THE EFFECTS OF CONTROL DESIGN AND WORKING POSTURE ON STRENGTH AND WORK OUTPUT:

AN ISOKINETIC INVESTIGATION.

BY

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THESIS

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ABSTRACT

The objective of the present study was to assess the isokinetic, cardiovascular and psychophysical responses of young adult males (N=30) during valve turning exercises. It aimed to evaluate the variables in relation to changes in control design and working posture. Isokinetic testing and ergonomics have not been widely linked and it was an aim of this study to show the advantages to the field of ergonomics. Furthermore, the “work-simulation” package used in the present study has not been widely exploited and it was believed that this study could thus contribute significantly to the literature.

Testing was carried out using a CYBEX ® 6000 isokinetic dynamometer, a polar heart watch, an Omron M1 semi-automatic blood pressure monitor and various perceptual rating scales. Testing involved the subjects having to perform 4 maximal turning efforts in 18 different conditions. These conditions were made up by using 6 different control designs in 3 varying positions. Subjects were required to attend two sessions, each approximately one hour long, in which nine randomised conditions were tested in each session. During these sessions, isokinetic responses: peak torque (Nm), total work (J) and average power (W); cardiovascular responses: heart rate (bt.min^{-1}) and blood pressure (mmHg); and psychophysical responses: RPE and discomfort, were observed. The results of the tests showed that in general significant differences were encountered for isokinetic, cardiovascular and psychophysical responses in relation to changes in the control design. However, significant differences were far less evident, and in most cases non existent, in relation to changes in the spatial orientation of the control types. The essence being that operator position with respect to the control is not as crucial as the control design.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

In all spheres of human existence, movement is the primary activity; it is essential in maintaining good health and well being, and is the basic means of *Homo sapiens'* interaction with the environment. Performance involves muscular work, the result of a series of complex phenomena in response to sensory input, initiated by information processing within the central nervous system. Physical labour usually involves movement of the body and/or parts of the body, relocation or transportation of external objects and sustained postures in various positions (Kilbom, 1990). All three contribute to the operators' manipulation of the environment in order to achieve a desired result.

Most descriptions of ergonomics relate to the interface between human operators and the tools they are working with. Humans and machines are competent workers when seen as separate entities, but it is the interface of the two that is vitally important in industry (Oborne, 1989), and is the essence of ergonomics. In the working environment, where the worker is associated directly or indirectly with a range of technologies, it is important to realise that output and productivity will be enhanced if the man-machine interface is compatible (Drury, 1985; Bridger and Poluta, 1998). In the cases where the interface is not compatible manual work can be emotionally and physically exhausting. Bridger and Jaros (1986) advanced the concept of an Ergosystem; that which emphasises the crucial interaction between the human operator, the machine and the work environment. The level of compatibility between operator and machine is often influenced by the design of the machine as it affects the working posture of the operator. Kroemer and Grandjean (1997) emphasised the need for "natural" working postures:

> *Since natural postures – attitudes of the trunk, arms, and legs which do not involve static effort – and natural movements are a necessary part of efficient work, it is essential that the workplace should be suited to the body size and mobility of the operator. (Kroemer and Grandjean, 1997; p135)*

Various tools and implements facilitating working conditions have assisted humans in altering the environment. This is as evident for the fire-starting implements of the Neanderthals as it is for the sophisticated microchips of modern man. In certain industries the manipulation of controls, knobs, wheels and valves are common practices. In Ergonomics, working posture and control design fundamentally influence the point-force workers are able to exert and the work outputs that they are able to accomplish.

All manipulations of controls require some level of strength. This applies to simply flipping a switch as much as it does to the brute strength required to budge a locked wheel valve. The strength that a person is able to exert in performing a given task is influenced by the posture the operator adopts and this in turn is governed by the design of the equipment. Often poor design of the worksite results in workers having to adopt awkward postures in which not only strength is severely limited, but the operators may also be put at an increased risk of injury, particularly where forceful or repetitive work is required (Haselgrave **et al.,** 1997). However, this is no new problem, for in 1713 Ramizzini noted that “violent motions” of harvesters working in the fields resulted in occupational injuries. The enormity of the predicament is such that although the problem has existed for centuries and researched profusely, it is, in practice, ignored.

After World War II there was a major surge towards automation, which was anticipated would put an end to repetitive work. However, though repetitive work decreased in certain areas, in other domains it remained, and in many situations actually increased (Trist **et al.,** 1963; Emery and Thorsud, 1976; Salvendy and Smith, 1981). This is especially true of under-developed countries where manual labour is abundant and organised technology transference is limited. The result is often that workers have to compromise natural work postures to carry out a repetitive activity in the execution of the required task. This is essentially due to the fact that automation is expensive to implement and labour is cheap in the Industrially Developing Countries (IDCs). Consequently working conditions are compromised (Kuorinka, 1995). With the introduction of ergonomic input, awareness of such exploitation has highlighted the haphazard way in which workers (often with unsuitable tools and equipment) have been thrown into inappropriate working environments (Fraser, 1989).

Awkward working postures are typical of numerous working conditions and there are countless examples of workers having to bend over, reach around, reach under, or work above their heads in order to reach machine controls. Any protracted sub-optimal postures will result in the worker experiencing abnormal fatigue levels and being exposed to increased risks of cumulative trauma disorders (CTDs). The positioning of controls is therefore an important factor in determining whether a worksite is optimal. A sub-optimally positioned control will severely limit strength expression, placing the worker under stress to achieve the required result (Haselgrave, 1994).

Ergonomic intervention is essential in identifying these problems. It can play a significant role in the design of workstations that are less awkward and that optimise the interaction between operators and their physical surroundings (Bridger, 1995). Ergonomic design takes the abilities of the human operator into account in order to ensure the safety and general well-being of the worker, while at the same time promoting system efficiency and improved work output. Ultimately worker well-being and increased job satisfaction will have a positive effect on people and their productivity (Zalewska, 1999). In order to obtain compatibility within the work-site, it must be well designed with readily accessible controls, easily manipulated by the operator. Controls are the interface through which human-machine information flow occurs; poorly designed controls can lead to a breakdown in the “man-machine” system (Bridger, 1995). Several factors require consideration before an effective control system may be designed that will accommodate operator expectations, abilities and behavioural responses. In the present study the effects of control design and working posture are seen as critical factors.

Tasks should be analysed to determine the degree of precision, force, accuracy and manipulation required; features that should be compatible with the operator's abilities to carry out such tasks. If abilities do not match requirements, changes in the mechanical parts of the system have to be considered (Oborne, 1989). These changes include investigating control design, i.e. shape and size, and particularly positioning of controls. These are important ergonomic considerations when designing or appraising any workplace. Ignoring these ergonomic considerations could result in sub-optimal working conditions. This is due to the fact that the position and design of hand controls in industry have an effect on the efficiency of performance of human operators. A further concern is that the design and positioning of controls may force the operator to work in unnatural, uncomfortable positions, sometimes for an extended period of time. This may eventually lead to accidents and injuries; commonly cumulative trauma disorders such as carpal tunnel syndrome, epicondylitis and tenosynovitis (Chumbley **et al.,** 2000). A rigorous study of the literature by Stock (1991) uncovered a strong relationship between repetitious, forceful work and the development of tendon and nerve entrapment disorders of the upper extremities. Earlier, in 1986, a study by Silverstein and associates yielded similar findings, demonstrating a direct correlation between the occurrence of hand/wrist cumulative trauma disorders and "high force-high repetition" jobs.

STATEMENT OF THE PROBLEM

Awkward working postures and poorly designed controls are ubiquitous in industry, particularly in the less-developed industries within IDCs. In many of the older workplaces valves are of the wheel-type (Figure 1), not Lever-type as used in more modern industrial sites (Figure 2). In certain instances the positioning and design of control valves create problems: they are often poorly situated and incorrectly used.

FIGURE 1: Wheel control in industry.

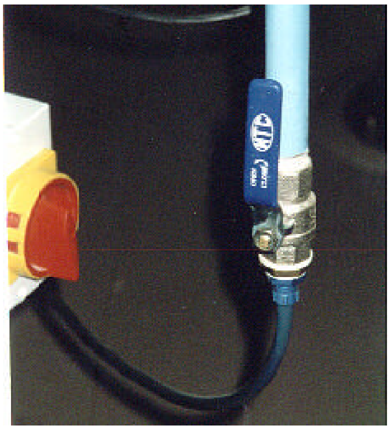

FIGURE 2: Lever control in industry.

The purpose of the present study was to investigate the way in which design and positioning of controls affects the output of the human operator. The question asked was whether changing position and/or design of the control would have an effect on strength expression and work output of the operator. Therefore the use if isokinetics was crucial as this provided valuable information about the torque, power and work output of the operator during the various testing conditions. The rationale being that the design and positioning of the controls would influence the isokinetic responses. In addition certain physiological responses were measured, namely heart rate and blood pressure. Due to the nature of isokinetic testing, marked changes were not expected in the physiological responses. However, the valsalva manoeuvre during heavy lifting was thought to play a certain role in these specific turning tasks, thereby eliciting small changes in various physiological parameters. In order to evaluate worker preferences, psychophysical assessments were included in the form of perceived exertion and discomfort ratings.

The specific problem was therefore twofold, involving:

1) The design component: to investigate performance outputs when the design of the control is altered, i.e. the type and/or size of the control.

2) The posture and position component: to determine whether or not changing the position of controls (i.e. man-machine orientation) will significantly affect performances.

RESEARCH HYPOTHESIS

Control position and design will influence the forces which operators are able to exert and consequently the quality of their performances.

STATISTICAL HYPOTHESES

H_o1 (a): $\mu I_1 = \mu I_2 = \mu I_3$ (regardless of control design)

H_a1 (a): $\mu I_1 \neq \mu I_2 \neq \mu I_3$

H_o1 (b): $\mu I_a = \mu I_b = \mu I_c = \mu I_d = \mu I_e = \mu I_f$ (regardless of spatial orientation)

H_a1 (b): $\mu I_a \neq \mu I_b \neq \mu I_c \neq \mu I_d \neq \mu I_e \neq \mu I_f$

Where: I reflects selected isokinetic responses (torque; work; power);

subscripts 1; 2; 3 reflect spatial orientations of controls (0º; 45º; 90º respectively); subscripts a to f reflect control design as follows. (a) large Knob-type control; (b) large Lever-type control; (c) medium Knob-type control; (d) medium Lever-type control; (e) small Knob-type control; (f) small Lever-type control.

H_o2 (a): $\mu C_1 = \mu C_2 = \mu C_3$ (regardless of control design)

H_a2 (a): $\mu C_1 \neq \mu C_2 \neq \mu C_3$

H_o2 (b): $\mu C_a = \mu C_b = \mu C_c = \mu C_d = \mu C_e = \mu C_f$ (regardless of spatial orientation)

H_a2 (b): $\mu C_a \neq \mu C_b \neq \mu C_c \neq \mu C_d \neq \mu C_e \neq \mu C_f$

Where: C reflects selected cardiac responses (heart rate; blood pressure)

H_o3 (a): $\mu P_1 = \mu P_2 = \mu P_3$ (regardless of control design)

H_a3 (a): $\mu P_1 \neq \mu P_2 \neq \mu P_3$

H_o3 (b): $\mu P_a = \mu P_b = \mu P_c = \mu P_d = \mu P_e = \mu P_f$ (regardless of spatial orientation)

H_a3 (b): $\mu P_a \neq \mu P_b \neq \mu P_c \neq \mu P_d \neq \mu P_e \neq \mu P_f$

Where: P reflects selected psychophysical responses [rate of perceived exertion (RPE); localised perceived discomfort (LPD); overall perceived discomfort (OPD)].

DELIMITATIONS

Right-hand dominant young adult students from Rhodes University were canvassed for participation in the study. In order to obliterate the effects of sex and age, the sample was delimited to males aged 18-28 years, without clinical histories of upper body injuries.

Investigation into the responses of the work-simulated tasks on the CYBEX ® 6000 involved the use of selected work simulated controls and positions. Subjects (n=30) were required to attend two one-hour testing sessions, one week apart. This was done in an attempt to minimise the effects of fatigue and to optimise motivation.

LIMITATIONS

At all times every effort was made to ensure rigorous control. However, the following factors could be seen as limitations on the study, which are beyond the control of the tester. These factors are:

1. Subjects were approached with an explanation of the study and the requirements, and were asked to participate. The project therefore dealt with a sample of convenience. Willing undergraduates of Rhodes University are not representative of the industrial workers. However, the size of the sample (n=30) was seen as contributing to reducing the negative influences.
2. The use of psychophysical category scales assumes that subjects have understood the verbal and written explanations provided and responded honestly. This assumption carries less assurance than is possible from purely physical responses.
3. Other than verbal assurances, no control was had over changes in the eating, sleeping, exercising and drinking habits of the subjects during the week lay-off between testing sessions.

CHAPTER II

REVIEW OF LITERATURE

INTRODUCTION

In the present study ergonomics is seen as the practise of fitting the task to the worker, not the worker to the task. In reality aims of this sort, such as that proposed by Pheasant (1995), are rarely implemented, as many industries do not follow even basic ergonomic principles. One reason for this is that interactions between ergonomists and engineers are comparatively rare and ergonomics is seen as a frill in the world of engineering design (Burns and Vincente, 2000). The ability of humans to adapt to varying situations is a great strength. However, this ability can cause untold damage as humans are often forced to adapt to poor working conditions and thereby are at risk. These adaptations can be seen as the cause of numerous injuries when using hand tools and manipulating the working environment (Aghazadeh and Mital, 1987).

