating that individuals were unable to maintain the required forces. This could also be attributed to the limited feedback regarding performance, which inhibited individuals from employing corrective measures to adjust force.

These results support the assertion made by Jonsson (1988) that force production gradually declines with time because of the high degree of static muscular contractions inherent in such tasks. As such, it is likely that inadequate proprioceptive feedback or the development of muscle fatigue or a combination of both may have been responsible for the reduced force exertion.

Since most forces in industry are exerted using hand held devices with variable loads, over time, these would make it even more difficult to maintain the required forces. This would be a particular concern given that force output was compromised in this study yet the weight of the load cell utilised was negligible. Presumably performance of tasks requiring force exertions would deteriorate even further in industry where heavier loads are handled. The design of these devices would also have an impact on force output where poor design, compounded by the effects of the awkward body posture, would lead to musculoskeletal strain and reduced force output (Pheasant and Haslegrave, 2006). Therefore, if workers are required to maintain constant forces this should be carried out in the shortest time possible as force output was evidenced to decrease over time in most postures. Furthermore, sufficient feedback regarding immediate performance is critical to enable workers to adjust performance accordingly.

The results discussed thus far indicate that the postures adopted in industries where precision tasks are a familiar occurrence are important contributors to overall performance outcomes. This highlights the fact that all elements within a system are inter-related and interdependent and that worker related ergonomics deficits do indeed have a direct influence on performance outcomes. However, for a comprehensive understanding of the relationship between postures and precision performance, these findings must be interpreted in conjunction with individual responses.

BIOMECHANICAL RESPONSES

PRECISION TASKS

Effect of precision demands on muscle activity

The difference between high and low precision demands was reflected in varying muscle activation levels for three of eight muscles that were tested. These muscles included brachioradialis, posterior deltoid and trapezius muscles. In each of these muscles higher precision requirements elicited higher electrical activity, although this was limited to specific postures. Other studies have been carried out on this topic, albeit with conflicting results. The main area of contention seems to be the justification given for the increased muscular load observed with higher precision requirements.

Brachioradialis, one of the forearm muscles used to move the hand-arm system, experienced significantly greater physiological strain when a high precision task was performed ($p<0.05$). The findings from the current study are therefore supported by Visser **et al.** (2004) and Escorpizo and Moore (2007) who found that the effects of high precision were contained in the forearm region. More specifically, Visser **et al.** (2004) reported a 21% increase in forearm muscles when a high precision task was performed in the seated posture. However, the explanations provided by these authors are not sufficient to account for the observed differences because in the current study, brachioradialis activity was observed to be elevated in selected postures only. Similarly to Visser **et al.** (2004), brachioradialis activation levels in the current study were affected in the seated posture, however, these differences were also observed in the overhead and twisting (non-preferred side) postures. In this regard, electrical activation levels for high and low precision tasks differed by 9%, 15%, and 10% for the seated, overhead and twisting (non-preferred side) postures respectively.

The seated posture is regarded as most appropriate for precision task performance and is not regarded as an awkward posture, while twisted and overhead postures are classified as such. Therefore, the fact that even in the seated posture electrical activity was influenced by precision demands further suggests that it was the precision demands that were responsible for these differences. Furthermore, it is noteworthy that brachioradialis activity did not vary significantly in five of the remaining postures. This suggests that a more comprehensive rationale is required than provided by Visser **et al.** (2004) and Escorpizo and Moore (2007) as the same forearm muscle was not affected in the same way in other postures.

High precision requirements also significantly increased trapezius muscle activity ($p<0.05$). This only occurred in the overhead posture and the observed difference between high and low precision demands was 6%. As trapezius is a shoulder stabiliser; these results concur with those of Sporrong **et al.** (1998). These authors suggested that shoulder muscle stabilisers are sensitive to precision demands and this would be elicited in increased muscle electrical activity with exposure to high precision demands. Milerad and Ericson (1994) however found the load on shoulder stabilisers to not reflect varying precision demands. Nonetheless, the current study found that high precision demands led to significantly higher ($p<0.05$) electrical activity of another shoulder muscle; posterior deltoid. In this regard, posterior deltoid muscle activity was augmented by high precision demands when the combined effect of all the postures was considered. This effect however, did not emerge in pair wise analyses of the individual postures thus making it difficult to further establish links between increased electrical activity during high precision demands in the different postures.

Therefore, this study investigated shoulder and forearm muscles and found that precision demands increase postural load in some muscles. These muscles are not confined to any region or function thus necessitating other possible explanations than provided in literature for the observed differences. Since even in the muscles that were affected by varying precision demands this was only evident in selected postures, it is hypothesised that posture may also be instrumental in determining muscular loading under different precision demands.

Effect of posture on muscle activity: precision demands

As yet, to the knowledge of the author, recommendations regarding the muscle activity limits for different tasks do not exist. This makes it difficult to further interpret or classify electromyography results. In the absence of a validated classification system, one was created for the purpose of contextualising the results obtained in this study. A detailed explanation of this classification system was discussed in Chapter II (49-51). To briefly reiterate, the three categories are present; namely low, moderate and high risk for the early onset of fatigue. These levels correspond to <5% MVC, 5-8% MVC and >8% MVC respectively (Table 2.I taken from page 51)

Table 2.I: Level of risk for the early onset of fatigue assigned to different levels of electrical activity

LOW RISK	MODERATE RISK	HIGH RISK
<5% MVC	**5-8% MVC**	**>8% MVC**

It is important to once again highlight that this classification system is used tentatively as epidemiological studies validating it have not been carried out. However, it was useful for interpreting the results obtained.

Movement component of precision performance

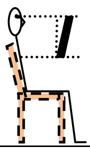
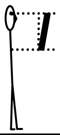
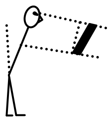
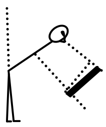
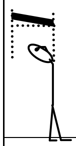
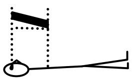
Overt movement of the hand-arm system is the result of well orchestrated processes where the hand, arm and shoulder musculature function in concert to bring the hand-arm system to the desired target (Herberts **et al.**, 1980; Magnusson and Pope, 1998). In this study brachioradialis, biceps brachii and triceps brachii were selected for testing because of the role they play in flexing the arm at the elbow and shoulder joints (Tortora and Grabowski, 2003). In all of the postures none of the muscles responsible for moving the hand-arm system elicited responses higher than 8% MVC. However, the biceps and triceps brachii both evidenced responses between the 5-8% MVC range for the overhead working posture, as was brachioradialis while stooping 60^0 (Table 2.XX). During all other postures activation levels for these muscles was below 5% MVC.

The relatively low levels of electrical activity evidenced in the muscles responsible for moving the hand-arm system can be partly attributed to the dynamic nature of the movements they execute in addition to the fact that the task that was tested was a light task. With the exception of the weight of the upper extremity, individuals did not have hold an external load that would potentially exacerbate the musculoskeletal responses. A combination of these factors, in the absence of residual strain and injuries, would allow for longer periods of work before local muscular fatigue becomes a concern.

Table 2.XX: Classification of muscle activity during precision demands in different postures based on the risk of early onset of fatigue

Brach = Brachioradialis; Bicep = Biceps brachii; Tricep = Triceps brachii; Ant Dt = Anterior Deltoid; Post Dt = Posterior Deltoid; Trap = Trapezius; L. ES = Left Erector Spinae; R. ES = Right Erector Spinae

<5% MVC Low Risk	5-8% MVC Moderate risk	>8 % MVC High risk
H: High Precision	L= Low Precision	* significant difference

POSTURE		Brach	Bicep	Tricep	Ant Dt	Post Dt	Trap	L. ES	R. ES
	H	*>			12%		10%		
	L				12%		10%		
	H				11%		9%		
	L				11%		9%		
	H				9%		9%	18%	22%
	L				9%		9%	18%	22%
	H							18%	19%
	L							18%	19%
	H	*>			22%		*> 20%		
	L				22%		18%		
	H								
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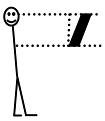	H						10%		
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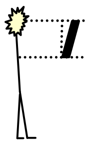
	H	*>			14%				9%
	L				14%				9%

Muscles for movement (Brach, Bicep, Tricep)

Muscles for stabilisation (Ant Dt, Post Dt, Trap, L. ES, R. ES)

Stabilisation component of precision performance

The muscles that were important for maintaining the hand-arm system and trunk included anterior and posterior deltoid, trapezius, and right and left erector spinae. Postural integrity and balance inevitably involve a significant proportion of static muscular contraction where the muscles are contracting isometrically (Jonsson, 1988). Static contractions have been implicated in the constriction of blood flow, the accumulation of metabolites, and the premature development of local muscular fatigue (Keyserling **et al.**, 1992; Milerad and Ericson, 1994; Magnusson and Pope, 1998). Fatigued muscles restrain force production and inhibit one from maintaining a constant force (Magnusson and Pope, 1998).

The anterior deltoid muscle evidenced electrical activity levels greater than 8% during seated, standing, stooping 30^0 and twisting to the non-preferred side postures. These levels of activation are a concern for the development of fatigue and musculoskeletal disorders due to the considerable static contractions which reached levels as high as 22% MVC in the overhead working posture for high and low precision demands. The remaining postures resulted in anterior deltoid activation between 5% and 8% MVC which would remain a concern for the development of fatigue and cumulative strain. The anterior deltoid muscle is likely to be critical in many tasks in industry because of its involvement in maintaining the arm in a raised position. Given these high levels of activation and static muscular contractions, shoulder injuries are likely to occur. Conversely to anterior deltoid, posterior deltoid activity was below 5% MVC in all postures, with the exception of the overhead working posture (5-8% MVC).

Trapezius muscle activity responses were greater than 8% MVC in the same postures as those for anterior deltoid. The only exception occurred during the twisting to the preferred side posture where observed trapezius electrical activity levels were greater than 8% MVC as opposed to the anterior deltoid muscle activity where twisting to the non-preferred side elicited responses greater than 8% MVC (Table 2.XX). Trapezius muscle activity in the current study was observed at 10% MVC in the seated posture. However, a study by Hagberg and Sundelin (1986), found that muscle activity in the ‘optimal’ seated posture (trunk and upper arm in vertical position and working with forearm at elbow height) led to trapezius muscle activity between 2 and 3% MVC. Although similar seated postures were adopted in both studies, in the current study individuals were working on a vertical surface that required slight elevation of the shoulder as opposed to the horizontal surface at elbow height. These results confirm that upper trapezius muscle activity is amplified by elevation of the hand-arm system (Magnusson and Pope, 1998). As such, rotator cuff muscles, and the trapezius muscle, are compromised by work done on a vertical surface requiring arm elevation.