Investigation of working posture is a vital ergonomic component of the overall assessment of working conditions. However, postural assessments are hardly ever conducted at the worksite and on the rare occasions when they are, the work durations assessed are usually insufficient (Oborne, 1995). This lack of workplace assessments makes it difficult to determine optimal working postures or to prevent hazardous working postures (Salvendy and Smith, 1981). Many companies, particularly in IDCs, see ergonomic interventions as a waste of time and money, and therefore do not implement them. Others are simply ignorant of the concept of ergonomic intervention and of the benefits it can bring (Pheasant, 1995; Bridger and Poluta, 1998). However, for companies that do implement ergonomic strategies the rewards may be great. For example, McNeil and Westby (1999) conducted an ergonomic evaluation of a manually operated cassava-chipping machine in Ghana. Cassava is an important food crop that has recently been seen as an important income-generator due to the exportation of cassava chips as animal feed. The machine used to make cassava chips exacerbated drudgery and postural discomfort. A new prototype machine was developed to accommodate user anthropometric profiles. The outcome was reduced discomfort and physiological strain, and a faster work rate. This example demonstrates how ergonomics can play a role in improving working conditions within the industrially developing world. However, these benefits are not only relevant to the IDCs, but also the industrially developed world in the form of increased job satisfaction, which arguably may lead to improved labour relations and in the long run improved productivity (Zalewska, 1999).

The human operator may be seen as a system that generates purposeful muscular activity by converting chemical energy into mechanical energy (Bonjer, 1973). Some muscular work is encountered in almost all types of human endeavour, even in sedentary occupations. In Western society the trend has been to attempt to eliminate all physically demanding activities from the working environment. This may be plausible in a First World situation, but would definitely not work in any poorly mechanised occupational ambiences. For example, in Mexico it has been reported that manual controls are sometimes preferred over automation as manufacturing costs are kept to a minimum (Lara-Lopez **et al.,** 1999).

The purpose of the present study was to investigate the strength workers are able to exert in operating wheel or Lever-type controls situated in various positions. As the positioning of these controls dictates the working posture adopted, it can be assumed that work output would also be affected (Charteris and Dirkse van Schalkwyk, 1999). It could be argued, therefore, that workers who are required to increase output while working in awkward postures would be putting themselves at higher risk of injury (Fransson and Winkel, 1991). This sentiment is echoed by Arokoski **et al.** (1998), who investigated the strain placed on hairdressers at work, where unsupported raised work arms placed strain on the shoulder girdle, contributing to musculoskeletal fatigue during long workdays. On assembly lines the same problem exists if assembly line workers assume elevated unsupported arm positions. Muscular strain over protracted periods and increased risk of injury are the likely results (Feng **et al.,** 1999). Movements in awkward working postures are identified as high risk factors for developing cumulative trauma injuries in industrial tasks (Kuorinka and Forcier, 1994; Stal **et al.,** 1999). The risk of injury in the workplace is a major ergonomic concern, and is a problem which can be prevented through implementation of sound ergonomic principles.

DESIGN OF CONTROLS

Controls are obviously designed to serve a specific function. A large control is consistent with a strength requirement, while a smaller control will be used for fine manipulative functions (Drury, 1995; Oborne, 1995; Mac Duff **et al.,** 1997). Numerous other authors support these sentiments. However, the literature is fairly sparse on different control types being used during isokinetic dynamometry work simulation testing. Control characteristics need to be compatible with the abilities of the human operator. These characteristics include size, shape, weight, texture and, to a lesser extent, control resistance as a feedback cue. Kinesthetic feedback from the muscles works in conjunction with any visual, auditory and/or tactile feedback loops, allowing the worker the opportunity to get a feeling for the correct action (Oborne, 1995). In the case of a control with inappropriate characteristics, the result may be undue stress on the worker which can lead to cumulative trauma disorders (CTDs), or even acute injuries (Oborne, 1995; Psacarelli, 1997). In a more drastic case of poor control design, three Russian cosmonauts were killed, during 1971, while trying to close a valve control which was letting oxygen escape from the space capsule (Casey, 1993). Investigators later determined that the emergency circular control-valve that had been designed for this type of emergency would have required another full minute of turning for it to be completely closed. Casey (1993) argued that the precise conditions under which the control had to be used were not considered during design and reconstruction. In the event of a valve having to be opened or closed quickly in an emergency, the type of control being used is vitally important. A lever type control-valve, which opens and closes with a quarter turn, might have been the answer to saving the lives of the Russian cosmonauts.

Size, Shape and Texture of Controls

Size

The dimensions of a control should be related to anthropometric dimensions of the limbs used (Haselgrave, 1994; Oborne 1995). Grip size should be related to the function for which it is required; for instance a delicate manipulative function would require a smaller fine tuning control-type than would a forceful action (Fransson and Winkel, 1991; Milerad and Ericson, 1994; Fleming **et al.,** 1997). The problem is that very often these controls are situated in awkward positions and the required force is thus difficult to generate. The outcome of having to exert force beyond safety limits is that the risk of physical strain increases (Van Wely, 1970; Anderson, 1971; Westgaard and Aarås, 1984). Related to size is the weight of control; a heavier control may be more difficult to turn forcefully or more difficult, because of its mass, to fine tune (Oborne, 1995). Clearly grip diameter is crucial as it determines the nature of forceful action on one hand and fine manipulation on the other.

Shape

Surprisingly little research appears to have been conducted to determine the role that control shape plays in the performance of the operator. In one study it was reported that circular grips are more prevalent as these allow the little and ring fingers to contribute materially to the total force exerted (Kinoshita **et al.,** 1996). Larger “knobs,” with a “wheel-like” appearance, such as those that operate valves, are the most reliable. This is because in any situation which allows the operator to use two hands instead of one, there will obviously be a substantial improvement in the grip strength (Drury, 1983; Fransson and Winkel, 1991; Woldstad **et al.,** 1995). The same applies if the control allows workers to use the whole upper extremity forcefully, as in lever handles, as opposed to circular valves, which may only allow the use of the wrist.

The movement of the hands while engaging a control is an important factor. If control rotation exceeds 120° the operator should be allowed to break the hand-control coupling in order complete the rotation (Ashby, 1978). If the design of a knob or lever does not allow for movement of the hands then the movement pattern, and the resulting force, will be affected within certain ranges of motion; generally force of rotations to the right or left will vary depending on hand dominance (Woldstad **et al.,** 1995). If the control allows workers to use both hands then the force will be that much greater, with less strain being experienced by the operator.

Texture

The texture (feel) of the control serves as the interface between the machine and the operator and forms part of the feedback loop (Oborne, 1995). It can thus be seen as relaying information about the control to the operator and thereby determining the outcome of the final action. Mismatched textures have been implicated in various injuries, especially those related to overuse (Drury, 1986; Frievalds, 1987). In other instances injuries may take the form of abrasions, blisters or cuts from the sharp or rough edges on the controls (Frievalds, 1987). Ergosense, a computer software programme developed by the Biomechanics Corporation of America (1995), has advocated that smooth surfaces tend to cause people to over-grip in order to obtain the same pressure or force as they would with a rough surface. These seemingly contradictory statements show the difficulties that ergonomists and engineers face when they try to design a control to meet all criteria. The essence is that the texture will influence the type of grip a worker uses, which in turn will influence the force the worker is able to exert (Frievalds, 1987).

HUMAN CHARATERISTICS

Dimensions of the human body have always been a source of interest and there is substantial literature on the topic. Anthropometric measures have been made of almost every conceivable morphological attribute, as depicted by Pheasant (1995) in his book, Bodyspace. Ironically these data are hardly ever used in the design process due to the lack of communication between ergonomists and engineers. Design would be facilitated if empirical data were used in the design of machinery (Pheasant, 1995). In far too many instances the empirical data is used incorrectly. It is used to facilitate designing a workstation for the “average” person. Vasu and Mital (2000) point out that it is faulty to assume that if a person falls into a certain percentile for stature then their other characteristics fall into the same percentile. Human variability is a challenge when designing any worksite as a workstation designed exclusively for a person with all “average” anthropometric dimensions will still lead to awkward working postures as body dimensions are not always equally distributed (Vasu and Mital, 2000). Therefore databases in design should be used to cater for a range of people and thus accommodate human variability (Pheasant, 1995). Engineers need to take cognisance of the size, shape and proportions of the workers operating machinery (Haselgrave, 1994; Pheasant, 1995; Vasu and Mital, 2000).

In industry, work that requires strength almost always seems to go to the larger person. Intuitively it is assumed that bigger people are absolutely stronger due to their larger muscle bulk (Charteris and Dirkse van Schalkwyk, 1999). However, this type of sweeping generalisation does not take into account the workspace the operator is using. In a small workspace of finite dimensions a smaller worker would be less confined than a bigger worker and therefore in all probability be able to move more freely and exert more force (Haselgrave **et al.,** 1997; Charteris and Dirkse van Schalkwyk, 1999). The size of the worker needs to be suited to the job as larger people cannot be assumed to be absolutely stronger than smaller counterparts in all working situations (Oborne, 1995; Charteris and Dirkse van Schalkwyk, 1999).

Strength

Strength is a complex phenomenon as there are numerous types of strength and consequently various measuring techniques. Therefore, it follows that the literature has copious different definitions of strength. Perrin (1993) defines strength as the ability to exert a force against a resistance. This is a simplified version of the definition used by Sale (1991*),* who defined strength as the peak force (newtons) or torque (newton meters) developed during a maximal voluntary contraction (MVC) under any given set of circumstances. Kroemer and Marras (1971*)* had earlier defined strength as: " the maximal force muscles can exert isometrically in a single, voluntary effort". However, this definition uses the term "isometric" which means that the length of the muscles does not change. In a working situation isometric contractions would be very rare, if they exist at all, as most types of work involve dynamic action. In defining strength, Mital and Kumar (1998) support Kroemer and Marras (1971) and Sale (1991), and define strength as a primary measure of an individual's physical capabilities, particularly those allowing the individual to sustain an external load. However, Mital and Kumar (1998) claim the sustaining of the external load must occur without inflicting any injury on the individual. This is the essence of ergonomics, as the working environment needs to be manipulated by the operators without the operators being harmed. Strength must therefore be seen as relative to the specific individual and relative to the task (Laubach and McConville, 1969; Woldstad **et al.,** 1995; Mital and Kumar, 1998; Nielson **et al.,** 1998).

In the world of sport it is very simple to quantify strength in terms of ability as to who can pick up the heaviest weights or throw a specified weight the furthest. A larger person may be able to lift a heavier weight, but when the force per kilogram is calculated, then large and small persons may be of equal relative strength. Matthews (1995) demonstrated the point by quoting from the 1996 Guinness Book of Records: in the men's weight-lifting section Halil Mutlu lifted a total of 290kg. His mass was 54kg. He therefore lifted 5.37 times his body weight. Aleksandr Kurlovich (at 108kg) lifted a total of 457.5kg, therefore, only managing 4.24 times his body weight.

In a working situation "strength" is not meaningfully related to a once-off maximal effort, but rather to capacity to exert some sub-maximal level(s) of tension over an eight hour shift. This type of sustained strength is the fundamental basis for movement in the working environment and is a performance component of daily life tasks (Richards, 1997). Strength is a complex phenomenon with many contributing factors, and many studies have been done to establish strength databases for the purpose of screening and to establish factors influencing strength (Keyserling **et al.,** 1980; Chaffin **et al.,** 1983; Mital and Das, 1987; Ruhmann and Schmidkte, 1989; Kumar, 1991; Kumar and Garand, 1992).

Although age and gender determine the strength abilities of a worker, the working posture adopted is still the major influencing factor (Woldstad **et al.,** 1995). This is emphasised by Haselgrave (1994) in a study in which she demonstrated that posture can lead to limitations in the range of motion, which in turn leads to strength decrements. Optimal working conditions are essential in eliminating strength decrements, for example, dorsal or palmar flexion exceeding 45° has been identified as unsuitable as it limits the strength a worker is able to exert (Stetson **et al.,** 1991; Armstrong, 1983; Punnet and Keyserling, 1987; Stal **et al.,** 1996; Stal **et al.,** 1999). In a study on force application to large hand wheels the results differed from previous studies as the subjects tended to adopt varying postures when executing the task (Woldstad **et al.,** 1995). However, Richards (1997) found that the grip strength of seated subjects was equivalent to the grip strength of the same subjects when they were in a supine position. Richards' (1997) findings are similar to those of Teraoka (1979) and Martin **et al.,** (1984). However, these findings are not new; it was indicated more than three decades ago that while posture affects strength in certain cases, in others it does not (Laubach and McConville, 1969). The study by Charteris and Dirkse van Schalkwyk (1999) showed that larger men could in fact be weaker than smaller men depending on the workspace design. This is in agreement with Pheasant (1986), who argued that for practical purposes questions of strength expression are almost always questions of posture adapted in order to express that strength. Haselgrave **et al.** (1997) emphasised that workplace posture may actually negatively impact on the ability of the worker to produce a force. It is thus abundantly clear that strength is affected by posture and therefore it can be affected by the method of testing.

However, strength expression is not only a physical phenomenon but is also influenced by psychological factors, as is the case of working from past experience and the amount of motivation involved (Ikai and Steinhaus, 1961; Kroemer and Marras, 1971; Asmussen and Mazin, 1978).

Cardiac Responses

In the field of research on isokinetic dynamometry, use of the work-simulation package is limited and inclusion of cardiac and psychophysical responses during this type of investigation adds to the contribution that this project can offer in an important area of research.

The Valsalva Manoeuvre is experienced during the execution of a task that requires a rapid and maximum application of force for a short period of time. This is very common in sports such as weight lifting and is often also experienced in the work place during manual materials handling (MMH). In the present study the subjects were not required to lift any objects, but rather required to produce maximal force in the turning of control valves. It is hypothesised that this task would elicit similar responses in respiration which in turn would reflect in the cardiac responses.

During the completion of a task which involves the Valsalva Manoeuvre, the glottis is closed and hence no breathing takes place (McArdle **et al.,** 1996). This action has significant effects as the minute ventilation is decreased, so when the subject releases the breath hold and breathes again, the resting tidal volume of

0.5 l of air and breathing frequency of 12 $bt.min^{-1}$ can be expected to be significantly increased in order to re-establish the resting minute ventilation (McArdle **et al.,** 1996), all of which will affect other physiological responses i.e. heart rate and blood pressure.

Heart Rate

The cardiac muscle, as opposed to any other muscle, has the ability to maintain its own rhythm. This normal rate of 70 to 80 times a minute can be influenced by numerous factors, including anticipation of an event and the type and intensity of exercise. It is well documented that heart rate increases with increasing oxygen uptake during arm and leg exercise (Pendergast, 1989; Aminoff **et al.,** 1998). However, maximum heart rate is significantly lower in arm exercise (McArdle **et al.,** 1996). In the present study subjects were required to work for a short period using the small muscle groups of one arm, which was unlikely to have a substantial effect on heart rate. However, if during the execution of the task the Valsalva Manoeuvre was used, resulting in the glottis being closed, no breathing would take place and the heart rate would slow (McArdle **et al.,** 1996). This bradycardial effect during the execution of the task would then reverse as soon as the task is completed and the subject breathes normally again.

Blood Pressure

At rest systolic blood pressure is usually 120 mmHg and diastolic 70 to 80 mmHg. At a given percentage of maximal oxygen uptake systolic and diastolic blood pressure is considerably higher for exercise involving the arms rather than the legs (Miles **et al.,** 1989; Pendergast, 1989; Toner **et al.,** 1990; Aminoff **et al.,** 1998). The smaller muscle mass and vasculature of the arms offers more resistance than the larger muscle mass and vasculature of the legs. McArdle **et al.** (1991) stated that upper body exercise represents greater cardiovascular strain as the heart has to work harder and such exercises should thus be avoided in cases which involve people with cardiovascular dysfunctions. This statement holds true in a working environment where people with cardiovascular dysfunctions are called on to lift heavy objects or turn heavy valves. It is important to note that in a work situation the strain of heavy lifting and arm work is often of very short durations, but highly repetitive. Even during a short period of strain, the involuntary action of a Valsalva Manoeuvre occurs when trying to elicit maximum effort during the lifting or tuning of the valve. According McArdle **et al.** (1991) the Valsalva Manoeuvre significantly reduces the return of blood to the heart because of the increased intrathoracic pressure collapsing the vein that passes through the chest cavity, the response being a considerable increase in the systolic blood pressure.

Gripping Action

As previously mentioned, the characteristics of the control and/or the requirements of the task determine the type of grip a worker takes. Sequentially the gripping action that workers use will govern the strength that they are able to exert. Fransson and Winkel (1991) investigated two types of grips; the traditional and the reverse grips. The traditional grip was seen as the gripping of a wrench with the hand over the top of the handles and the reverse grip with the hand gripping from underneath the handles. They found that the traditional grip facilitated greater force production than the reverse grip. Therefore in a task requiring a large amount of force the traditional grip was used even if it is uncomfortable in a specific situation. If a forceful grip is required then the body will need to be positioned in such a way as to take most advantage from major muscle groups, body weight and the interface with the equipment (Haselgrave, 1994). It is evident that in the design of a control one has to take cognisance of many factors in order to optimise the interface between the equipment and the human (Bridger and Poluta, 1998; Kroemer and Grandjean, 1997; Grandjean, 1998).

ERGONOMICS OF WORKING POSTURES

The importance of understanding posture has long been at the forefront of ergonomic considerations. In the early 1700s Ramazzini (1713) had already seen the need to develop a natural working posture to combat the "certain violent and irregular motions and unnatural postures of the body".

Haselgrave (1994) argued that posture has no clear definition in ergonomics due to its ever-changing status. There are many functional aspects of posture and Corlett (1981) defines it as "the position adopted because it is appropriate for the task being performed". Corlett emphasised that an inappropriate posture could lead to postural stress, fatigue and pain, all of which may force the worker to abandon the specific task. Westgaard and Aarås (1984) supported Corlett (1981) and suggested that inappropriate loads on muscles and joints can in the long-term lead to cumulative physiological changes and injury. It is these types of findings and studies that have led ergonomists to understand the crucial role that working postures play and to reflect on the meaning of fundamental “natural” working postures in the context of the working environment. However, optimal working postures are rarely achieved as numerous factors are involved in the compilation of a “perfectly natural” working posture. These factors include preferred viewing angle (Grandjean, 1998); comfortable head position when performing long-duration tasks (Chaffin, 1973); endurance for elevated arm postures (Chaffin, 1973); and comfortable ranges of joint angles when seated (Rebiffe, 1967). All these factors are essential in helping ergonomists assess various workspace designs. However, they do not help in predicting the posture a worker will adopt. The simple reason for this is that the body link system is very complex and unlike an engineering construction, many alternative postures are possible for any given situation (Haselgrave, 1994). This is because posture is not only about a body in space, but also about the forces that the muscles are imposing in order to maintain position and balance, and about the duration of the exposure to the specific environment (Haselgrave, 1994). In order for the muscles to maintain position and balance, strength is required. Workers who are involved in the turning of knobs or levers, or any task that requires strength, will adopt a posture that allows them to exert the required amount of strength with the least amount of exertion. While posture is affected by many circumstances, it in turn will also affect numerous factors. As mentioned earlier, Haselgrave (1994) has shown how a working posture can lead to anatomical restrictions within a specific workspace. These anatomical restrictions limit the range of motion thereby decreasing the potential forces exerted and placing the worker at an increased risk of injury (Corlett **et al.,** 1986).

It is well established that dynamic strength is significantly affected by the posture adopted (Pytel and Kamon, 1981; Kroemer, 1983,1985; Kumar and Chaffin, 1985; Grieve, 1984; Marras, 1985; Mital **et al.,** 1986a, 1986b, 1986c, 1987; Kumar **et al.,** 1988; Mital and Genaidy, 1989; Mital and Faard, 1990; Kumar, 1991; Kumar and Garand, 1992). However, the above are all artificially restricted studies and detailed *in situ* studies of postural effects on dynamic strength are few (Mital and Genaidy, 1989; Mital and Faard, 1990). Mital and Faard (1990) demonstrated that standing subjects were able to exert more force in the horizontal plane than seated subjects (see Figure 3), a finding supported by Woldstad **et al.** (1995) in a study on forces applied to large hand-wheels. All their subjects chose to use a standing posture rather than a seated one, as there was a perception that standing postures offer more leverage. Haselgrave (1994) and Oborne (1995) agreed with this, and Mital and Kumar (1998) showed that subjects were able to exert on average 37% more force when standing than when seated.

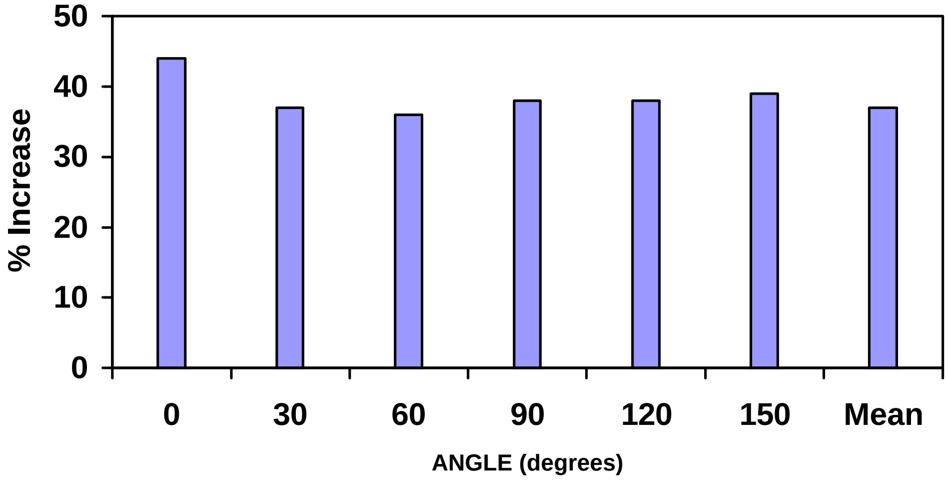

FIGURE 3: Percentage increases of standing over seated peak pull strengths at varying angles, in the longitudinal plane (Adapted from Mital and Faard, 1990).

In work requiring control manipulation, whether for strength or fine-tuning, the positioning of the controls is crucial. The more awkward the position of the control the more awkward will be the posture of the worker. If workers are expected to exert a force, the strength of that force will decrease as the awkwardness of the position increases. Similarly, the manipulative accuracy of the workers will decrease with an increase in the awkwardness of the posture. This would also be the case when the distance between the operator and the control is increased. The increased reach would result in an increased awkwardness and thus a decrease in the strength and manipulative ability of the worker (Mital and Kumar, 1998; Mital and Faard, 1990). Mital and Faard (1990) argued that the increased reach would significantly alter the natural working posture. An increased reach distance would prompt the worker to use a standing posture instead of a seated one, in order to elicit a forceful exertion (see Figure 4).

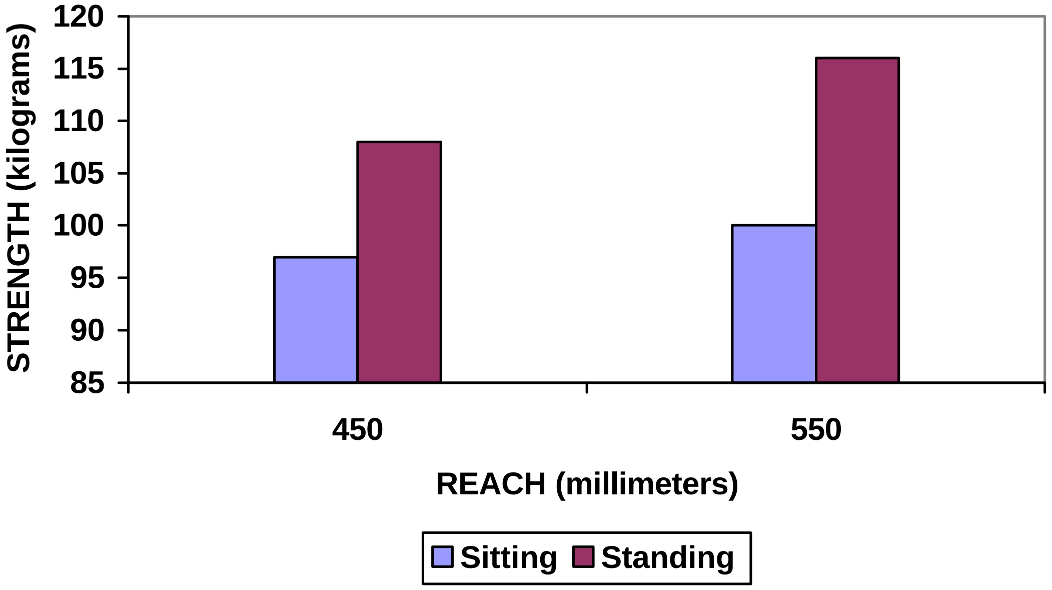

FIGURE 4: Effect of reach distances on pull strength in the horizontal plane for seated and standing subjects (Adapted from Mital and Faard, 1990).

In a recent study by Meyer **et al.** (2000) they reported that the position of the large wheel controls did not significantly influence the power output produced. The reason for this could be that the study conducted by Meyer **et al.** (2000) did not vary the testing positions and in all these positions the workers were comfortable and did not experience severe awkwardness of posture.

Awkward postures could alter the natural orientation of the wrist and hand, thereby altering mechanical advantage when exerting a force (Rebiffe, 1967; Chaffin, 1973; Oborne, 1995; Grandjean, 1998; Mital and Kumar, 1998). Mital and Kumar (1998) showed that wrist orientation is critical and that 70% more torque is generated when wrenches were held in the horizontal plane as opposed to the vertical plane.

The overall design of the work place is important as it is here that the positioning of the controls is determined (Bridger and Poluta, 1998). The provision of a natural working posture is fundamental to the design of work places (Haselgrave, 1994). The efficiency of the design will go a long way to providing effective work and limiting the occurrence of CTDs (Oborne, 1995).

> *When any form of body activity calls for a considerable expenditure of effort the necessary movements must be organized in such a way that the muscles are developing as much power as possible with the least effort feasible. In this way the muscles will be at their most efficient and skilful (Kroemer and Grandjean, 1997; p102).*

This statement by Kroemer and Grandjean (1997) stipulates the essence of how the human-machine interface should work. It should allow the human to exert as much force as is needed without being placed in an awkward posture, which could cause bodily harm.

INJURIES IN THE WORKPLACE

One of the main challenges facing ergonomists worldwide is the high rate of leave attributable to occupational musculoskeletal problems in industry worldwide (Aarås, 1994). The problem is twofold: the economist wants to reverse financial losses due to absenteeism, and the ergonomist is looking to increase productivity and worker well-being at the same time. Solutions are possible, as was highlighted in a study conducted by Aarås and Westgaard between 1967 and 1984 at a telephone plant in Kongsvinger, which was facing large labour turnover and rehabilitation problems (Aarås and Westgaard, 1980). In 1975, midway through the study, major changes were made in improving the workplace and allowing the workers greater flexibility in adopting less constrained working postures. Sick leave was reduced from 5.3% to 3.1% and the labour turnover was reduced from 30.1% to 7.6%. This was significant as a high percentage of sick leave and labour turnover rate had been due to musculoskeletal injuries. On the economic front Aarås (1994), reporting on the final outcome, demonstrated a 9:14-fold return on the initial investment in redesigning the workplaces.