Erector spinae is important for trunk stabilisation (Tortora and Grabowski, 2006). Studies of this muscle indicate that trunk flexion changes the recruitment pattern at different angles, which translates to varied strain on lower back musculature (Granata and Marras, 1995). With increased flexion of the trunk there is a corresponding increase in muscle activation and potential risk of injury (Floyd and Silver, 1955; McGill, 1997). However, at full trunk flexion muscle electrical activity is dramatically reduced as the load is borne by the passive structures of the back (Floyd and Silver, 1955). Left erector spinae electrical activity was similar for stooping 30^0 and 60^0 (18% MVC) (Table 2.XX). However, stooping 30^0 resulted in significantly higher right erector spinae (22% MVC) than stooping 60^0 (19% MVC) (Table 2.XX). Stooping, even by Rohmert’s (1973) high limits (15-20% MVC to sustain exertions indefinitely) was clearly a concern for the development of musculoskeletal disorders. As such these postures should be eliminated, avoided or the exposure doses limited to short infrequent exertions in industry.

For both stooped postures, right erector spinae brought about relatively higher muscle responses than left erector spinae. Bearing in mind that only right hand dominant individuals were tested; these responses could be related to the fact that the right arm was extended in front of the individual possibly falling outside the base of support. As such, right erector spinae may have had to contract at a slightly higher level to maintain balance with the trunk in the flexed position. The effect of the extended hand-arm system in causing greater muscular load is supported by the fact that even in the overhead working posture where left erector spinae activity was below 5% MVC, its right counterpart was activated to between 5 and 8 % MVC. Therefore, if stooped postures cannot be avoided, the upper extremities should be kept as close to the body as possible to minimise the requirement for counter-balancing strategies that may cause increased static muscular loading. This suggestion is supported by Das and Sengupta (1996) who state that unsupported arm reaches cause increased shoulder muscle activity and, if the task is performed with the trunk flexed as was the case in this study, may also augment loading spinal.

Twisted postures have also been identified as a health concern due to increased torsion and shear forces (if trunk flexion is present) between the inter-vertebral discs (McGill, 1997; Magnusson and Pope, 1998). Trunk muscles have been reported to act in a synchronised manner where simultaneous co-contraction of surrounding trunk muscles occurs, particularly when postures with a biomechanical disadvantage (stooping and twisting postures) are adopted (Granata and Marras, 1995; Marras **et al.**, 1998). Twisting to either side led to right and left erector spinae activity of between 5% and 8% MVC. However, while twisting to the non-preferred side, right erector spinae activity was above 8% MVC (Table 2.XX). This was an expected reaction because the whole trunk has to be twisted to the extreme left so the right hand could reach the target easily; this would inevitably cause greater strain on right erector spinae. Therefore, although all twisted postures are not favourable, extreme twisting postures should definitely be avoided.

Relationship with performance variables

The awkward nature of twisted and stooped postures did not hamper performance outcomes of the precision tasks that were tested. However, the musculoskeletal load experienced during these postures is a cause for concern in terms of discomfort, fatigue, and injury despite the short duration in which these tasks were performed. It can be assumed that if these tasks, and similar precision tasks in industry, are performed for longer periods with insufficient rest breaks, residual strain would further amplify the musculoskeletal demands.

Performance was found to be the least accurate and least efficient in the overhead and lying supine postures. Electrical activity in the overhead posture was greatest in anterior deltoid (22% MVC high and low precision) and trapezius (20% MVC high precision, 18% low precision) muscles (Table 2.XX). In this posture, biceps and triceps brachii, posterior deltoid and right erector spinae evidenced activation levels between 5 and 8% MVC (Table 2.XX). Only brachioradialis and left erector spinae were deemed to be within the ‘low risk’ category below 5% MVC (Table 2.XX). This suggests that for the most part, work in the overhead posture causes elevated muscle activation levels that would make workers susceptible to musculoskeletal disorders. This conclusion was also arrived at by Sood **et al.** (2007) and Elliott (2007). However, not only is this posture detrimental to the health of workers, but it also causes performance decrements. For these reasons, overhead working postures should be eradicated through redesigning workstations utilising ergonomics precepts. A redesign compromise for workstations where overhead work is unavoidable is to reduce the working surface such that extreme reaches are limited. If this is not possible, exposure to overhead working postures must be limited either by introducing frequent rest breaks or through worker rotation.

The lying supine posture was one of the least strenuous with regards to muscle activation. In this regard all muscles in this posture elicited activation levels below 5% MVC. The only exception was anterior deltoid which was activated between 5-8% MVC. Although working while lying supine is the least taxing on the musculoskeletal system, this posture was associated with poor performance and should thus be avoided if productivity and quality are a priority. However, it would be worth investigating if training workers to work in this posture would not lead to improvements in performance to match that of the other postures. Based on practicality, feasibility, flexibility of workstations and tools and acceptance by managers and workers alike, lying supine postures could be used as an alternative to the more straining postures prevalent in industry and could assist in temporarily relieving and managing musculoskeletal injuries in the workplace. In doing so, however, one would have to take in cognisance the fact that lying supine is the most difficult posture from which to get up (or down) and would thus require excessive energy expenditure if this had to be done frequently.

PRECISION OF FORCE APPLICATION

Hand-arm and shoulder muscles during force tasks

Applying a pushing force led to significantly higher brachioradialis activity in all postures than did pulling. This response led to brachioradialis activity between 5-8% MVC during pulling in all postures except while lying supine (<5% MVC) (Table 2.XXI). It is unlikely that the direction of force application required to perform specific tasks in industry can be changed thus if workers have to exert pulling forces, the duration over which this is done and any loads that have to be moved should be kept to a minimum.

In most postures the biceps brachii electrical activity was observed to be below 5% MVC. While pushing when twisted (non-preferred side) posture biceps electrical activity was between 5 and 8% MVC (Table 2.XXI). Pushing and pulling while in the overhead posture led to biceps activity levels between 5-8 % MVC and above 8% MVC respectively. Similarly, triceps brachii activity for both pushing and pulling in the overhead posture elicited activation levels between 5-8% MVC whereas it was observed to be below 5% MVC in the remaining postures. As biceps and triceps brachii are antagonistic muscles it was expected that pushing was more strenuous on biceps that pulling whereas greater strain was experienced by the triceps brachii during pulling in the overhead posture.

Anterior and posterior deltoid activity varied significantly between pushing and pulling as both these muscles act in an antagonistic fashion. In this regard pushing caused greater anterior deltoid electrical activity while pulling led to higher posterior deltoid electrical activity (Table 2.XXI). Anterior deltoid electrical activity was above 8% MVC while pushing in the seated, standing, overhead, lying supine, and twisting to the non-preferred side. Pulling in the lying supine and twisting to the non-preferred sides also led to muscle activity responses greater than 8% MVC. Although posterior deltoid muscle activity was below 5% MVC for the majority of postures, the overhead posture brought about activation levels at 8% and 10% MVC for pushing and pulling respectively (Table 2.XXI). It must be pointed out that the forces participants were required to exert were low (<50N), yet resulted in high levels of electrical activity. It can be surmised that if high forces and greater loads are handled, muscle activity would increase further and exacerbate fatigue responses and shoulder injuries. If workers are already experiencing shoulder pain and injuries, these would be intensified further.

Upper back and trunk muscles during force tasks

Trapezius muscle activity levels were a concern in the overhead posture; pushing was significantly higher than pulling with 18% and 14% MVC responses respectively (Table 2.XXI). In the remaining postures (seated, standing, stooping 30^0 and both twisted postures) trapezius electrical activity during pulling was more straining when compared to pushing. Pulling in the seated posture resulted in activation levels that were at 8% MVC.

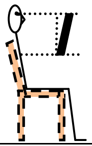
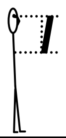
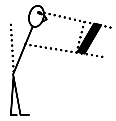
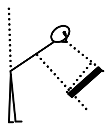
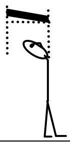
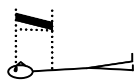
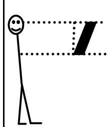
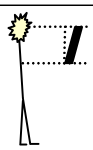
As expected, left and right erector spinae muscle activity was considered high risk in both stooping postures. Both right and left erector spinae muscles were strained at the same level for pushing and pulling. In this regard stooping 30^0 elicited significantly greater left (21% MVC) and right (22% MVC) erector spinae electrical activity for both forces than stooping 60^0 (17% and 18% for left and right erector spinae respectively) (Table 2.XXI). Electrical activation at 9% MVC was observed in left erector spinae when forces were applied while twisting to the preferred side. In contrast right erector spinae activation was at 11% for pushing and pulling in the twisting to non-preferred (left hand) side posture (Table 2.XXI).

It was interesting to note that the interaction effect of both right and left erector spinae muscles was not significant (Appendix B.3C). Contrary to this, the remaining muscles showed a significant interaction of posture and direction of force application (Appendix B.3C). This means that, with the exception of erector spinae, the effect of pushing and pulling on electrical activity is different under different postures.

Table 2.XXI: Classification of muscle activity during force demands in different postures based on the risk of early onset of fatigue

Brach = Brachioradialis; Bicep = Biceps brachii; Tricep = Triceps brachii; Ant Dt = Anterior Deltoid; Post Dt = Posterior Deltoid; Trap = Trapezius; L. ES = Left Erector Spinae; R. ES = Right Erector Spinae

<5% MVC Low Risk	5-8% MVC Moderate risk	>8 % MVC High risk
PS: Pushing Force	PL= Pulling Force	* significant difference

POSTURE		Brach	Bicep	Tricep	Ant Dt	Post Dt	Trap	L. ES	R. ES
	PS	* <			* > 10%	* <	* <		
	PL						8%		
	PS	* <			* > 9%	*<	*<		
	PL								
	PS	* <			* >	*<	*<	21%	22%
	PL							21%	22%
	PS	* <			* >	*<		17%	18%
	PL							17%	18%
	PS	* <	* > 9%	*<	* > 23%	*< 8%	*> 18%		
	PL				12%	10%	14%		
	PS	* <			* > 8%	*<			
	PL								
	PS	* <			* >	*<	* <	9%	
	PL							9%	
	PS	* <	* >		* > 11%	*<	* <		11%
	PL				8%				11%

Hand-arm & shoulder muscles (Brach, Bicep, Tricep, Ant Dt, Post Dt)

Upper back & trunk muscles (Trap, L. ES, R. ES)

Relationship with performance variables

The stooped postures were found to elicit levels of erector spinae activation that were considered high risk (up to 22% MVC) (Table 2.XXI) for the early development of fatigue. This was also a concern because overuse injuries and musculoskeletal disorders on the lower back involve these muscles. While stooping, individuals increased pushing force output more than was necessary, and more so in the stooping 60^0 posture. This over-compensation would have required greater muscular activation which would in turn compound postural strain and increase the potential risk of injury.