In many industries, the amount of man-hours of work that are lost through musculoskeletal injuries costs the industry millions of Rands in payoffs, insurance premiums, rehabilitation costs and decrease in efficiency (Olivier, 1997). Olivier (1997) supported the work done by Spilling **et al.** (1986), which showed the cost benefits, in the form of reduced labour turnover and decreased sick leave, that are evident when ergonomic principles are implemented in workspace design.

Injuries in the workplace are an all too common occurrence in most working situations. A prime example is that of railcar handbrakes, which need to be manually implemented, and which have been identified by industry representatives as posing a potential risk of causing musculoskeletal injuries in workers (Woldstad **et al.,** 1995). Although general injuries do occur, Corlett **et al.** (1986) argued that it is the upper extremity cumulative trauma disorders that are the major causes of lost time and workers' compensation in hand intensive industries. Wiker **et al.** (1989) support this and stipulate that the hands of an operator should be in a posture near waist level and close to the body when performing lightweight assembly tasks. Unfortunately this recommendation is frequently ignored in assembly-line environments, where workstations force the hands away from the body and above shoulder height, or well below waist level. In support of Corlett **et al.** (1986), numerous clinical reports and ergonomic studies have concluded that upper extremity posture, influenced by workplace layout, job and tool design, is a prime factor in the development of short term and chronic pain in the joints and muscles of the shoulder and upper limbs (Meyer, 1921; Beyer and Wright, 1951; Lord and Rosati, 1958; Floyd and Ward, 1967; Bateman, 1968; Bjelle **et al,** 1979; Van Wely, 1970; Armstrong and Chaffin, 1979; Westgaard and Aarås, 1984). Other authors have reported that industrial workers continuously complain of musculoskeletal pain in the shoulders, arms and hands (Anderson, 1971; Maeda, 1975; Marras and Schoenmarklin, 1993). Anderson (1971) found that the shoulder complex and upper limbs were the loci of 21.1% of all complaints of musculoskeletal pain. Similar findings were reported by Maeda (1975), when observing complaints of fatigue and discomfort in a Japanese manufacturing industry. He found that pain was analysed to be in the shoulders, arms and hands in nearly 21% of the all the workers that were involved in the study. A figure very similar to that was obtained by Anderson

(1971), and in both cases the results can be attributed to poor workplace design.

Cumulative Trauma Disorders (CTDs)

Cumulative trauma disorders (CTDs) are soft tissue disorders most frequently involving tendons and nerves of the upper extremity (Armstrong, 1983; Mac Duff **et al.,** 1997). While CTDs have been of concern for many decades, a steady increase in incidence has raised the level of this concern in recent times. Marshall **et al.** (1999) echo the National Institute for Occupational Health and Safety's caution that in order to minimise the risk of repetitive strain injuries in workplace postures, or motions that place joints at or near their limits of range of motion, should be avoided. This advice has by and large not been heeded and many easily avoidable injuries are still reported regularly in many industries. Anderson (1962) showed that musculoskeletal pain and discomfort are frequently cited factors in the incidence of disability leave. He found that work days lost increased as musculoskeletal demands increased. Bjelle **et al.** (1979) reported a relationship between musculoskeletal pain in the upper extremities and work posture; nearly 40% of occupational health clinic visits being diagnosed as non-traumatic musculoskeletal disorders. Keyserling **et al.** (1982) stipulated that poor working postures are especially significant when they are combined with a task that requires high force exertions and/or highly repetitive motions. This study formed the basis for a study which demonstrated that upper extremity musculoskeletal disorders usually result from work done under conditions that require workers to perform tasks in awkward positions, which lead to a prevalence of upper extremity tendonitis (Bernard, 1997). The incidence of CTDs of the upper extremity is clearly on the increase (Psacarelli, 1997).

Hsaio and Keyserling (1991) found that people were more willing to compromise the positioning of the distal segments of the body than the trunk; the result being that the distal segments take more strain. Muscles of the forearm do most of the work required to move the fingers and wrists. These small muscle groups are not designed for extended periods of repetitive contractions, so they are vulnerable to injury during such work. This is especially true if the work requires operators to use their hands in pronated positions. Grevsten and Sjogren (1996) in a study on forestry machine operators found that injury is even more likely to occur if the functioning of the stronger muscles of the back, shoulders and upper arms is compromised by hazardous postures or poorly fitted equipment, thus forcing the forearm and hand muscles to do more work. With overuse, forearm muscles contract too often, decreasing oxygen supply to the muscle. Acid metabolites build up in the muscles, causing fatigue and pain (Psacarelli, 1997), and the muscles then contract further in response to the pain. This contraction of the muscle has two-sequellae; tendinitis and nerve entrapment.

Tendon and Nerve Injuries

A decreased blood supply to the muscles of the upper extremity causes the tendons to tighten, which in turn limits wrist and finger ranges of motion. When tendons are continually tightened in this way they can be further injured by friction against soft- or osseous tissues, causing tendinitis (Psacarelli, 1997). This type of injury is particularly common in the hand and wrist when workers are involved in tasks that require a large degree of force to be exerted continually (Silverstein **et al.,** 1986b). On the other hand, nerves can be compressed when surrounding tissues swell, as for example occurs in Carpal Tunnel Syndrome. A diminished blood supply can also damage nerve tissue and Psacarelli (1997) identified friction as a causative factor in neural tissue damage.

Preventing CTDs requires changes in work style, pacing and conditioning (Oborne, 1995). Stal **et al.** (1996) showed that of 161 active female milkers, 81 reported problems associated with at least one wrist or hand. These symptoms consisted of pain, tingling and numbness and were accompanied by reduced muscle strength. Fourteen of these women presented clinical symptoms indicating median nerve entrapment. Awkward postures can damage nerves and weaken the shoulder and upper back muscles. As the upper back and shoulder muscles weaken, the burden of work shifts to weaker muscles of the forearms and hands thereby increasing the potential risk of injury. Corlett (1981) advocated increasing the workspace available to a worker in order to minimise awkward postures. He also called for consideration of rest breaks as a means of reducing the cumulative effects of repetitive work.

ISOKINETIC DYNAMOMETRY AND PSYCHOPHYSICAL RESPONSES

Isokinetic Dynamometry

Kinesiologists have for a long time striven for an accurate way to measure human muscle performance, and the recent advent of Isokinetic work-simulation systems holds promise for the ergonomist. In the past these assessments involved primarily either isometric (static) or isoinertial (dynamic) methods (Perrin, 1993).

Isokinetic exercise is not a new concept and was developed by James Perrine in the early 1960s and then introduced into the scientific literature in 1967 by Hislop and Perrine and by Thistle, Hislop, Moffroid and Lohman during the same year (Hislop and Perrine, 1967). The advantage of isokinetic devices is that they allow the individual to express maximal force throughout the full range of motion at a preset velocity. No matter how forceful an input is, the dynamometer produces a counteracting force, which causes the musculoskeletal lever system to move at a constant rate. Hinson **et al.** (1979) showed mathematically that the constant rate of angular limb movement is not accompanied by a constant rate of muscle shortening.

One of the major advantages of isokinetic dynamometry compared to other devices is that it provides accommodating resistance throughout the range and has the ability to quantify torque, work and power (Baltzopoulos and Brodie, 1989). While peak torque is the most commonly used parameter, the present study included torque, work and power in the strength assessment.

Force and Torque

A muscle can only contract or relax. When a muscle is stimulated to contract it produces a force, which can be measured about the joint's axis of rotation as a moment of the force or a torque (Perrin, 1993). This torque can be assessed as either a peak or an average torque value, the peak torque being the highest point on an isokinetic curve.

Through an entire range of motion the mechanical advantage of the muscle will increase and decrease as shown theoretically by Hislop and Perrin (1967), in Figure 5 below.

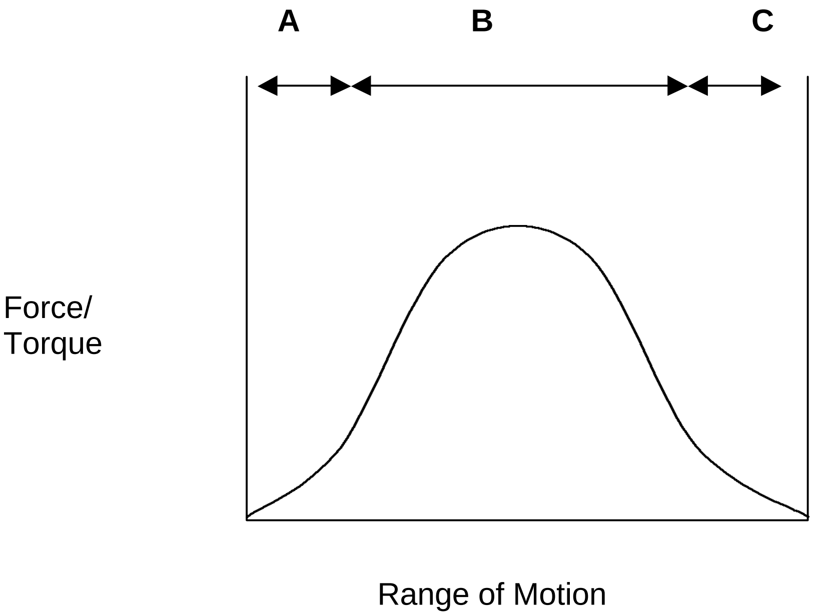

Figure 5: Theoretical force/torque output during a range of motion. The force is decreased at the extremes due to the mechanical disadvantage of the musculoskeletal lever system during these periods. (Adapted from Hislop and Perrin, 1967).

Thus, for example the mechanical advantage is poor during the start and end of a range of motion (A and C in Figure 5) and good during the middle of the range of motion (B in Figure 5).

Torque is not only affected by the range of motion, but also by the testing velocity of the isokinetic dynamometer. The ability of a muscle to generate a concentric force is greatest at the slow isokinetic velocities and decreases progressively as the test velocity increases. Figure 6, adapted from Perrin (1993), illustrates the theoretical decrease that can be expected in the concentric torque of a group of muscles when the test velocity is increased from 60°.s^{-1} to 240°.s^{-1}.

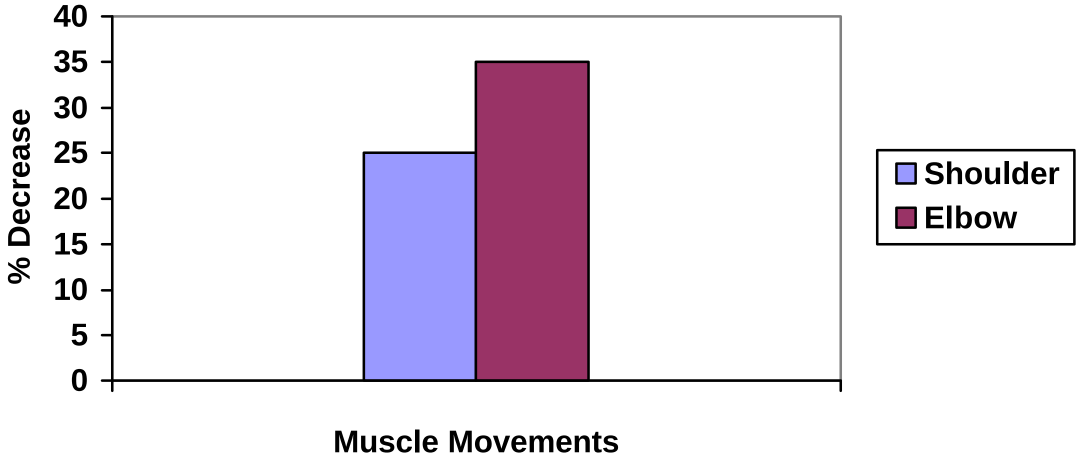

Figure 6: Percentage torque decreases experienced when the testing velocity is increased from 60°.s^{-1} to 240°.s^{-1} during the observation of shoulder and elbow movements. A clear decrease in peak torque is observed with an increase in the testing velocity. (Data adapted from Pawlowski and Perrin, 1989).

Shoulder internal-external rotation and flexion-extension peak torque decrement are in the region of 25 percent. Elbow flexion and extension demonstrate an elevated decrement in peak torque, in the region of 35 percent. These findings are consistent with Hill's (1938) Torque/Velocity relationship. Apparently Hill's "knee-velocity" drop-off is demonstrated in any isokinetic velocity spectrum test and equally apparently decrement rates are joint specific (see Figure 6).

Work and Power

Perrin (1993) cautions that there is a misconception that peak torque at slow test velocities reflects strength and that torque at higher velocities reflects power. Determination of torque, work and power are independent of the testing velocity and isokinetic testing allows testing of these variables at slow, medium and fast velocities.

Psychophysical Scales

Workspaces should facilitate efficient, safe and comfortable work. However, "comfort" has both physical and emotional dimensions. Balogun **et al.** (1986) suggested that equipment should not only be physically undemanding, but that it should also be perceptually acceptable to the user. Given this, the present study included psychophysical ratings of discomfort and effort level. It is too often assumed that in testing of strength expression only the physical findings are of importance. However, biophysical and psychosocial components are of equal importance (Singleton **et al.,** 1973). In the present study the psychophysical observations included the rating of perceived exertion (RPE).

Perceived Exertion

Numerous methods exist which allow the user to identify the perceived exertion experienced while executing a physically taxing task. One of these is a ratio scaling method developed at Harvard by S.S. Stevens and his co-workers in 1957 and improved in 1966 (Borg, 1975). These ratios permit the perceptual intensity to be measured roughly by a ratio scale (Borg, 1975). Borg goes further by pointing out that the ratios give ratios between intensities, but do not give absolute values for differential use, the problem being that this model does not allow for interindividual comparisons. Borg then proposed a model in 1961, 1962 and 1970 in which the perceptual intensities at the maximal or terminal thresholds are set equal for all subjects and the total range is used as a frame of reference (Borg, 1975).

In 1962 Borg derived a 21-grade scale that allowed for direct interindividual comparisons. In 1970 the scale was reduced to a 15-grade scale and since then it has been used in countless studies of perceived exertion throughout the world (Borg, 1975). The major advantage of the RPE scale is that if it is understood and used correctly, a high correlation exists between the physical exertions and the perceived psychological effort required for progressively increasing physical demands.

High correlation coefficients, 0.87 to 0.9, have been reported between RPE and heart rate, and RPE versus other physiological parameters (Borg, 1962 and Mihevic, 1981). Skinner **et al.** (1973) have demonstrated high reliability coefficients and high validity using RPE in a study to determine whether subjects could perceive small differences in varying work intensities presented in random order, a finding supported by Pandolf (1978), who found a close correlation between the perceived exertion and the actual stress that the subject was experiencing.

In order to improve RPE validity it should be understood that there are numerous interacting stimuli responsible for a person’s response to a task demand. These inputs could emanate from the central nervous system and/or from peripheral working muscles and joints. Ekblom and Goldbarg (1971) proposed a two-factor model, comprised of a “local” factor, the working muscles and joints, and a “central” factor, predominantly the cardiovascular system. This two-factor model makes it possible to rate different types of work affecting either the predominantly peripheral muscles or predominantly the cardiovascular system (Ekblom and Goldbarg, 1971). Robertson (1982) has contended that the “local” factors tend to dominate RPE to a large extent, particularly in tasks of short duration; he plays down the role of the “central” factor.

In a study conducted by Meyer **et al.** (2000) they found high ratings of strain for high and low torque work in conditions similar to the working environment. In the same study, on the actuation of large hand wheels, they found that the position of the wheels did not significantly influence the rating of perceived exertion.

Discomfort

Discomfort maps and rating charts have been used in numerous studies to identify the most affected area(s) of the body while the subject is completing a task. Schulze and Woods (1994) used a rating scale in conjunction with a whole body map during an investigation into workplace accommodations. The scale used had a range of 1 to 10; 1 being a rating of “just noticeable” to 10 being “intolerable”.

Marley and Fernandez (1995) combined the use of a body map with the identification of RPE for these specific ratings, thereby identifying localised RPE during the observation of asymmetrical lifting. In the present study a combination of both of the above mentioned studies were adapted and used to observe the discomfort the subjects were feeling during the completion of the specific task. The body map from Marley and Fernandez (1995) was combined with the rating scale of Schulze and Woods (1994) (see Appendix B page 161).

CHAPTER III

METHODS

INTRODUCTION

Strength assessments of simulated work tasks using an isokinetic dynamometer have been used in recent years, but are still sparse in the literature (Cabri, 1991). This is in dramatic contrast to the many hundreds of isokinetic assessments of, for example the knee and shoulder (Perrin, 1993).

It was the aim of the present study to provide some insight into isokinetic assessments involving work-simulated tasks. The specific work-simulating tasks under investigation were established after numerous surveys were conducted in various industries within South Africa.

SUBJECT SELECTION

Thirty young adult males from Rhodes University, all reading for the bachelor degree in Human Kinetics and Ergonomics, agreed to participate in the study. All potential subjects were presented with a letter informing them about the procedures and aims of the study (see Appendix A, page 143). Any queries were addressed verbally. In addition all subjects were required to complete an informed consent form prior to testing (see Appendix A, page 146). Institutional ethical standards requirements were met as a pre-requisite to commencement with the project.

Demographic Profile and Antropometric Characteristics of the Sample.

Demographic information (including relevant anthropometric measures) was gathered prior to the strength testing sessions on the CYBEX ® 6000 WSS. The following data were obtained:

Stature (mm); Mass (kg); RPI (mm/kg$^{0.333}$); BMI (kg/m^{2}); Hand length (mm) and Hand breadth (mm); Xiphoid Process height (mm); Age (yr).

This was done to establish a morphological profile of the subjects so that aspects of morphology relating to strength could be identified. As the study focused on the knob- or lever-turning strength of the participants, hand size was seen as a critical variable which could influence the outcome of the results. It was proposed that subjects with large hand areas would be able to exert more force than subjects with smaller hands, particularly for the larger controls. For this reason hand length and breadth were measured. According to Mital and Kumar (1998) strength is influenced significantly by age, which as Table I shows, was constrained to a low coefficient of variation in the present project.

The specific procedures for each measurement were as follows:

1) STATURE was measured using a Holtain Stadiometer. Subjects were instructed to remove footwear and headgear. They were then required to stand erect with heels together and buttocks, upper back and rear of head in contact with the vertical backboard of the stadiometer. The feet were kept flat on the base of the stadiometer. Stature was recorded (mm) from the vertex in the median sagittal plane using the stadiometer branch (Tanner, 1964).
2) MASS was recorded using a Toledo electronic scale. Subjects were required to remove all clothing except undergarments. They were then instructed to stand on the pressure plate and an electronic reading was taken (kg).
3) BODY MASS INDEX (BMI) is used to determine ponderosity by using body mass and stature (McArdle **et al.,** 1996). BMI was computed as follows:

$$\text{BMI} = \text{Body mass (kg)} / \text{Stature } (\text{m}^2).$$

(McArdle **et al.,** 1996).

4) RECIPROCAL PONDERAL INDEX (RPI) is an index, that uses stature and mass to calculate relative linearity. RPI was calculated in the following manner:

$$\text{RPI} = \text{Stature (mm)}/ \text{ mass (kg)}^{0.333}$$

5) XIPHOID PROCESS height was measured using a Holtain Stadiometer. This was done immediately after the stature measurement, as the conditions for measurement were the same.

6) HAND LENGTH AND BREADTH were recorded using a Takei athropometry measuring set. Measurements were made of the dominant (right) hand. The length of the hand was measured from the tip of the middle finger to the crease marking the articulation between the carpals and the radius (the wrist joint) with the hand supinated (see Figure 7). The breadth of the hand was measured across its broadest part, distal head of metacarpal II to V (see Figure 7). The hand remained in the same position for both measurements.

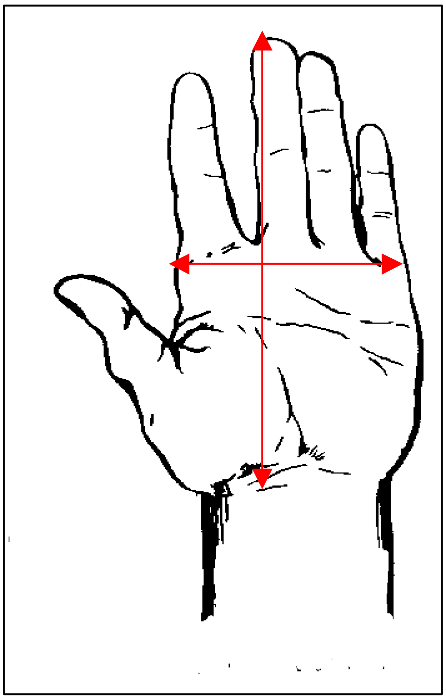

Figure 7: Diagram of hand depicting the measurements taken for hand length and breadth.

In addition to these demographic data, grip strength, anticipatory heart rate and blood pressure were recorded. Grip strength was measured (using a grip dynamometer) in order to determine the strength of correlations between hand size and strength, and to assist in determining whether or not hand size may be implicated in the final outcome of the results.

In order to standardise grip strength testing, subjects were required to hold the dynamometer overhead with the arm fully extended. On a verbal command of "go" the subject would bring the dynamometer down keeping the elbow extended and squeezing at the same time, eliciting a maximal voluntary contraction (MVC). Subjects were required to repeat this procedure, the better of two responses being recorded (N).

Reference blood pressure and heart rates were monitored in order to provide data for comparison against cardiorespiratory responses collected during the testing phase. Heart rate was measured using a Polar S410 heart rate monitor and blood pressure by using an Omron M1 semi-automatic blood pressure monitor.

Before the onset of the isokinetic testing, subjects were shown the knob and lever controls to be used and asked to rate them subjectively as to which they thought were the "best", and which the "worst" controls. As there were six controls, the subjects were required to rate these from 1 (best) to 6 (worst). This subjective test of preference was repeated at the end of the Isokinetic testing session (see Appendix B, page 149).

TABLE I: Demographic profile of subjects (n=30) of the present study. Means with standard deviation in brackets.

Age (yr)	20.8 (±2.4)
Mass (kg)	84.2 (± 2.4)
BMI (kg/m^2)	25.8 (± 4.6)
RPI (mm/$kg^{0.333}$)	416.0 (±24.1)
Stature (mm)	1 803.1 (±79.7)
Xiphoid Process Height (mm)	1 271.5 (61.3)
Hand Breadth (mm)	866.3 (±49.6)
Hand Length (mm)	1 902.0 (±102.3)
Grip Strength (N)	530.4 (±7.0)
Systolic Blood Pressure (mmHG)	126.6 (±6.0)
Diastolic Blood Pressure (mmHG)	76.8 (±8.3)
Heart Rate (b.min^{-1})	62.5 (±10.1)

Two testing sessions were needed for each subject. These sessions were conducted either in the morning or in the afternoon of a specified day and then a week later during the same slot; i.e. morning or afternoon. The two-session allocation helped to combat fatigue and boredom during the testing, which might have been the case had the testing been conducted in one long session. The combating of fatigue was seen as crucial as it was felt that subjects would not be able to exert themselves maximally for the duration of one continuous test session.

WORK-SIMULATION

According to Meister (1990) work-simulating systems vary along two continua: "realism" relative to the operational systems they represent, and "comprehensiveness" or extent to which operational functions and environmental characteristics are reproduced. In the present study it was deemed necessary to visit industrial sites to observe workstations so that the work-simulation testing could be set up in such a way as to reflect industrial settings.

Consequently the test conditions were determined on the basis of a number of visits to selected industries in Gauteng Province and in the Grahamstown municipal district. In these industrial settings observations were made with respect to the position of controls and the particular control types in use.

Spatial Orientation of Controls

Although many industries have reduced locating controls either awkwardly high or awkwardly low, many waist height controls are still situated in awkward places. In certain instances these awkward locations are underneath or behind an obstacle. The orientation of controls varied from vertical positioning to horizontal positioning, and in certain instances the control valves were set at oblique angles. None of them appeared to force the operator to adopt poor overall body working posture. However, several did require awkward hand positioning which would influence work efficiency. Therefore the need exists to establish an optimal control position that contributes the most to worker efficiency and reduction of physical strain. Accordingly the following locations were used in the present study: dynamometer in the upright position (90°); dynamometer set at 45° and dynamometer set horizontally (0°) (see Figure 8).

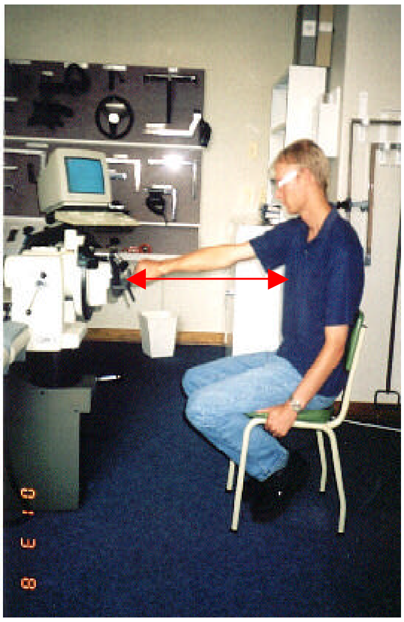

Figure 8a: Dynamometer at 0º.

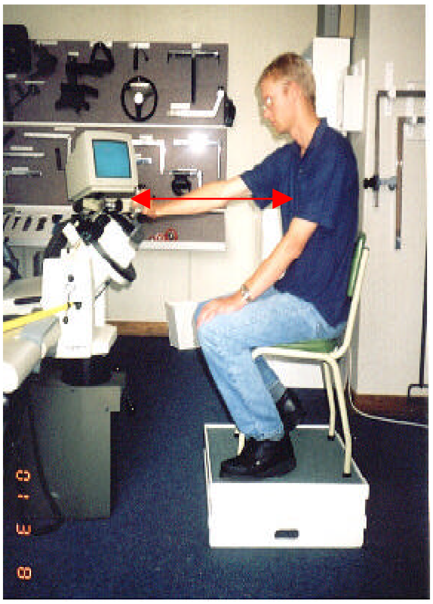

Figure 8b: Dynamometer at 45º.

Figure 8c: Dynamometer at 90º.

Figure 8: The three testing positions used. Arrows show the alignment of the axis of the control with the xiphoid process on a transverse plane.

In certain positions the restricted height of the dynamometer caused a problem, as the dynamometer could not be lowered enough for the axis of the control to align with the xiphoid process. In these instances placing wooden boxes under the subject's chair raised the height of the supporting surface. This situation was especially true during the testing of controls at 45º and 90º (see Figure 8b and 8c). This adjustment ensured that in all conditions the axis of the control was aligned in the transverse plane with the xiphoid process. However, in the sagittal plane the subject was allowed a certain amount of movement. The subject was allowed to move the centre of his chair, identified by a black strip, 20cm to the left or right of the axis of the control. This allowed the subject to pick a spot, within limits, where he was most comfortable to perform the test. Before the start of a new test the centre of the chair was aligned, in the sagittal plane, with the axis of the control.