In the remaining postures pushing and pulling force production decreased with time. This effect was greater for pulling as force decreased to lower levels than for pushing. In this regard, pulling force production when working overhead and twisting (preferred side) showed the biggest absolute reduction and attests to the fact that individuals found maintaining a pulling force to be more difficult than pushing. Accordingly, electrical activity in the overhead posture were observed to be at a level that was in excess of 23% MVC in the anterior deltoid and 18% MVC in the trapezius muscle (Table 2.XXI). Additionally, twisting to the preferred side led to activation levels at 9% MVC in the left erector spinae while the right erector spinae and trapezius muscle activity was in the moderate risk level (5-8% MVC) (Table 2.XXI).

Individuals were able to sustain a constant pushing force in the twisting (non-preferred) condition only. This was not expected because anterior deltoid and right erector spinae electrical activity as high as 11% MVC was evidenced while several of the other muscles were in the moderate risk category (Table 2.XXI). These results are indicative of substantial muscular load that could potentially hamper force production and aggravate the precipitation of musculoskeletal disorders. These negative health effects cannot be overlooked and despite the fact that force production was maintained at the required levels while twisting to the non-preferred side, this posture is not ideal for tasks involving force application in industry.

PHYSIOLOGICAL RESPONSES

HEART RATE (HR)

Precision task

Precision demands did not affect HR responses in any of the postures that were analysed. This indicates that the precision task demands were not different in terms of the required physiological effort. It would be worth investigating tasks with greater variation in precision demands to determine if higher precision demands would affect physiological responses.

The lowest HR values were attained in the lying supine posture as expected. The standing, overhead and both twisted postures elicited comparable HR responses. This may be attributed to the upright stance characteristic of these postures. In these postures gravity is acting downwards through the body thus no additional energy is required to try and stabilise whole body posture. Stooping 30^0 led to equivalent HR responses when compared to the standing posture. As steady state had not been attained, HR values measured within the 40 seconds of task performance could still have been escalating, especially in the stooping posture where high HR values were expected. Had HR been recorded over a longer duration, the evidenced similarities between standing and stooping 30^0 would have ceased.

When the stooping postures were compared significantly greater physiological strain was experienced while stooping 30^0 than 60^0. This was not an expected finding because trunk flexion has been reported to increase physiological parameters such as HR, and breathing frequency (McArdle **et al.**, 2001). It was also noteworthy that HR responses were significantly lower in the stooping 60^0 posture than while standing. The reason provided above regarding steady state not being attained in the short duration of task execution does not apply here. Even if steady state had not been reached, stooping 60^0 would still be expected to elicit higher HR responses than standing, as was found in this study, because there is even greater trunk flexion when stooping 60^0 than when standing. The effect of gravity on the hand-arm system while performing the task could have influenced the results discussed above. However, further investigations regarding HR changes at different angles of trunk flexion would assist in clarifying these results.

Force tasks

The overall effect of force on HR responses was significant. However, pair wise analyses of HR responses revealed no significant differences of HR responses between pushing and pulling. Similarly to the precision tasks, HR during pushing and pulling tasks did not exceed 90bt.min^{-1}. In fact, with a few exceptions, the pattern and range within which HR responses were observed was comparable to that occurring during the precision tasks. The stooping postures brought about similar HR responses, thus suggesting that HR was affected more by trunk flexion than the requirement of force application.

Relationship with performance variables: precision and force tasks

The physiological strain experienced, as indicated by HR, was equivalent for high and low precision demands. As precision tasks are light and mostly manipulative in nature, biomechanical responses (in conjunction with performance outcomes) are of great concern. When considering pushing and pulling forces, no differences in physiological strain were evidenced although force augmented HR responses. Similarly to muscle activity responses, working when lying supine posture was the least physiologically taxing of all the postures for both precision tasks and pushing and pulling performance. However, HR responses in all postures were within the recommended limits. These results must not therefore be considered in isolation because although the stooping, twisted and overhead postures are acceptable in terms of HR responses, biomechanical limits were breached and performance outcomes were not optimal under these postures. Prolonged exposure in these postures would arguably exacerbate the observed responses.

PSYCHOPHYSICAL RESPONSES

RATINGS OF PERCEIVED EXERTION:

Precision and Force tasks

High and low precision demands were perceived to require similar muscular effort. The seated and standing postures were rated to be least demanding (RPE= 9) whereas the highest ratings were assigned to the overhead posture followed by stooping 60^0 and then 30^0. Lying supine and twisting to either side was perceived to be similar (RPE= 10) in terms of the contribution of local factors.

Ratings of perceived exertion varied significantly only for the standing posture, with perception of effort being greater for pulling than pushing. The ratings assigned to the different postures for the force tasks followed the same pattern as those for the precision tasks.

Relationship with performance variables

Performance under varying precision demands and force tasks was not reflected in the local ratings of perceived exertion. Postural load, however, had significant bearing on perception of muscular contribution to performance. The overhead and stooped postures were given the highest local ratings of perceived exertion. These findings coincide with the biomechanical results where 'high risk' muscle activation levels were observed in the same postures. These findings support the claim made by Lindström and Kadefors (1980) and reiterated by Herberts **et al.** (1980) that local muscular fatigue is closely related to perceived exertion. Thus, if a task is perceived to be highly demanding it is likely that discomfort will be heightened and fatigue may set in. It has been suggested (Gallagher, 2005) that tasks that are perceived to cause discomfort and fatigue result in changes in the manner in which the worker performs the task. This coping mechanism is achieved by way of postural shifts that temporarily relieve excessive demands on the body (Magnusson and Pope, 1998; Gallagher, 2005). It has been found that in some cases these changes may compromise output and quality as workers find it difficult to deliver to the required standard given the reduced capabilities (Laville, 1985; Eklund, 1995; Gallagher, 2005). Therefore, although RPE can be used as an indicator of physiological strain, this measure does not reflect performance changes as perceived by the worker.

LIMITATIONS OF THIS STUDY

Despite the controlled laboratory environment in which this study was conducted, a number of extraneous and possibly confounding factors relating to the experimental design and the variables under investigation have to be acknowledged.

A larger variety of postures and conditions exist in industry where precision tasks are performed. However, time constraints limited the number of postures that could be studied, thus from an infinite possibility, eight postures were analysed. The postures that were selected are commonly found in industry where precision tasks are performed and were thus thought to be a small but representative sample of the majority of postures prevalent in industry.

Most tasks in industry are performed over an extended period of time or are repeated several times throughout the working day. In the current study each of the tasks were performed once and did not exceed forty seconds for each posture. These restrictions in terms of duration of task execution were necessary in order to limit the effects of fatigue, especially given that each task had to be repeated in all eight postures. Nonetheless, although these restrictions may not be a true reflection of the situation in industry, they should provide some indication of the interaction between posture and precision performance. The short duration of the tasks also meant that a heart rate (HR) steady state could not be reached; thus the HR data for each condition may have been erratic. Despite this, HR was included, albeit as a secondary measurement, because of the strong influence that posture has on HR as a result of static loading. Moreover, even if HR steady state was not reached during the execution of each task, a higher HR would be indicative of a higher workload. However, it is acknowledged that in the 2 minute rest break HR may not have reached 'resting' levels thus potentially affecting the average HR.

The participants that were tested in this study were between the ages of 18 and 26. However, the age range of a typical workforce is much wider and incorporates much older individuals. Therefore, caution must be exercised when transferring these results to industry where older workers are present because age-related differences were not analysed in this study. Another potential limitation relating to the sample was the fact that inexperienced students were utilised to research a problem pertaining to industry where workers are skilled at the tasks they perform. This limitation was overcome by carrying out intra-individual comparisons as opposed to inter-individual assessments within the sample thus excluding any effects of experience. In any case, the focus of the study was on examining the effects of posture on individual performance such that the effect of experience would be the same in each posture. However, similar research still needs to be carried out on experienced workers to determine is the observed responses are in fact true regardless of the level of experience.

The number of muscles selected had to be limited to those involved in (a) task execution and (b) postural stability. In addition, the selected muscles were required to play an integral role in each of the eight postures in order for comparisons to be drawn between them. Various muscles in the forearm (brachioradialis, flexors and extensors of the wrist), arm (biceps brachii, triceps brachii), shoulder (anterior, middle and posterior deltoid, infraspinatus), and back (latissimus dorsi, trapezius, erector spinae) were piloted. From each group of muscles, representative muscles were discriminately selected based on the activation levels observed during pilot studies, feasibility (in terms of accessibility of the muscles) and practicality (eg: proximity of muscles and the size of the electrodes). In addition, the muscles that were selected had to be superficial as surface electromyography was to be utilised. In accordance with these criteria, eight muscles (brachioradialis, biceps brachii, triceps brachii, anterior deltoid, posterior deltoid, trapezius, and left and right erector spinae) were analysed.

CONCLUDING REMARKS

The holistic approach advocated by Dempsey (1998) was adopted in the current study with the aim of obtaining a true reflection of the effects of posture on precision performance and the extent to which precision demands influence postural strain. Given the varied domains that were investigated, it was expected that performance, biomechanical, physiological and psychophysical outcomes would be conflicting (Dempsey, 1998). This was true, for example, in the stooping and twisted postures (both of which are awkward postures). The awkwardness of these postures was further supported by the activation levels observed in erector spinae in the current study which were high enough to raise concern regarding the risk of early onset of fatigue and, with prolonged exposure, injury. Despite this, there did not seem to be an overt relationship between these postures and performance outcomes. It may be possible that individuals are able to, taking advantage of the flexibility and adaptability of the musculoskeletal framework (Gallagher, 2005), overcome the strain imposed by these postures without there being a decrement to performance.