Control Types

The visits to industries not only revealed how and where controls were positioned, but also gave clear insight into the type of controls used by a specific industry. These controls varied in texture, shape and size, as Figures 9a to 9d show. These figures illustrate that in the older industries there was still a tendency to employ the more established Knob-type control (Figures 9c and 9d), as opposed to the Lever-type design being used more commonly in the new industries (Figure 9a and 9b).

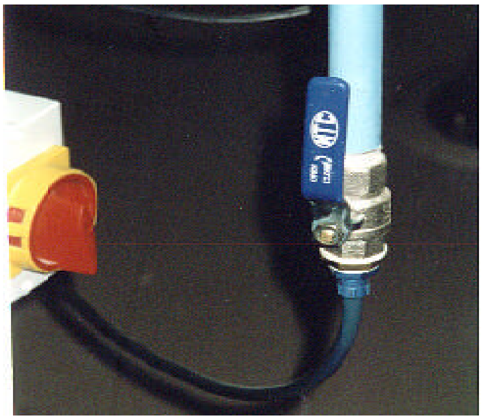

Figure 9a: Lever-type control in industry.

Figure 9b: Open/close valve.

Figure 9c: Large fluted design.

Figure 9d: Small fluted design.

Figure 9: Various controls in varying industrial settings within South Africa.

However, as most industrial sites, particularly in IDCs, are still of the older generation, the circular Knob-type controls are more prevalent in local industry. These Figures also show the range of sizes of controls and the diversity of their positions. Figure 9c, for example, depicts a horizontal orientation whereas Figure 9d is an oblique orientation. The Lever-type control, Figure 9a and 9b, allows the operator to fully open or close a valve using as little as a 90° turn of the handle.

The controls observed *in situ* in industry were of three standard sizes, the smallest being a 13mm valve, the largest a 64mm valve and the intermediate size a 38mm valve. In the present study similar control valves were purchased in both the circular knob and Lever-type designs in these three sizes (Figure 10).

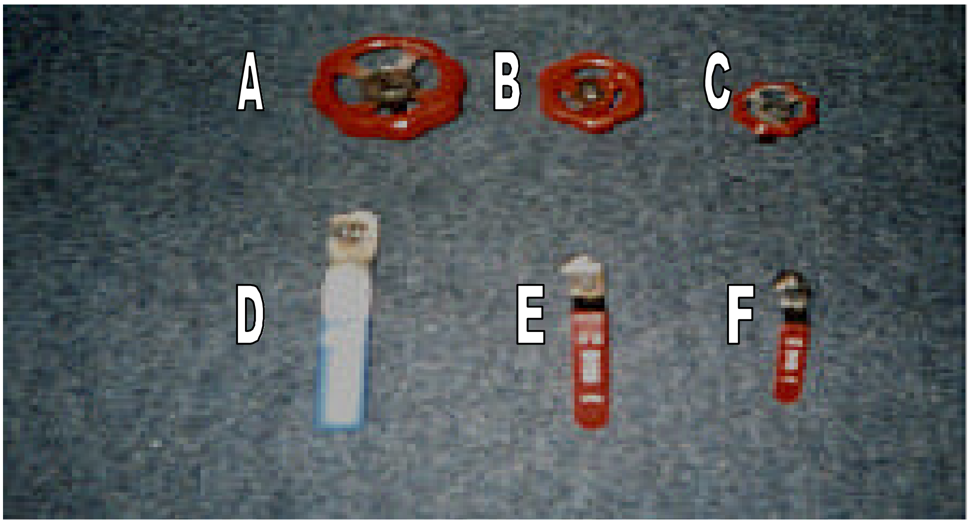

Figure 10: Controls used in the work simulation testing.

The six controls chosen for investigation were separated into three pairs, namely; large (A; D), medium (B; E) and small (C; F). In comparing the controls it is easy to assume that the larger controls should enable the operator to produce more force due to the increased leverage they offer through having longer effort arms. However, the leverage offered by each control differed as the effort arm for each control was different.

Establishment of Effort Arms

The positioning of the hands on the Lever-type controls provided a problem. This was because the Knob-type controls only provided one gripping position, that being with the centre of the hand over the centre of the control, meaning that the effort arm (ea) was standardised for all subjects (see Figure 11). However, the Lever-type control provided numerous gripping options with different effort arms for each Lever-type control. Therefore it was necessary to establish a single gripping action for all the Lever-type controls and to standardise an effort arm for each of the lever controls. Observation of diverse gripping actions in industry and during pilot work established a standardised gripping action and effort arm. These observations were done by presenting the individuals with the Lever-type control and asking them to grip the control in the most comfortable manner. This procedure was repeated for each of the Lever-type controls. The type of gripping action and the position of the centre of the hand was noted. Analysis of these data lead to the establishment of the “fingers over the top, thumb underneath” gripping action as the most representative coupling style used. Data collected on the centring of the hand on the Lever-type controls allowed for the establishment of effort arms for each of the Lever-type controls through noting the mean distance from the pivot point (see Figure 11).

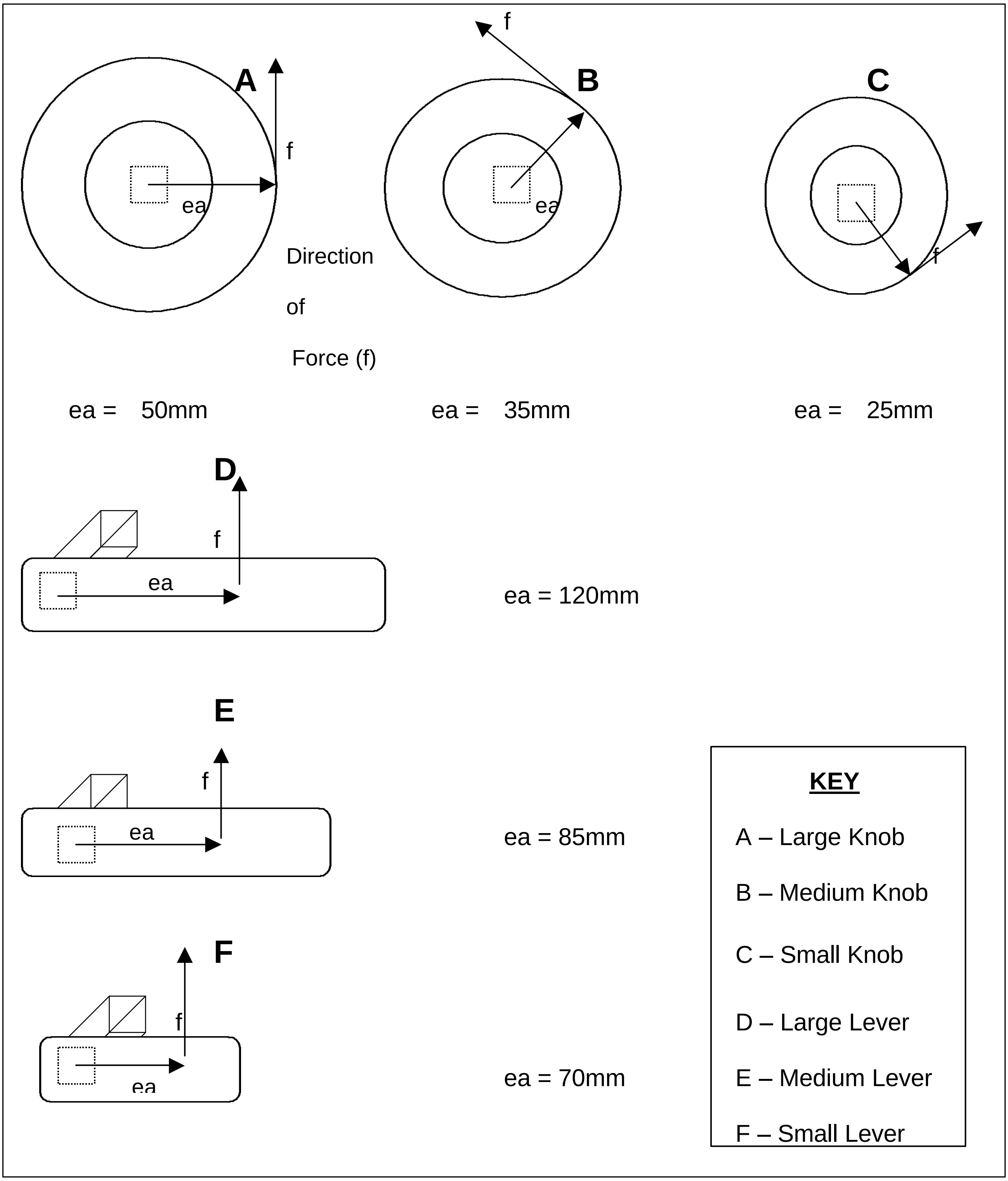

Figure 11: Schematic representation of the controls showing the effort arm (ea) for each control and the accompanying directional force (f), tangential in the case of the circular controls.

TABLE II: Characteristics of the controls used in the study.

Effort Arm (ea) Largest to smallest (mm)	Controls		Lever length; knob circumference (mm)	Effort arm as a % of total length or circumference
	Knob-type	Lever-type		
120	--	D	150	80.0
85	--	E	120	70.8
70	--	F	85	82.4
50	A	--	314	15.9
35	B	--	220	15.9
25	C	--	157	15.9

Figure 11 and Table II show that the bar controls (D; E; F) offer more effort arm leverage. However, the fact that control A has an effort arm of 50mm, 41.6% of the effort arm of control D, implies that all things being equal, control A should elicit a torque exactly 41.6% of that of control D. This implication follows for the other controls. Therefore, if the predicted outcome does not materialise, the discrepancy can be assumed to be as a result of other coupling factors relative to design and/or positioning of the controls.

Hand Position on Lever-Type Controls

In order to standardise the positioning of hands on the Lever-type controls, a white sticker was placed on the midpoint (Figure 7) of the hand (dorsal and volar surfaces), and at the end of the effort arm of the lever. The hand was then aligned to the particular lever control (see Figure 12a).

Figure 12a: Alignment of control and dominant hand.

Figure 12b: Centre of hand closing in on the centre of control's effort arm.

Figure 12c: Final position of hand.

Figure 12: Correct positioning of dominant hand over a Lever-type control.

The subject was then instructed to place his hand over the control keeping the sticker on the palm aligned with the sticker on the control (see Figure 12b). This ensured that the centre of the hand was on the end of the control's effort arm, the final outcome being that the sticker on the outside of the hand identified the position of the effort arm and could be checked to see that the grip had not changed through the range of motion (see Figure 12c).

Hand Position on Knob-Type Controls

As was the case with the Lever-type controls, care was taken to ensure that the subjects gripped the Knob-type controls in a standardised manner. The protocol and positioning of stickers on the hands was identical to that of the Lever-type controls. The stickers on the Knob-type controls were placed in the centre of the control and once again the subjects were instructed to align the stickers on their hands with those of the Knob-type controls, as with Lever-type controls (see Figures 13a-13c).

Figure 13a: Alignment of control and dominant hand.

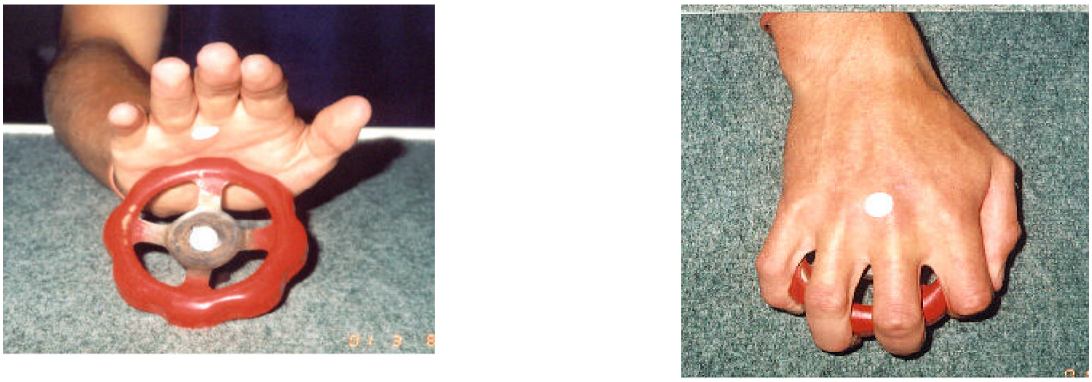

Figure 13b: Centre of hand closing over centre of control.

Figure 13c: Final position of hand over control.

Figure 13: Correct positioning of dominant hand over a Knob-type control.

The correct positioning of the hand for all controls is crucial as it standardises the hand placement for all subjects and the length of the effort arm under observation.

Adaptations to Controls

Although the CYBEX ® WSS package offers a wide range of input attachments, the present study used controls purchased or custom-altered to conform to those observed in various industries. These alterations entailed welding the handle of a purchased control to a length of quadrangular metal 40mm x 10mm which fitted the universal tool adaptor of the CYBEX ® 6000 WSS. A local metalworking firm, Grahamstown Engineering, custom-adapted the controls to fit the CYBEX ® universal adapter input attachment.

PILOT INVESTIGATIONS

Pilot work was done in order to test the experimental controls and positioning of these controls. During this phase the test velocity was established ($60^{o}.s^{-1}$). The primary reason for the pilot work was to eliminate any procedural problems that may arise during the actual data collection sessions. This included making sure that the specific equipment in fact measured what it purported to measure. A test-retest design was used in which the protocol for all tests remains the same, but all control-types and positions were randomly assigned.

During pilot work the demographic profile and anthropometric measures of the subjects were obtained and isokinetic testing performed. Subjects performed all 18 conditions at $60^{o}.s^{-1}$. For this phase of the project all controls were compared to the large bar control, which had the largest effort arm, 120mm. The effort arms of the other controls could thus be seen as a ratio against the large bar control and thus an expected torque could be calculated. For example, the control with an effort arm of 85mm could be expected to have a torque 70.83% of the torque produced by the large bar control. This expected torque was then compared to the produced torque and deficit or excess torque calculated.