However, there is a limit to this adaptability, as was the case with overhead work. Although HR responses were relatively low in this posture, precision performance results were the lowest and muscle activity reflected considerable musculoskeletal load, which was also translated to high ratings of local perceptions of effort. It can be surmised that awkward postures compound task demands and place additional strain on the human operator. Although the physical capacity of the human operator may initially be able to cope with these demands, performance in such conditions cannot be sustained and will cause performance decrements and increase the risk of injury. Postural strain resulting from varying precision demands was only different in a few muscles and only in selected postures whereas physiological and psychophysical responses were not sensitive in this regard. This suggest that there may be a possible effect but further studies are necessary to fully appreciate such interactions. The findings from this study further reiterate the importance of two key tenets in ergonomics;

taking a holistic integrated approach and matching task demands to the individual's capabilities (Pheasant and Haslegrave, 2006).

SECTION 2

CHAPTER VI
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The contribution of awkward postures to musculoskeletal disorders is a widely accepted notion. However, the influence these commonly occurring awkward postures have on performance outcomes is not well documented. Precision tasks are a particular area of concern in this regard. The inherent demands (cognitive and physical) on the human operator imposed by the nature of precision tasks, coupled with ergonomic deficiencies intrinsic to many poorly designed workstations, are the main forces behind workers adopting awkward postures while performing these tasks (Laville, 1985; Haslegrave, 1994; Martin **et al**., 2000 and Gallagher, 2005). It has been reported that these awkward postures are central to the development of musculoskeletal injuries and disorders (Pheasant, 1996; Vieira and Kumar, 1996), and force application has been identified as an aggravating factor in this regard (Armstrong **et al.**, 1993; Grieco **et al.**, 1998; Punnett and Wagman, 2004). Therefore, studies are required that will determine the extent to which awkward postures specifically impact precision performance. The current research therefore endeavoured to explicitly study the link between awkward working postures, precision performance, and their impact on the human operator.

SUMMARY OF PROCEDURES

This study was concerned with elucidating the effects of awkward working postures on precision performance. The impact of varying precision demands on the resulting postural strain was also of interest. The research design was such that three precision tasks were performed in eight different postures thus resulting in twenty-four (24) experimental conditions. The eight postures that were investigated were the seated, standing, stooping 30^0 and 60^0, working overhead, lying supine and twisting to either side postures. The precision tasks comprised of three tasks; namely a low and high movement precision task and a force production task. The high and low precision tasks were essentially tapping tasks that allowed for the measurement of movement time and target deviation where participants had to select targets on a touch screen using their index fingers. These tasks were each performed over approximately 40 seconds. The force task measured the precision of 2-handed pushing and pulling force application utilising a hand-held load cell. Pushing and pulling forces were exerted consecutively and each lasted 20 seconds such that the combination of the two was still 40 seconds.

Forty-eight (48) right hand dominant participants (24 males and 24 females) were recruited from the Rhodes University student population. Participants were required to participate in two sessions; a habituation and experimental session both of which were carried out in a laboratory in the Human Kinetics and ergonomics Department. Subjects performed 24 conditions (all randomized through permutations of the postures and tasks) during which the following dependent variables were measured: performance (movement time and deviation from centre of target), biomechanical (muscle activity of eight arm shoulder and back muscles), physiological (heart rate) and psychophysical (local ratings of perceived exertion) responses.

Prior to testing, electrical activity of maximal voluntary contractions (MVCs) of the 8 muscles (brachioradialis, biceps brachii, triceps brachii, anterior deltoid, posterior deltoid, trapezius, and left and right erector spinae) were obtained in order for intra-individual comparisons of muscle responses between the different postures could be carried out. Muscle activity and heart rate were monitored throughout the duration of each condition. Upon completion of each condition participants were asked to give a rating of their perceptions of muscular effort. After all conditions for each posture had been performed, rest breaks of approximately 2 minutes were provided.

SUMMARY OF RESULTS

Performance variables

Movement time was significantly affected by the posture that was adopted while performing the task ($p<0.05$). In this regard, the slowest movement times were obtained while working overhead and while lying supine for both high and low precision tasks. Overhead and supine postures were slower by 9% and 8% when compared to the seated posture and a 9% difference was found when compared to the standing posture. Movement time in the remaining postures was similar.

The posture adopted was also found to have an effect on the extent to which individuals deviated from the centre of the target. When considering high precision demands deviations were the greatest in the overhead, supine and standing postures while no significant differences were found when the remaining postures were contrasted. When compared to the seated posture, deviations were greater by 28% and 27% for the overhead and supine postures respectively. The discrepancies were slightly lower when compared to the standing posture where deviations in the overhead and supine postures were greater by 10% and 9% respectively. For low precision tasks a 10% difference was evidenced when the overhead posture was compared to stooping 60^0, with deviations being higher in the overhead posture.

On consideration of both performance variables it was evident that the overhead and supine working postures lead to poor performance when individuals are faced with high precision demands. This means that in such conditions, productivity and quality of product output are compromised. The fact that under high precision demands the performance was similar in the remaining postures suggests that individuals were able to overcome the postural strain imposed by the awkward postures. However, over longer durations performance may start to deteriorate. During low precision task performance the lying supine posture was only a concern in terms of movement time. This means that if workers are working in the supine position the quality of the product can be maintained, but this can only occur if longer cycle times are permitted to complete the task. The stooping posture resulted in deviations that were similar when compared to the standing posture. However, stooping led to higher movement times, which would be a concern where efficiency is a priority.

The trend of force was used as an indicator of the individual's ability to maintain a constant force over time. This trend followed by the forces was found to be significantly influenced by the posture that was adopted ($p<0.05$). Moreover, the trend was affected by the direction in which the force was applied. In each posture, the pulling force led to greater decrements in force exertion than pushing. Force output followed a negative trend in all except both stooping postures. This was an indication that individuals cannot keep even low forces constant over a prolonged duration. An overcompensation reaction, where force exertion was increased more than necessary, was evidenced in the stooping postures. This overcompensation was greater in the stooping 60^0 than stooping 30^0 postures, which suggests an association with increased trunk flexion.

Biomechanical responses

The effect of precision demands on muscle responses was significant only in the brachioradialis, posterior deltoid, and trapezius muscles. In this regard, high precision demands augmented muscle activation levels. The overhead working posture was implicated in two of these muscles with electrical activity differences between high and low precision demands ranging from 6% in the trapezius muscle to 15% in brachioradialis. High and low precision demands elicited brachioradialis muscle activity that differed by 9% in the seated posture and up to 10% in the twisted (non-preferred side) posture. The varying precision demands led to electrical activity differences ranging from 4% to 12% of the posterior deltoid muscle. It must be pointed out that for the muscles that were affected by varying precision demands, this did not occur in all postures that were analysed. This suggests that posture may have played a significant role in augmenting muscle electrical activity during high precision tasks.

That muscle activity was significantly affected by the posture adopted was an expected finding and confirmed previous literature findings regarding the importance of posture in determining muscle responses. In the twisted and stooping postures, for example, erector spinae muscles were strained to levels of up to 22% MVC. The arm and shoulder muscles, particularly anterior deltoid and trapezius, were critical in all postures because of their involvement in stabilising the hand-arm system while performing all precision tasks. As the stabilising role involves substantial static muscular contractions, the levels of activation were elevated and were a cause for concern in terms of fatigue, injury and musculoskeletal disorders of the shoulder. The overhead posture led to activation levels between 5% MVC and up to 22% MVC when all muscles are considered during all tasks that were performed but especially so for the force tasks. Contrary to this, the supine posture was the least straining on all the muscles under investigation.

A major concern in the muscle responses to these tasks were the high levels of activation caused by the awkward postures and task demands despite the short duration and frequent rest breaks that were provided. Moreover, the loads that were handled were very light. As work in industry is performed over longer periods and much larger loads are handled, it can be expected that the strain on the musculoskeletal system will be augmented. The repercussion in terms of the development of fatigue, pain and injury are thus warranted. Given that performance in some of these awkward postures was shown to be negatively impacted, it can be deduced that performance would deteriorate further with increased muscle activation.

Physiological responses

Heart rate (HR) responses were not altered when tasks with varying precision demands were performed. Posture, as expected, had a significant influence on HR responses. HR was significantly higher when standing than when stooping 60^0; an unexpected finding as HR responses generally increase with increased trunk flexion. Force application had a significant effect on HR responses and this effect was similar for pushing and pulling force application. Although HR responses for the force tasks generally followed a similar response pattern to the high and low precision tasks, the effect of posture seems to have been more pronounced when force tasks were performed. This was evidenced in the fact that the stooped postures elicited similar HR values suggesting that trunk flexion, rather force application was moderating the physiological strain experienced.

Psychophysical responses

High and low precision demands were perceived to be equally taxing in terms of local ratings of muscular effort. Similarly, no differences were found when comparing the perceived effort invested in pushing and pulling tasks except in the standing posture where pulling was perceived to be slightly more taxing. Posture, however, was significantly related to the ratings provided by participants. In this regard, the stooping and overhead working postures were found to require the greatest muscular effort. This corresponded to the responses obtained from the muscles where these postures were found to cause considerable strain on several muscles.

RESPONSE TO HYPOTHESES

NULL HYPOTHESIS 1

In the first hypothesis it was proposed that the independent variables relating to precision performance and individual responses would be affected in the same way by the different postures.

Movement time (MT)

Ho: $\mu MT_{(Posture1)} = \mu MT_{(Posture2)} = \ldots\ldots\ldots \mu MT_{(Posture8)}$

Movement time was significantly affected by posture for both high and low precision demands. The null hypothesis is therefore rejected.

Deviation from centre of target (D)

Ho: $\mu D_{(Posture1)} = \mu D_{(Posture2)} = \ldots\ldots\ldots \mu D_{(Posture8)}$

Posture had a significant influence on the extent to which individuals deviated from the centre of the target thus necessitating the rejection of the null hypothesis.

Precision of force application (PF)

Ho: $\mu PF_{(Posture1)} = \mu PF_{(Posture2)} = \ldots\ldots\ldots \mu PF_{(Posture8)}$

The trend followed by the force exerted by individuals was significantly different between the postures. This trend was also significantly influenced by the direction in which the force was applied. The null hypothesis is therefore rejected.