The limited data from the pilot work revealed that subjects using the wheel controls, with less leverage, performed equally and better than when manipulating bar controls, which have far greater leverage. This was demonstrated by the bar controls having a far greater deficit in the expected torque than the wheel controls (see Table III).

TABLE III: Isokinetic data for subjects involved in pilot investigation.

Size of Control	Control	Total Torque (Nm)	Total Work (J)	Total Power (Watts)	Torque as a % of 120mm.	Deficit/ Surplus
120mm	LL	149	188	107		
85mm(70%)	ML	94	123	70	63.08	-6.92
50mm(41,6%)	LK	77	97	51	51.67	+10.07
35mm(29.2%)	MK	46	52	28	30.87	+1.67
70mm(58.3%)	SL	39	45	27	26.17	-32.33
25mm(20.8%)	SK	19	21	9	12.75	-8.05

NOTE: Large Lever (LL); Large Knob (LK); Medium Lever (ML); Medium Knob (MK); Small Lever (SL) and Small Knob (SK).

The pilot work also highlighted the need to include physiological responses, hence the monitoring of heart rate and blood pressure were included in the study. The essence of this was to try and identify any correlation that may exist between heart rate, blood pressure and psychological ratings. The study included these physiological and psychological variables to recognise the importance of personalised responses of operators while executing such tasks and to contribute to the isokinetic literature, where very few studies have included the above-mentioned parameters.

Testing Velocities

The CYBEX ® 6000 can test at speeds ranging from 15°.s^{-1} to 500°.s^{-1}. In an industrial setting the turning of control valves is usually done at slow angular velocities. Often a rusty or “jammed” control causes the turning speed to be very slow. Consequently a slow, medium and a fast speed were chosen for the pilot study. One speed would then be chosen for use in the study. The chosen speed had to be the speed that was seen to best simulate the working environment. The slowest speed was excluded on the basis that it was too slow and because subjects complained of bruised hands during the pilot work. The fastest speed was excluded on the basis that it was too fast and that it hardly offered any resistance and therefore did not simulate the working environment, as most valves require some form of force to open. The speed of 60º.s^{-1} was seen as most accurately simulating the working environment and thus was used as the testing speed in the present study. It is not the aim of the present study to show the effects of speed on torque, work and power, as this has been shown by, Hill (1938) and Pawlowski and Perrin (1989), among numerous others.

ISOKINETIC STRENGTH TESTING

Isokinetic strength testing was done on a CYBEX® 6000 isokinetic dynamometer using a work-simulation package, with control and spatial orientation of controls adapted from trips to industry.

The order of presentation of control type and position of dynamometer was randomised for each test session (see appendix B, page 152). Subjects were required to attend two testing sessions. These sessions were one week apart and were both conducted either in the afternoon or the morning. During each session nine conditions were tested i.e. three controls in three positions. In the second session the remaining three controls were tested, once again in all positions.

In all strength tests the subjects were seated in front of the dynamometer. To standardise the height of the dynamometer and the distance of the subject from the dynamometer, the axis of the control (Knob or Lever-type) was adjusted to lie in the transverse plane through the subject's xiphoid process while the subject was in the seated position. The subject was positioned at knuckle length away from the control to ensure optimal "functional reach" while in a normal seated position (see Figure 14). The centre of the chair was aligned with the axis of the control and the subject was allowed to move the chair 20cm left or right of the central position, in order to accommodate the range of motion the subject required and to prevent any constriction of ranges of motion.

Figure 14: Subject seated knuckle distance from the control being tested, with the axis of the control aligned, in the transverse plane, with the subject's xiphoid process when seated (see red arrow).

CARDIAC RESPONSES

In the present study it was deemed important to observe certain physiological responses, namely heart rate and blood pressure. In a task requiring heavy lifting the breathing frequency is altered in association with the Valsalva Manoeuvre. This alteration in the breathing frequency and the volume of air moved affect cardiac responses such as heart rate and blood pressure. Due to the maximum effort required from subjects executing the tasks in the present study, similar physiological responses were expected. Breath holding is known to cause bradycardia, which in turn might affect blood pressure (McArdle **et al.,** 1991). However, on completing the task normal respiration occurs, which could influence the responses of the other physiological variables.

Heart rate

Heart rate was measured at 5s intervals using a Polar S410 Plus heart rate monitor, for the entire duration of the test session. Anticipatory heart rate was recorded, on both testing days, as the lowest heart rate before the onset of isokinetic testing. The heart rate was taken when the subject was seated in front of the dynamometer. The results obtained during testing would then be compared to the anticipatory heart rate of that particular day. Manual readings were recorded before and immediately after each condition tested.

Blood Pressure

Blood pressure responses were monitored using an Omron M1 semi automatic blood pressure monitor. blood pressure was recorded before the onset of isokinetic testing on each of the testing days. Results obtained during the testing would then be compared to the blood pressure of that particular day. The cuff was positioned over the right arm and inflated immediately after the subject completed the 4 maximal repetitions for a specific condition. Subjects were instructed to keep their arm as still as possible, as any significant movement may affect the data. The testing assistant then recorded the electronically monitored blood pressure on the relevant data sheet. Blood pressure was monitored for every subject under all conditions.

PSYCHOPHYSICAL RESPONSES

The physical and psychological factors in work performance operate reciprocally in cueing muscular and cardiovascular effort in relation to feelings of workload, exertion and fatigue (Fleishman **et al.,** 1984). In the present study physical strength testing was complemented by psychophysical assessments. These included: Perceived Exertion (RPE), localised hand/arm discomfort and overall body discomfort.

Perceived Exertion (RPE)

This psychophysical rating was based on the 15-point Borg scale (Borg, 1970). The subjects rated perceived exertion by pointing to the number most closely related to the corresponding verbal description of the exertion felt. For example, a rating of 7 corresponded to a verbal description of “very, very light” whereas a rating of 19 corresponds to “very, very hard” (see appendix B, page 160). In the present study subjects were instructed to rate both “local” and “central” perceptions of exertion. Local exertion referred to the effort experienced by the peripheral muscles and central exertion related to the cardiovascular system (Ekblom and Goldbarg, 1971). Subjects were given verbal and written instructions (Appendix B, page 158) into the use of RPE, and any questions arising were dealt with verbally. RPE was taken immediately after each set.

Localized Hand and Arm Exertion and Discomfort

As the emphasis of the study was on the manual manipulation of controls, subjects were required to give a localised perceived discomfort (LPD) response regarding the discomfort felt in the hand and forearm. The subjects were instructed to point out an area on a diagram of the hand and forearm which was perceived to be experiencing the most discomfort (see appendix B, page 162). LPD was assessed after the completion of each testing condition.

Body Part Discomfort Scale

In respect of overall perceived discomfort (OPD) subjects were required to identify an area of the upper extremity that had experienced discomfort during the testing. In addition the subjects had to identify the extent of the discomfort, ranging from 1, " just noticeable", to 10, " intolerable". The body map and scale (see appendix B, page 161) were adapted from Schulze and Woods (1994) and Marley and Fernandez, (1995). OPD was assessed after the completion of each condition. Instructions for the use of OPD and LPD were given verbally and in written form (see appendix B, page 159), and any questions were answered verbally.

EXPERIMENTAL PROCEDURE

Two subjects were present during each test session on the same day, one week apart. The order of the testing in the first session was repeated in the second test session, one week later. The protocol was rigorously controlled and standardised for each pair of subjects.

The protocol started with the first subject being seated in front of the dynamometer and the height of the dynamometer and the subject's distance from the dynamometer being standardised. The blood pressure cuff was attached to the subject's bicep brachii and cardiac responses (heart rate and blood pressure) were recorded. The subject then performed the test by executing four maximal valve turns. One-minute rest was allowed before the next test. During this time blood pressure and an end heart rate were recorded immediately after the test followed by the recording of psychophysical responses and the changing of the spatial orientation and standardising of the dynamometer. Subject one was then tested, under the second condition, in exactly the same manner as the first condition using the same control, but in a different spatial orientation. The same protocol was repeated for the third condition, spatial orientation being the only variable to change. This would mark the end of the first subject's testing of a specified control in three spatial orientations i.e. 0º, 45º and 90º in randomised order. The same protocol would be followed for subject two. Once subject two had been tested on the same control in the three spatial orientations, the control design was changed. Subject one was then tested on the new control in the three spatial orientations, followed by subject two. The testing of the third control was completed following the same protocol. This testing session was now complete as both subjects had been tested on three control designs all in the required spatial orientations i.e. nine conditions. The following week the subjects were tested in exactly the same manner using the three remaining controls. Under all conditions the selection of control design and spatial orientation of the dynamometer were randomised and the testing speed standardised at $60^{\circ}.s^{-1}$.

The testing was completed when both subjects had attended two testing sessions and been tested in all 18 conditions, namely: six different controls, three in each session, and 3 different testing positions. In order to simulate the working environment as effectively as possible, no verbal encouragement was given. Graphic and numeric representation of each subject's results was produced as a computer printout from the CYBEX ® 6000 for strength expression (see Appendix C, page 166). The heart rate, blood pressure and psychophysical responses were manually recorded on a data sheet (see appendix B, page 150).

STATISTICAL ANALYSES

The STATGRAPHICS® package (Version 6) was used to test the hypotheses (see appendix C, page 167). The significance level was set at $p = 0.05$. A 2-way ANOVA (Control design by Spatial orientation) was used in the statistical analysis of data. Factor A (control design) consisted of six sections (a to f). These were: (a) large Knob-type control; (b) large Lever-type control; (c) medium Knob-type control; (d) medium Lever-type control; (e) small Knob-type control; (f) small Lever-type control. Factor B (spatial orientation) consisted of three parts. These were: 1; 2; 3 and reflect spatial orientations of controls (0º; 45º; 90º respectively). The analysis of factors A and B used a Post Hoc (Tukey method) analysis. In addition descriptive statistics and t-tests analyses were conducted when required.

CHAPTER IV

RESULTS AND DISCUSSION

INTRODUCTION

The purpose of the present study was to quantify the isokinetic, cardiovascular and psychophysical responses to the manipulation of various controls in selected spatial orientations. Occupation-simulating isokinetic assessments in this study involved the measurement of musculoskeletal torque, work and power outputs through a range of motions in which the limb was moving at a constant angular velocity, while the systemic responses included heart rate and blood pressure. Ratings of perceived exertion and discomfort comprised the psychophysical measures. The inclusion of heart rate and RPE in the study is justified as it seeks to emulate the working environment, were valve operators perform shorts bouts of activity, as accurately as possible.

Three Lever-type controls (small, medium and large) and three Knob-type controls (small, medium and large) were used in each of three different positions (spatial orientations), i.e. vertical (90°), diagonal (45°) and horizontal (0°). Each subject (n=30) performed four maximal turning efforts on each of the 6 controls in each of the 3 spatial orientations, thereby fulfilling 18 conditions. Data were later statistically analysed, using STATGRAPHICS® software, via multiple factor ANOVAs. In addition, related t-tests were conducted in specified situations requiring them. Tables IV and V on the following two pages summarise the isokinetic, cardiovascular and psychophysical responses of the group.

TABLE IV: Summary of Isokinetic responses for all controls in all spatial orientations. (Means, with SD in brackets)

Control			Vertical Orientation (90°)		Diagonal Orientation (45°)		Horizontal Orientation (0°)	
Type	**Size**	**Measures**	**Ext.**	**Int.**	**Ext.**	**Int.**	**Ext.**	**Int.**
Lever	Large	Torque	29.4 (6.3)	31.8 (7.9)	28.3 (5.5)	24.0 (5.0)	28.3 (7.1)	23.4 (7.1)
		Work	29.8 (8.0)	35.7 (8.9)	31.5 (7.3)	27.4 (6.9)	32.7 (9.1)	29.5 (8.2)
		Power	19.1 (4.6)	22.9 (5.1)	20.2 (4.5)	17.7 (4.2)	20.4 (8.2)	18.7 (4.8)
	Medium	Torque	21.2 (4.6)	22.6 (5.6)	19.6 (3.1)	18.9 (4.0)	19.6 (4.1)	19.4 (4.0)
		Work	20.9 (5.0)	24.6 (6.1)	21.8 (5.7)	22.3 (5.7)	24.0 (6.5)	23.6 (6.2)
		Power	14.0 (3.9)	16.2 (4.1)	13.5 (2.0)	13.8 (3.1)	14.7 (3.8)	14.7 (3.6)
	Small	Torque	10.6 (2.9)	12.3 (2.9)	10.1 (2.7)	10.8 (2.7)	10.1 (2.9)	11.4 (2.6)
		Work	10.2 (3.5)	13.3 (3.9)	10.4 (3.4)	11.5 (3.5)	12.5 (4.2)	12.9 (3.8)
		Power	6.6 (1.7)	8.2 (2.3)	6.7 (1.8)	7.5 (2.1)	8.1 (2.7)	8.3 (1.9)
Knob	Large	Torque	8.8 (2.8)	10.7 (3.1)	8.7 (2.4)	10.9 (3.1)	8.7 (2.3)	9.5 (2.9)
		Work	8.9 (3.9)	11.8 (4.7)	9.7 (3.9)	12.5 (5.0)	9.2 (3.6)	10.9 (4.0)
		Power	5.5 (2.4)	7.2 (2.5)	6.0 (1.8)	7.9 (2.5)	5.7 (2.1)	6.7 (2.0)
	Medium	Torque	5.1 (1.5)	6.4 (2.0)	5.0 (1.7)	6.2 (2.1)	5.0 (1.4)	6.2 (1.9)
		Work	4.7 (1.9)	6.3 (2.4)	5.0 (2.1)	6.8 (2.8)	4.8 (1.7)	6.3 (2.4)
		Power	3.1 (1.1)	4.0 (1.4)	3.2 (1.4)	4.4 (1.5)	3.1 (1.3)	4.0 (1.5)
	Small	Torque	2.6 (1.1)	3.4 (0.6)	2.3 (1.1)	3.4 (0.6)	2.3 (1.1)	3.5 (0.6)
		Work	2.0 (1.7)	3.6 (1.8)	1.4 (1.1)	3.2 (1.1)	2.0 (1.1)	3.1 (1.2)
		Power	1.4 (1.0)	2.1 (0.5)	1.0 (0.6)	2.1 (0.6)	1.2 (0.5)	2.0 (0.6)

NOTE: Torque=Peak Torque (Nm); Work=Total Work in the “best work rep” (J); Power= Average Power (W); Ext=External Rotation; Int=Internal Rotation.