Biomechanical responses (BM)

Ho: $\mu BM_{(Posture1)} = \mu BM_{(Posture2)} = \ldots\ldots\ldots \mu BM_{(Posture8)}$

Posture had a significant effect on the electrical activity of all the muscles that were analysed. This was true for all the tasks that were performed, hence the null hypothesis is rejected.

Physiological responses (PS)

Ho: $\mu PS_{(Posture1)} = \mu PS_{(Posture2)} = \ldots\ldots\ldots \mu PS_{(Posture8)}$

Heart rate responses varied significantly in all the postures for all the tasks that were analysed. The null hypothesis is therefore rejected.

Psychophysical responses (PP)

Ho: $\mu PP_{(Posture1)} = \mu PP_{(Posture2)} = \ldots\ldots\ldots \mu PP_{(Posture8)}$

The null hypothesis regarding psychophysical responses is rejected because local ratings of perceived exertion differed significantly between the postures for all the tasks that were performed.

NULL HYPOTHESIS 2

The second hypothesis was concerned with establishing the postural load imposed by varying precision demands; namely high and low precision tasks.

Biomechanical responses (BM)

Ho: $\mu BM\ High_{(Posture1\ldots\ldots Posture\ 8)} = \mu BM\ Low_{(Posture1\ldots\ldots Posture\ 8)}$

Activation levels ensuing from high and low precision demands varied in a significant manner in only three of the eight muscles that were analysed. Therefore, the null hypothesis is tentatively rejected as far as brachioradialis, trapezius and posterior deltoid muscles are concerned. As muscle activity was not significant in the remaining five muscles the null hypothesis is accepted although tentatively so.

Physiological responses (PS)

Ho: μPS High$_{(\text{Posture1……Posture 8})}$ = μPS Low$_{(\text{Posture1……Posture 8})}$

There were no differences observed in heart rate responses when high and low precision demands were compared. The null hypothesis is therefore tentatively retained.

Psychophysical responses (PP)

Ho: μPP High$_{(\text{Posture1……Posture 8})}$ = μPP Low$_{(\text{Posture1……Posture 8})}$

Ratings of perceived exertion were similar for high and low precision demands. The null hypothesis was thus rejected.

CONCLUSIONS

An important finding of this study was that the posture adopted has a direct influence on performance variables which are associated with productivity and the quality of product output. Therefore, this provides evidence that ergonomics interventions are relevant and critical in contributing positively to organisational goals simultaneously to taking cognisance of worker needs. Moreover, the results indicate that although precision tasks are considered to be ‘light’ tasks, the static muscular contractions required to stabilise individuals in awkward postures are high enough to be a cause for concern with regards to the early onset of fatigue and the precipitation of musculoskeletal injuries. This emphasises the importance and necessity of workstation design to simultaneously consider performance outcomes and the strain on workers. Accordingly, recommendations made to industry should reflect these considerations. As such, overhead working posture must be avoided because performance and health outcomes will be infringed upon. Although working supine may be the least taxing on the worker, performance may be compromised. Additionally, the fact that performance outcomes were preserved in the other postures that were analysed does not justify the existence of awkward working postures because of the associated threats to worker health. Therefore, performance deteriorates in biomechanically taxing postures such as overhead work for short duration precision task performance. It can be expected that with longer duration, performance would be further compromised. Although longer duration tasks were not analysed, over extended periods, it can be deduced that awkward postures such as stooping and twisting may start to cause performance decrements.

Based on assertions in literature (Gallagher, 2005) and the outcomes of the current study it is also clear that a ‘perfect’ posture which can guarantee optimal performance while not compromising the health of the worker does not exist and cannot be recommended to industries where precision tasks are performed. This can be attributed to worker, task, and environmental factors, and the complex interaction of all these processes in mediating performance. This also means that interactions between posture, worker and precision tasks are context specific and as such, different postures are more preferable in certain situations than others.

RECOMMENDATIONS

The results from this study indicate that postures are an important determinant of performance outcome and human operator responses. This information needs to be communicated to industry as the survey (refer to Section 1) provided evidence that managers are under the perception that ergonomics deficits have no bearing on critical performance variables such as productivity and quality. The results from the current study further allude to the possibility that varying precision demands influence the strain experienced. Additional research is required in order to explore these relationships further with the aim of transferring the findings to industry where they are needed the most. In so doing, the following recommendations can be considered:

Further research

It is acknowledged that realising these recommendations may be a methodological challenge and are therefore quite idealistic.

1. Tasks of longer duration should be analysed in order to determine the effects over the duration of a shift and to gain an understanding of the effects of muscle fatigue on precision performance.
2. A greater number of muscles should be investigated. This should also include the analysis of deep muscles as these may be instrumental in deciphering their contribution to the performance of precision tasks.
3. The effect of varying precision demands on the spinal loads experienced should be investigated. Such investigations should be included in future analyses and should consider different awkward postures in order to complement the information obtained regarding muscle responses.
4. Similar studies should be conducted on workers in industry to ascertain if the effects observed in this study hold true for individuals with experience in performing precision tasks in the awkward postures that were analysed. This is necessary because as yet, it is not clear what effect learning and experience have on motor behaviour in awkward postures.
5. Although awkward postures are associated with negative health ramifications the biomechanical limits and exposure levels that are critical in fatigue and injury causation and performance decrements are yet to be established. These limits should include recommendations for dynamic task as these tasks make up the majority of the tasks in industry.

Industrial application

1. Since the current study was done on a sample of inexperienced students, it would be worth carrying out the same study on experienced workers to determine if the observed effects hold true in practice. This would also increase the external validity of the study and ensure higher generalisation to industry problems.
2. Although a link was found between posture and performance in some of the postures tested in the current study, these results cannot necessarily be extrapolated to all postures. Therefore future studies should analyse a greater number of postures in order to more closely reflect the wide array of postures prevalent in industry and increase the applicability of the results.
3. Future studies should reflect the multi-faceted nature of work settings by carrying out in-situ investigations. Such studies will allow for a complete appreciation of imbalances between of the demands imposed on the worker and the outcomes thereof.

In order for the above mentioned recommendations to be applied successfully several contextual considerations should be taken into account:

Workstations should be designed to allow for more than one posture to be adopted in order to allow for appropriate postural changes. Any recommendations made regarding posture should also incorporate options to vary posture without compromising performance. Moreover, such recommendations should be low-cost or no-cost interventions starting at the micro-ergonomics level. Any successes thereof, no matter how small, can be used as motivators for bigger and far-reaching interventions at the macro-ergonomics level. Therefore initial ergonomics awareness campaigns should focus on the basic interactions at the elementary level.

While ergonomics claims to contribute positively to improvements pertaining to any work settings, it is not uncommon to find that the research findings from ergonomics studies remain within the fraternity and journals used predominantly by ergonomics professionals. As such, there is limited transference and application of this valuable knowledge in industry. This is said acknowledging some of the practical issues plaguing ergonomics research findings that limit applicability to industry. Nonetheless, it is recommended that the results from the current research and future studies in this area be made known to industry where they will be useful in solving the many and varied challenges relating to performance and worker health. This is especially relevant given that the survey conducted (refer to Section 1) indicates that managers are not aware of the link between ergonomics deficiencies and worker performance in terms of productivity and quality of output. What's more, although the prevalence of MSDs in IDCs has yet to be quantified, it can be estimated that the figures are staggering. Thus, there is great potential for ergonomics to effect the positive changes it purports to produce at both micro and macro levels.

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APPENDICES

APPENDIX A: Section 1

A.1: Cover letter for survey

A.2: Ergonomics and quality survey

Cover letter for survey

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

HUMAN KINETICS & ERGONOMICS
Tel: (046) 603 8468 • Fax: (046) 603 8934 • e-mail: hke@ru.ac.za

23 July 2007

Re: Assistance with surveying quality management

Dear Sir/Madam

We are researchers from the Human Kinetics and Ergonomics (HKE) department at Rhodes University and are performing research on quality issues. We would appreciate it if you could kindly pass this document on to the individual(s) concerned with quality management within your organisation.

The objective of the survey (attached) is to investigate quality concerns within industry. We are attempting to determine whether ergonomics applications in industry can lead to improvements in quality of output. The results from this survey will form part of an MSc project. Moreover, a report documenting the overall outcomes from this study can be made available to your organisation upon request.

The survey
The survey will take you approximately 10-15 minutes to complete. Please answer all questions. Be assured that any information provided will be treated **confidentially** and that you have a **choice to remain anonymous, if you wish so.**

Please complete and return the survey within a week of receiving it, either by fax (046-603 8934) or post using the provided envelope.

Should you be uncertain about anything or want further explanation, please do not hesitate to contact us. Thank you for your assistance.

Best Regards

Prof Matthias Goebel	Nokubonga (Sma) Ngcamu [BSc(Hons)]
______________________	______________________
Head of department	MSc student

HUMAN KINETICS AND ERGONOMICS DEPARTMENT
RHODES UNIVERSITY

ERGONOMICS AND QUALITY SURVEY

INSTRUCTIONS

- Time required : 10-15 minutes
- Please answer the following questions, substantiating your responses where required. If you need extra space to answer please number your responses and write on the back of the page or attach another sheet.
- Please return this form by **fax** (046-603 8934) or **post** using the enclosed envelope (Rhodes University, Human Kinetics and Ergonomics Department, Grahamstown, 6140) within a week of receiving it.
- If you encounter any problems please contact us on **Tel**: (046-603 8468) or hke@ru.ac.za

QUESTIONS

1. Are there any issues related to output quality (past and present) that your organisation is facing?

   YES ☐ ☐ **NO**

   If you answered 'NO' for this question, you do not have to continue with the questionnaire. However, we kindly ask you to return the survey.

2. Please describe some of the major quality problems in your organisation

   ____
   ____
   ____
   ____

3. Do you think that quality improvements could be instrumental in contributing to the following (Please tick the appropriate answer):

	YES	NO	NOT SURE
Productivity			
Market share			
Profit			
Organisation's reputation			
Certification requirements			

4. Do you estimate that quality issues could be an additive factor to the overall costs of your organisation?

   YES ☐ ☐ **NO**

If you answered 'YES', please list and describe some of these cost factors.

____
____
____
____
____
____

5. What, in your experience, are the causes of the quality problems you have encountered? Please tick to indicate the level of relevance for each factor.

DOMAIN	POSSIBLE CAUSE	RELEVANCE		
		None	Minor	High
MATERIALS & ENGINEERING	Poor product design			
	Defective raw materials			
OTHERS				
ORGANISATION	Inefficient work-cycles			
	Difficult manufacturing process/ task demands			
	Lack of documentation			
	Inadequate quality control			
	Insufficient communication			
	Lack of instruction			
	Incomplete feedback about performance			
	Lack of awareness regarding quality requirements			
	Status differences and/or tensions between workers in different hierarchical levels			
OTHERS				
HUMAN FACTOR	Untrained and/or inexperienced worker(s)			
	Incompetent worker(s)			
	Fatigued worker(s)			
	Inability to keep up with prescribed working pace			
	Poor physical conditioning			
	Awkward working postures			
	Highly repetitive tasks			
	Inability to apply sufficiently high forces			
	Inappropriate use of technology/ equipment			
	Inadequate mental capacity/ decision making ability			
	Boredom			
	Lack of motivation			
	Dissatisfaction about work			
	Inability to interact well with colleagues			
	Unable to 'fit in' with the organisational culture			
OTHERS				
ENVIRONMENT	Workstation design			
	Constrained working conditions			
	Climatic conditions			
	Inadequate ventilation			
	Vibration interference			
	Inadequate illumination			
	Noise disruptions			
	Inappropriate tools			
OTHERS				

6. Referring to question 5, what strategies have been deployed by the organisation to deal with these issues? Please mention the three most important strategies.

I. ____

II. ____

III. ____

7. Does your organisation plan to implement any quality improvement strategies in the future?
YES ☐ ☐ **NO**

If you answered 'YES', please specify.

____

8. Which sector does your organisation belong to? (please tick the relevant box)

Agriculture	Production	Service	Other (please specify)

9. How many employees does your organisation employ in South Africa?

1 – 10	11-50	51-250	251-1000	1000-5000	>5000

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS SURVEY.

If you wish to remain anonymous please return the survey with the following box empty. However, if you would like to receive feedback or a follow-up on your responses, please provide the necessary information below. If you would like to remain anonymous yet receive feedback, please cut out the box below and return in a separate letter.

Title…………. Name and Surname………………………………………………………………………………………

Name of Organisation…………………………………………………………………………

Position within organisation…………………………………………………………………………

☎……………………………………………………………………………………

e-mail address ……………………………………………………………………

APPENDIX B: Section 2

B.1: Measurement

A. Posture Descriptions
B. Mathematical equations for postural configurations
C. Electrode Placement
D. Ratings of Perceived Exertion (RPE) Scale

B.2: General Information

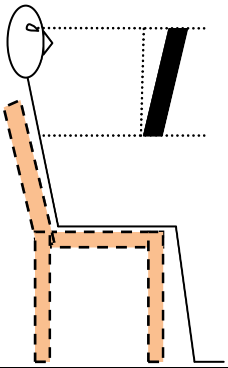
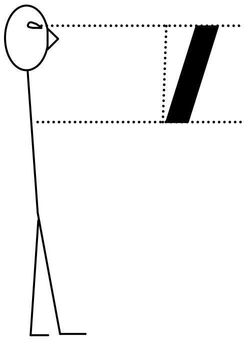
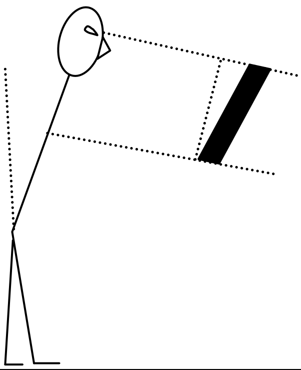
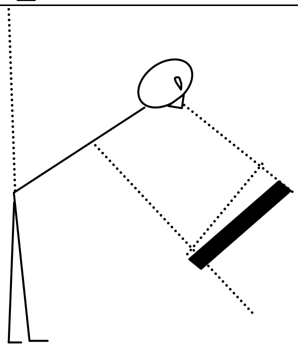
A. Information for participants
B. Consent form
C. Order of proceedings

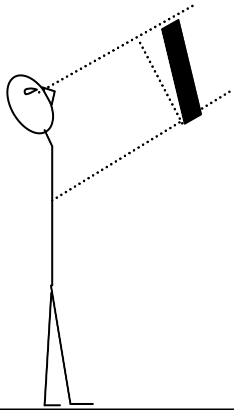
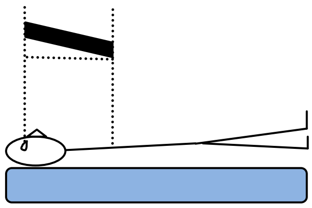
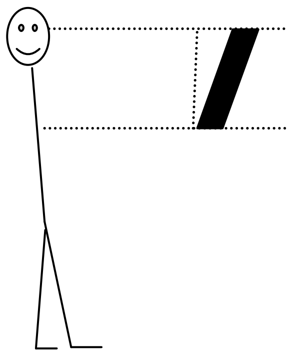
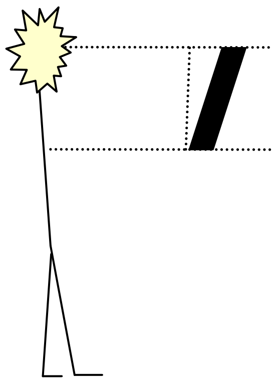
B.3 Data Collection

A. Anthropometric measurements data sheet
B. Data collection sheet
C. Statistics analyses of muscle responses (non-significant results)

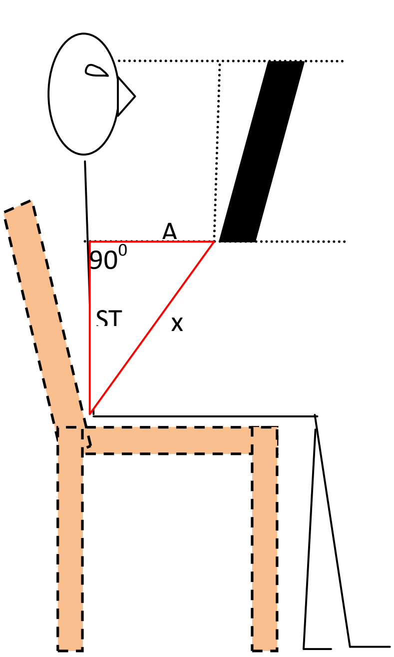
B.1A: Posture Descriptions

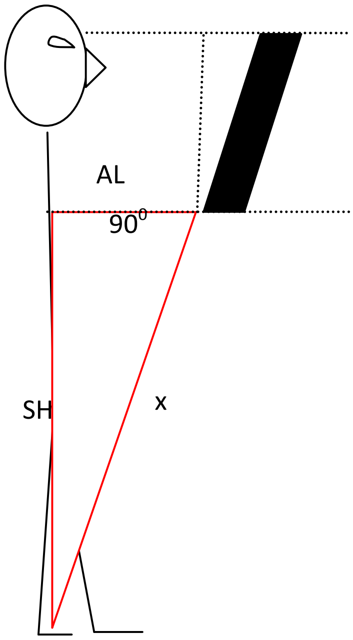
Postures that were investigated in the current study

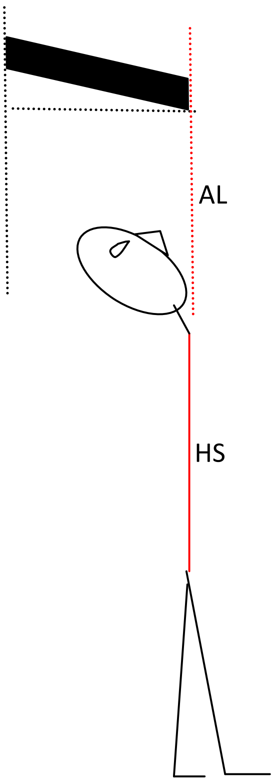
CONDITION/ POSTURE	DESCRIPTION
Condition 1: Seated posture 	• Seated posture with chair adjusted such that the knees are bent to approximately 90^0 (popliteal height) with the feet touching the floor • Monitor positioned at a distance equivalent to the subject's horizontal distance from the acromion process to 75% of arm length • Top edge of monitor positioned at eye height • Hand not performing task must be placed on top of the lap • Subjects encouraged to use back rest • No arm rests provided
Condition 2: Standing upright 	• Standing upright with feet shoulder width apart (or within demarcated area) • Monitor positioned at a distance equivalent to the subject's horizontal distance from the acromion process to 75% of arm length • Top edge of monitor positioned at eye height • Hand not performing task must remain in the anatomical position next to the body
Condition3: Stooping30^0 	• Standing with torso bent 30^0 forward from the waist with feet shoulder width apart (or within demarcated area) • Monitor positioned at a distance equivalent to the subject's horizontal distance from the acromion process to 75% of arm length • Top edge of monitor positioned in line with the eyes • Hand not performing task must remain in the anatomical position next to the body or must hang freely on the side
 Condition 4: Stooping 60^0	• Standing with torso bent 60^0 forward from the waist with feet shoulder width apart (or within demarcated area). Knees must be kept straight while stooping forward and only bent if the subject cannot maintain the stooped posture • Monitor positioned at a distance equivalent to the subject's horizontal distance from the acromion process to 75% of arm length • Top edge of monitor positioned at eye height • Hand not performing task must remain in the anatomical position next to the body or must hang freely on the side

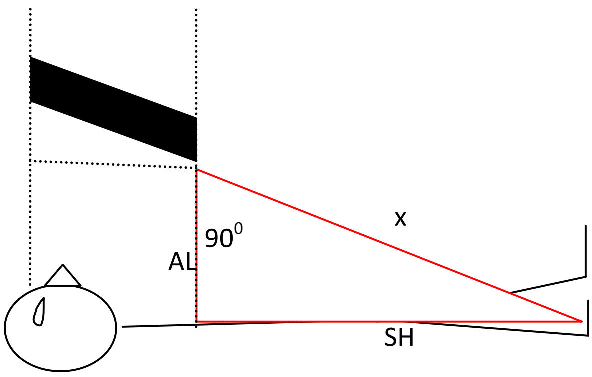
Condition 5: Standing working overhead 	• Standing upright with the arm performing the task raised above head (to the lower limit of overhead height to make sure that hand-arm position closely resembles that of other conditions). • Head has to be tilted back at the neck to view the screen • Monitor positioned at a distance equivalent to the subject's horizontal distance from the acromion process to 75% of arm length • Top edge of monitor positioned in line with the eyes • Feet shoulder width apart (or within demarcated area) • Hand not performing task must remain in the anatomical position next to the body
Condition 6: Lying supine 	• Subject lying supine (flat on their back) in the anatomical position • Monitor positioned at a distance equivalent to the subject's horizontal distance from the acromion process to 75% of arm length • Top edge of monitor positioned at eye height • Hand not performing task must remain in the anatomical position next to the body
Condition 7: Twisting to preferred side 	• Standing upright with feet shoulder width apart (or within demarcated area) at 90^0 from the monitor in the left direction • With feet facing in the left hand direction, subject must then twist from the waist until upper body is facing the monitor as in the normal standing posture. • Monitor positioned at a distance equivalent to the subject's horizontal distance from the acromion process to 75% of arm length • Top edge of monitor positioned at eye height Hand not performing task must remain in the anatomical position next to the body
Condition 8: Twisting to non-preferred side 	• Standing upright with feet shoulder width apart (or within demarcated area) at 90^0 from the monitor in the right direction • With feet facing in the right hand direction, subject must then twist from the waist until upper body is facing the monitor as in the normal standing posture. • Monitor positioned at a distance equivalent to the subject's horizontal distance from the acromion process to 75% of arm length • Top edge of monitor positioned at eye height Hand not performing task must remain in the anatomical position next to the body

B.1B: Mathematical equations for postural configurations



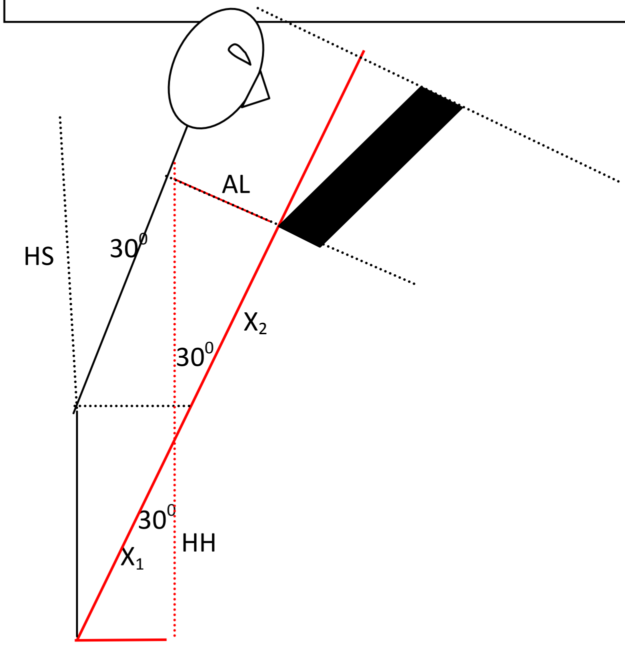




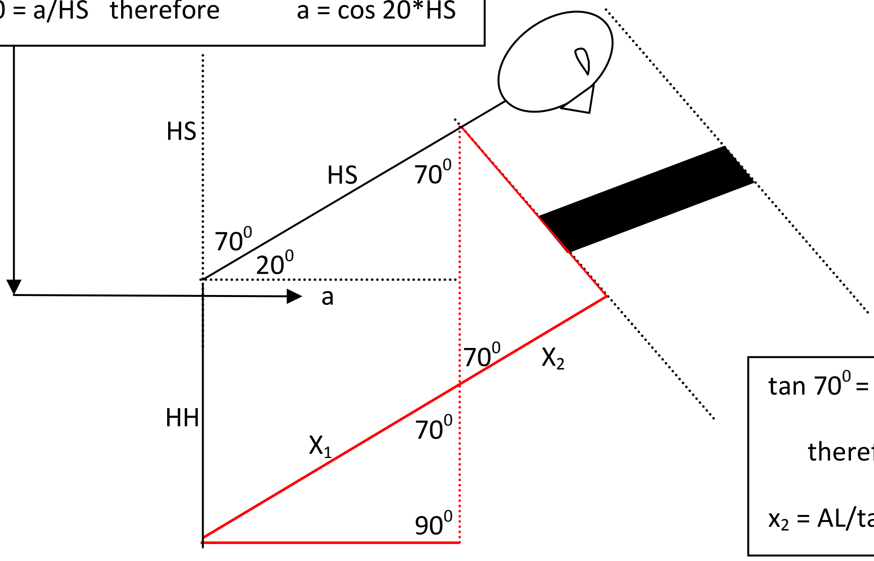


$HH/x_1 = \cos 30^0$ therefore $x_1 = HH/\cos 30^0$

$AL/x_2 = \tan 30^0$ therefore $x_2 = AL/\tan 30^0$



Cos 20 = a/HS therefore a = cos 20*HS



$\tan 70^0 = AL/x_2$

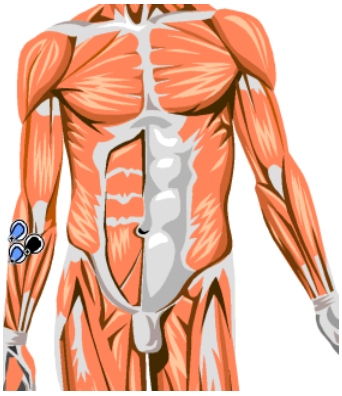
therefore

$x_2 = AL/\tan 70^0$

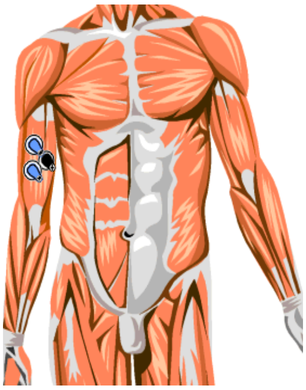
$\cos 20 = X_1/a$ BUT $a = \cos 20 * HS$

So $\cos 20 = X_1/\cos 20 * HS$ therefore $X_1 = HS$

B.1C: Electrode Placement

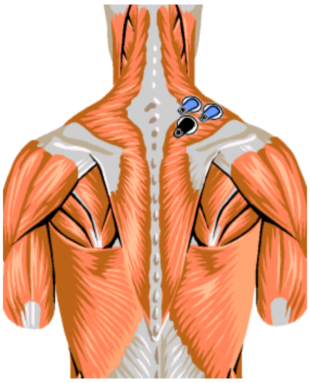


Brachioradialis muscle

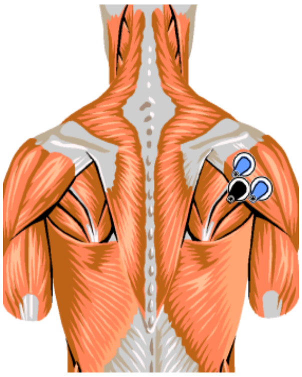


Biceps brachii muscle

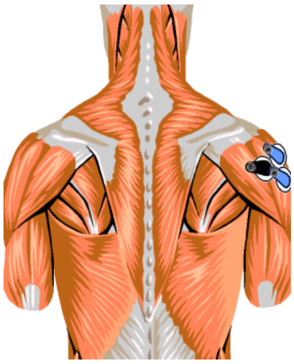
Triceps brachii



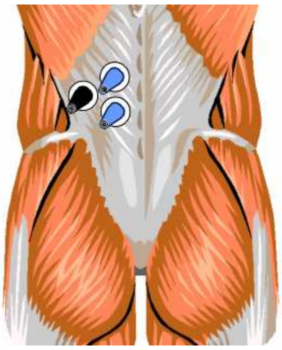
Trapezius



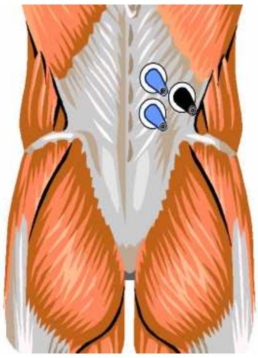
Posterior Deltoid



Anterior Deltoid



Erector spinae (L)



Erector spinae (R)

Electrode placement for the muscles that were analysed (Muscle Tester ME6000 Biomonitor System). Please note that only one ground electrode was used and this was adhered over the wrist flexors.

B.1D: Ratings of Perceived Exertion (RPE) Scale

The Rating of Perceived Exertion (RPE) Scale

RPE SCALE

6.
7. VERY, VERY LIGHT
8.
9. VERY LIGHT
10.
11. FAIRLY LIGHT
12.
13. SOMEWHAT HARD
14.
15. HARD
16.
17. VERY HARD
18.
19. VERY, VERY HARD
20.

The participants were asked to use the RPE scale to "rate their perception of muscular effort in terms of how much they perceived their muscles were contributing to task execution".

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DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

INFORMATION FOR PARTICIPANTS

Dear Participant

Thank you for agreeing to participate in this study. Your contribution is greatly appreciated. This document contains information regarding the research that will be carried out and how you will be assisting in this regard. Also attached to this document is a consent form which you have to sign prior to commencing with the testing. Please ensure that you read everything carefully before signing. Should you be uncertain about anything or want further explanation, please do not hesitate to contact the researcher, who will attempt to timeously address any queries.

PURPOSE OF RESEARCH/ STUDY

The aim of this study is to investigate the impact of (awkward) working postures on precision performance and to evaluate the effect of precision demands on the postural strain experienced thereof. This will be evaluated through assessing how performance variables change when a precision tapping task is performed under eight (8) different predefined postures and under two (2) indexes of difficulty. Muscle activity will be measured using electromyography (EMG) and heart rate (HR) will be monitored. The changes that occur in terms of performance and within the body when performing the tapping task under the different postures will be measured and compared.

You will be required to attend two sessions. The first session is for familiarising you with the experimental set up and the equipment and obtaining your anthropometric measurements. This session should last for approximately 15-20 minutes. The second session is for data collection. On arrival at the laboratory, a heart rate monitor will be attached to your chest and some surface electrodes will be adhered on the skin above certain muscles of the body. The researcher will then explain the requirements for each condition thoroughly before commencing. Before beginning with the protocol you will be required to do maximal force contractions (MVCs) for the different muscles that will be measured.

You will then be required to perform 24 conditions lasting approximately 40 seconds each. Rest breaks will be provided between conditions and after each task. During each condition, muscle activity will be examined using electromyography (EMG) analysis and the signals will be picked up by electrodes which will be placed on the skin. If necessary, some hair may have to be removed in the areas where electrodes will be placed so as to ensure that they adhere properly to the surface. Your heart rate will be recorded using a heart rate monitor. You will also be required to rate your perception of the effort you invest in the task in terms of both muscular and cardiovascular effort. This will be done using a rating of perceived exertion scale (RPE).

'Dos' and 'Donts'

In the interests of limiting the effects of extraneous variables you are asked to please refrain from the following before coming for your data collection:

- consuming alcohol
- strenuous exercise/ activities
- medication such as stimulants or performance enhancers.

If you do any of the above, please inform the researcher

RISKS AND BENEFITS

The likelihood of the presence of risk factors was minimised as far as possible. The ethics committee approved the protocol because it was seen as not being potentially injurious to the participants. However, although the necessary precautions have been taken, any unforeseen accidents cannot be prevented.

One of the benefits of participating in this study is that you will gain knowledge about the manner in which your body reacts to different conditions and how this can be measured. It is also hoped that you will gain a better understanding of research methodology and how this can be applied in the Ergonomics field.

Please note that if you feel that you need to withdraw from the study, you can do so at any stage. Should you have any questions regarding the study, please do not hesitate to contact the researcher. Thank you again for your participation, your assistance is greatly valued.

Yours sincerely
Nokubonga (SMA) Ngcamu
(MSc student – Department of Human Kinetics and Ergonomics)

RHODES UNIVERSITY

DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

INFORMED CONSENT FORM

SUBJECT CONSENT FORM

I,…………………………………….. having been fully informed of the research project entitled:

THE IMPACT OF (AWKWARD) WORKING POSTURES ON PRECISION PERFORMANCE

do hereby give my consent to act as a subject in the above named research.

I am fully aware of the procedures involved as well as the potential risks and benefits associated with my participation as explained to me verbally and in writing. In agreeing to participate in this research I waive any legal recourse against the researchers of Rhodes University, from any and all claims resulting from personal injuries sustained whilst partaking in the investigation. This waiver shall be binding upon my heirs and personal representatives.

I have read, and understood, the information sheet accompanying this form and any questions I had have been adequately addressed. I realise the importance of promptly reporting to the researchers any signs or symptoms indicating any abnormality or distress. I am aware that I may withdraw my consent and may withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and agree that all the information collected may be used and published for statistical or scientific purposes.

SUBJECT (OR LEGAL REPRESENTATIVE):

……………………….	……………………..	…………………
(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT:

………………………	……………………..	…………………..
(Print name)	(Signed)	(Date)

WITNESS:

………………………	………………………	…………………..
(Print name)	(Signed)	(Date)

B.2C: Order of proceedings

ORDER OF PROCEEDINGS

HABITUATION

1. Hand out "Information to subjects"
2. Explain what project is about and the procedure and answer questions
3. Hand out "Consent form" to be signed at the session
4. Do measurements

Measurement	Description
Mass	
Stature	Floor to vertex
Shoulder height/ Acromiale height	Floor to acromion process
Hip height/ Iliospinale height	Floor to iliac crest
Hip to shoulder height	Acromion to iliac crest
Sitting trunk height	Surface of seat to (suprasternal notch) acromion process
Arm length	Acromion process to styloid process

5. Go to room 30 to do stature and mass
6. Set dates for data collection

DATA COLLECTION

Before subject arrives

1. Make sure all equipment (EMG, HR, Precision task software) is working
2. Take out relevant data sheet making sure order of conditions is chosen
3. Mark all the subject relativised lengths on the screen stand and floor for all the conditions
4. Set up the workstation layout for the first condition and open and save the relevant task on software

When subject arrives

1. Summarise procedure
2. Attach HR monitor and electrodes
3. Do MVCs
4. Get reference HR
5. Check if all equipment is working
6. Start first condition
7. Subject rests while workstation is laid out for the following condition
8. After all conditions have been done, take electrodes and HR monitor off

Things to remember

- Markers for each condition on EMG
- Save HR files separately for each condition

ANTHOPOMETRIC DATA SHEET

Subject:	
Mass (kg)	
Stature (mm)	
Standing eye height (mm)	
Shoulder height (mm)	
Arm length (mm)	
Sitting eye height (mm)	
Hip height (mm)	

Subject: Reference HR: Real' Time switched **ON** EMG and HR:				Date: Real' Time switched **OFF** EMG and HR:				
		EMG and HR times		**Push force**		**Pull force**		
Condition	**Order**	**Start**	**Stop**	**Start**	**Stop**	**Start**	**Stop**	**Comments**
	Force							
	Hi prec							
	Low Prec							
	Force							
	Low prec							
	Hi Prec							
	Hi Prec							
	Force							
	Low prec							
	Hi prec							
	Low prec							
	Force							

B.3B: Data collection sheet

B.3C: Statistics analyses of muscle responses (non-significant results)

<u>TABLES FOR APPENDIX</u>

Biceps Brachii responses for high and low precision tasks

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization
Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	9328.919	1	9328.919	71.98974	0.000000
POSTURE	959.780	7	137.111	12.04558	0.000000
DIFFICUL	0.000	1	0.000	0.00118	0.972784
POSTURE*DIFFICUL	1.261	7	0.180	0.56864	0.781328

Anterior Deltoid responses for high and low precision tasks

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization
Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	95874.97	1	95874.97	434.1661	0.000000
POSTURE	18777.69	7	2682.53	132.9912	0.000000
DIFFICUL	1.83	1	1.83	1.0665	0.307031
POSTURE*DIFFICUL	6.53	7	0.93	1.0326	0.407926

Triceps brachii muscle responses for high and low precision tasks

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization
Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	7486.143	1	7486.143	77.32049	0.000000
POSTURE	601.892	7	85.985	18.17271	0.000000
DIFFICUL	0.119	1	0.119	0.11923	0.731413
POSTURE*DIFFICUL	5.438	7	0.777	1.25281	0.273364

Left Erector Spinae muscle responses for high and low precision tasks

Repeated Measures Analysis of Variance (Spreadsheet1) Sigma-restricted parameterization
Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	46055.06	1	46055.06	231.2408	0.000000
POSTURE	28019.15	7	4002.74	98.9783	0.000000
DIFFICUL	0.29	1	0.29	0.0375	0.847326
POSTURE*DIFFICUL	15.32	7	2.19	0.3098	0.949337

Right Erector Spinae muscle responses for high and low precision tasks

Repeated Measures Analysis of Variance (Spreadsheet1) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	73239.30	1	73239.30	364.2315	0.000000
POSTURE	32059.40	7	4579.91	121.1960	0.000000
DIFFICUL	0.85	1	0.85	0.1909	0.664198
POSTURE*DIFFICUL	9.40	7	1.34	0.2903	0.957524

Effect of posture and precision demands on HR responses

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	4967223	1	4967223	1828.612	0.000000
POSTURE	27477	7	3925	58.363	0.000000
DIFFICUL	7	1	7	0.847	0.362143
POSTURE*DIFFICUL	110	7	16	1.762	0.094271

Ratings of perceived exertion to precision tasks

Repeated Measures Analysis of Variance (Spreadsheet11) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	74536.92	1	74536.92	1971.068	0.000000
POSTURES	1017.81	7	145.40	40.993	0.000000
DIFFICUL	0.52	1	0.52	0.860	0.358602
POSTURES*DIFFICUL	3.25	7	0.46	0.769	0.614087

Effect of force tasks on brachioradialis activity

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	13983.39	1	13983.39	136.0481	0.000000
POSTURE	207.41	7	29.63	24.6872	0.000000
FORCE	1296.09	1	1296.09	79.7499	0.000000
POSTURE*FORCE	28.62	7	4.09	3.1211	0.003334

Biceps Brachii responses for pushing and pulling force tasks

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	12230.77	1	12230.77	114.8820	0.000000
POSTURE	1985.14	7	283.59	24.2275	0.000000
FORCE	26.89	1	26.89	7.6096	0.008246
POSTURE*FORCE	218.07	7	31.15	19.1598	0.000000

Anterior Deltoid responses for force tasks

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	46092.21	1	46092.21	271.8135	0.000000
POSTURE	12557.36	7	1793.91	135.4153	0.000000
FORCE	3483.98	1	3483.98	100.5631	0.000000
POSTURE*FORCE	1337.85	7	191.12	24.4511	0.000000

Trapezius muscle responses for force tasks

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	28350.68	1	28350.68	193.2864	0.000000
POSTURE	13127.67	7	1875.38	87.4968	0.000000
FORCE	443.86	1	443.86	44.2286	0.000000
POSTURE*FORCE	1042.67	7	148.95	29.8521	0.000000

Triceps brachii muscle responses for force tasks

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	5923.264	1	5923.264	98.44354	0.000000
POSTURE	1525.605	7	217.944	52.17119	0.000000
FORCE	11.943	1	11.943	4.14264	0.047476
POSTURE*FORCE	22.032	7	3.147	4.65055	0.000055

Posterior deltoid muscle responses for force tasks

Repeated Measures Analysis of Variance (All subject data) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	7476.705	1	7476.705	111.8971	0.000000
POSTURE	4157.599	7	593.943	65.4426	0.000000
FORCE	554.260	1	554.260	52.6868	0.000000
POSTURE*FORCE	54.371	7	7.767	4.3784	0.000116

Left Erector Spinae muscle responses for force tasks

Repeated Measures Analysis of Variance (Spreadsheet1) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	61493.21	1	61493.21	245.8007	0.000000
POSTURE	27769.83	7	3967.12	84.5651	0.000000
FORCE	4.45	1	4.45	0.8454	0.362542
POSTURE*FORCE	15.07	7	2.15	0.4364	0.879034

Right Erector Spinae muscle responses for force tasks

Repeated Measures Analysis of Variance (Spreadsheet1) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	82889.18	1	82889.18	324.3202	0.000000
POSTURE	29156.50	7	4165.21	89.7609	0.000000
FORCE	5.85	1	5.85	0.9797	0.327340
POSTURE*FORCE	20.47	7	2.92	0.5598	0.788382

Ratings of perceived exertion to force tasks

Repeated Measures Analysis of Variance (Spreadsheet11) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	Degr. of - Freedom	MS	F	p
Intercept	84357.29	1	84357.29	1745.532	0.000000
POSTURE	1206.78	7	172.40	43.033	0.000000
FORCE	0.57	1	0.57	3.545	0.065927
POSTURE*FORCE	0.08	7	0.01	0.737	0.640622