External rotation: Knob Type Controls=Ulnar Deviation.
Lever Type Controls=Shoulder Abduction.
Internal rotation: Knob Type Controls=Radial Deviation.
Lever Type Controls=Shoulder Adduction.

TABLE V: Summary of Cardiovascular and Psychophysical responses for all controls in all spatial orientations. (Means, with SD in brackets)

Control			**Heart Rate (bt.min^{-1})**		**Blood Pressure (mmHg)**		**RPE**	
Type	**Size**	**Orientation**	**AHR**	**EHR**	**Sys.**	**Dias.**	**Local**	**Central**
Lever	Large	Vertical	74 (12)	102 (12)	142 (7.8)	76 (9.1)	11	10
		Diagonal	73 (12)	103 (12)	138 (8.5)	75 (8.6)	11	10
		Horizontal	73 (13)	108 (13)	137 (7.4)	74 (8.7)	11	10
	Medium	Vertical	75 (14)	102 (13)	140 (11.4)	74 (9.4)	11	10
		Diagonal	75 (13)	102 (14)	141 (8.5)	75 (8.6)	11	10
		Horizontal	75 (14)	105 (16)	141 (8.9)	74 (8.7)	12	10
	Small	Vertical	73 (12)	93 (11)	139 (10.1)	79 (6.5)	11	9
		Diagonal	71 (11)	95 (10)	138 (8.6)	76 (7.3)	11	10
		Horizontal	71 (13	97 (11)	136 (10.8)	76 (6.8)	11	10
Knob	Large	Vertical	74 (15)	95 (14)	136 (10.5)	78 (8.6)	11	10
		Diagonal	72 (11)	98 (15)	137 (11.4)	79 (9.1)	11	9
		Horizontal	72 (12)	95 (14)	139 (10.8)	79 (7.4)	11	10
	Medium	Vertical	75 (14)	96 (14)	134 (7.2)	76 (8.9)	11	9
		Diagonal	72 (13)	95 (14)	139 (9.1)	78 (8.5)	12	9
		Horizontal	74 (12)	95 (14)	138 (9.1)	77 (8.0)	12	10
	Small	Vertical	75 (13)	94 (12)	134 (7.0)	75 (7.2)	13	10
		Diagonal	75 (15)	94 (14)	131 (5.9)	78 (7.9)	12	10
		Horizontal	75 (15)	95 (13)	135 (8.0)	76 (7.3)	13	10

NOTE: AHR denotes Anticipatory Heart Rate (bt.min^{-1}).
EHR denotes Exertional Heart Rate (bt.min^{-1}).
Sys. denotes Systolic Blood Pressure (mmHg).
Dias. denotes Diastolic Blood Pressure (mmHg).
RPE denotes Rating of Perceived Exertion.
Vertical=90°; Diagonal=45°; Horizontal=0°.

The present study focused on control design and position, and the effect of these on the various isokinetic, cardiovascular and psychophysical responses. For this reason the following sections of this chapter have been divided into isokinetic, cardiovascular and psychophysical responses. In addition the sub-sections below concentrate on control types and spatial orientation followed by summaries and concluding remarks on each specific section. The main sections are followed by a discussion of ergonomic implications.

ISOKINETIC RESPONSES

The CYBEX ® 6000 work-simulation systems allows the user to simulate real-life working situations in the laboratory setting. Despite its relevance to the field of ergonomics very little research has been done using the CYBEX® 6000 work-simulation package, or similar apparatus and packages.

Control Types

The following results relate to the isokinetic responses on each control under each spatial orientation. Statistical analyses were conducted using one way ANOVAs (Isokinetic responses over control type). In all data presentations the Lever-type controls (largest to smallest) are shown first, followed by the Knob-type controls (largest to smallest). Due to the large number of significant differences in Peak Torque, Total Work and Average Power between the control types, only those combinations which were *not* significant are identified and/or mentioned in notations under the relevant Table. The details of the statistical analysis relating to $H_o1(b)$ can be found on page 164 (Appendix C).

TABLE VI: Isokinetic responses for all controls with the dynamometer in the vertical (90°) spatial orientation. (Means, with SD in brackets)

Control		**Peak Torque (Nm)**		**Total Work (J)**		**Average Power(W)**	
Type	**Size**	**Ext.**	**Int.**	**Ext.**	**Int.**	**Ext.**	**Int.**
Lever	Large	29.4 (6.3)	31.8 (7.9)	29.8 (8.0)	35.7 (8.9)	19.1 (4.6)	22.9 (5.1)
	Medium	21.2 (4.6)	22.6 (5.6)	20.9 (5.0)	24.6 (6.1)	14.0 (3.9)	16.2 (4.1)
	Small	10.6 (2.9)	12.3 (2.9)	10.2 (3.5)	13.3 (3.9)	6.6 (1.7)	8.2 (2.3)
Knob	Large	8.8 (2.8)	10.7 (3.1)	8.9 (3.9)	11.8 (4.7)	5.5 (2.4)	7.2 (2.5)
	Medium	5.1 (1.5)	6.4 (2.0)	4.7 (1.9)	6.3 (2.4)	3.1 (1.1)	4.0 (1.4)
	Small	2.6 (1.1)	3.4 (0.6)	2.0 (1.7)	3.6 (1.8)	1.4 (1.0)	2.1 (0.5)

NOTE: Significant Differences (p=0.0000) were encountered for all combinations of control types, internal and external rotation, except in the case of bracketed items: [Large Knob versus Small Lever (internal and external rotation); and Medium Knob versus Small Knob (internal and external rotation)].

The statistical analysis showed that significant isokinetic output differences were encountered in respect of all the controls except between the small lever and the large knob, and the medium knob and the small knob. This trend was encountered for all isokinetic responses of Peak Torque, Total Work and Average Power in the vertical position regardless of direction of rotation, Table VI.

However, in the diagonal spatial orientation only the comparisons between the small lever and large knob show no significant difference (Table VII) for all isokinetic responses. All other controls showed significant differences in Peak Torque, Total Work and Average Power, regardless of direction of rotation.

TABLE VII: Isokinetic responses for all controls with the dynamometer in the diagonal spatial orientation (45°). (Means, with SD in brackets)

Control		**Peak Torque (Nm)**		**Total Work (J)**		**Average Power(W)**	
Type	**Size**	**Ext.**	**Int.**	**Ext.**	**Int.**	**Ext.**	**Int.**
Lever	Large	28.3 (5.5)	24.0 (5.0)	31.5 (7.3)	27.4 (6.9)	20.2 (4.5)	17.7 (4.2)
	Medium	19.6 (3.1)	18.9 (4.0)	21.8 (5.7)	22.3 (5.7)	13.5 (2.0)	13.8 (3.1)
	Small	10.1 (2.7)	10.8 (2.7)	10.4 (3.4)	11.5 (3.5)	6.7 (1.8)	7.5 (2.1)
Knob	Large	8.7 (2.4)	10.9 (3.1)	9.7 (3.9)	12.5 (5.0)	6.0 (1.8)	7.9 (2.5)
	Medium	5.0 (1.7)	6.2 (2.1)	5.0 (2.1)	6.8 (2.8)	3.2 (1.4)	4.4 (1.5)
	Small	2.3 (1.1)	3.4 (0.6)	1.4 (1.1)	3.2 (1.1)	1.0 (0.6)	2.1 (0.6)

NOTE: Significant Differences (p=0.0000) were encountered for all combinations of control types, internal and external rotation, except in the case of bracketed items: [Large Knob versus Small Lever (internal and external rotation)].

Responses under the horizontal position are presented in Table VIII, and follow a similar trend to those elicited by the vertical spatial orientation. Once again all responses to the manipulation of the controls were significantly different except for the small lever and large knob, and the medium knob and the small knob.

TABLE VIII: Isokinetic responses for all controls with the dynamometer in the horizontal spatial orientation (0°). (Means, with SD in brackets)

Control		**Peak Torque (Nm)**		**Total Work (J)**		**Average Power(W)**	
Type	**Size**	**Ext.**	**Int.**	**Ext.**	**Int.**	**Ext.**	**Int.**
Lever	Large	28.3 (7.1)	23.4 (7.1)	32.7 (9.1)	29.5 (8.2)	20.4 (8.2)	18.7 (4.8)
	Medium	19.6 (4.1)	19.4 (4.0)	24.0 (6.5)	23.6 (6.2)	14.7 (3.8)	14.7 (3.6)
	Small	10.1 (2.9)	11.4 (2.6)	12.5 (4.2)	12.9 (3.8)	8.1 (2.7)	8.3 (1.9)
Knob	Large	8.7 (2.3)	9.5 (2.9)	9.2 (3.6)	10.9 (4.0)	5.7 (2.1)	6.7 (2.0)
	Medium	5.0 (1.4)	6.2 (1.9)	4.8 (1.7)	6.3 (2.4)	3.1 (1.3)	4.0 (1.5)
	Small	2.3 (1.1)	3.5 (0.6)	2.0 (1.1)	3.1 (1.2)	1.2 (0.5)	2.0 (0.6)

NOTE: Significant Differences (p=0.0000) were encountered for all combinations of control types, internal and external rotation, except in the case of bracketed items: [Large Knob versus Small Lever; and the Medium Knob versus Small Knob].

The fact that the small lever and large knob, and the medium and small knob were the only controls which did not elicit significant differences is a reflection of the size of the control. The small lever has an effort arm of 70mm, while the large knob has an effort arm of 50mm. One might assume that the small lever should provide significantly more torque, work and power, but this was not the case because the gripping area of the small lever was 900mm^2, while that of the large knob was 7 857mm^2. Given that the average subject's hand surface area was 16 471.3mm^2, it is clear that the large knob fitted more comfortably into the subject's hand while the small lever had a tendency to "disappear" in the operator's hand. All subjects were able to get a better hold on the large knob as opposed to the small lever, due to the larger gripping area. Because the leverage advantage offered by the small lever was nullified, no significant differences (p 0.05) were encountered.

The medium and small knobs elicited no significant differences during tests in the vertical and horizontal planes. Therefore, the optimum position for these controls was observed to be the diagonal spatial orientation. In this position significant differences were encountered in Peak Torque, Total Work and Average Power. This was due to the fact that the controls are small and the subjects found them difficult to hold, especially in the less comfortable postures of vertical and horizontal orientation. In the diagonal plane the natural angle of the working wrist helped the operator to use the advantage which the medium knob offered, namely more leverage due to a larger effort arm. As the advantage which the medium knob has over the small knob was only 10mm, this was nullified in the vertical and horizontal orientations, when the natural wrist posture disappears. This observation supports Oborne (1995) who argued that the posture of the wrist influences its mechanical advantage.

A large control is consistent with strength requirement, while a smaller control is usually used for fine manipulative functions (Drury, 1995; Oborne, 1995; Mac Duff **et al.,** 1997). These recommendations are supported in the present study in which the large lever and large knob provided for significantly higher Peak Torque, Total Work and Average Power outputs than the medium and small levers and knobs respectively, regardless of spatial orientation.

Spatial Orientations

Note: The details of the statistical analysis relating to $H_o1(a)$ can be found on page 164 (Appendix C).

The present study found some significant differences related to spatial orientations (Table IX). These results are in contrast to the results of a similar study by Mital and Kumar (1998) who showed that wrist orientation is critical and that 70% more torque is generated when wrenches were held in the horizontal plane as opposed to the vertical plane. However, this discrepancy is due to a number of reasons; firstly the studies were not identical; Mital and Kumar (1998) used wrenches and not knob or lever controls. While lever controls may be similar to some wrenches, the type used in the present study did not offer anything like the leverage advantage that wrenches do. Secondly, the present study used seated subjects, whereas Mital and Kumar (1998) used standing subjects who could take full advantage of leverage offered by the wrenches, especially in the horizontal plane.

The present study found that significant orientation-related differences were evident in the case of some of the levers, but none of the knob controls (see Table IX). This is because lever controls allowed the operator to use the upper body during maximal turning efforts in certain spatial orientations. On the other hand the knob controls do not offer this advantage, as most of the turning effort came from the forearm and not the shoulder as is the case with the Lever-type controls.

Table IX shows that the large and medium Lever-type controls produced significantly more torque in the vertical plane than in the diagonal and horizontal orientations during internal rotation, but not during external rotation. The reason offered is that all subjects were right-hand dominant; internal rotation allowed the use of the upper body during a maximal turning effort in some positions. The use of the large lever in the vertical orientation allowed the subjects to exert on average 1.34 times more internal rotation torque than in the diagonal or horizontal orientations. While internal rotation torque for the medium lever was 1.20 times higher in the same positions, it appears that maximisation of the torque when using a large or medium lever control is achieved when the lever is vertically orientated.

TABLE IX: Effect of Spatial Orientation on Peak Torque (Nm); Total Work (J) and Average Power (W). (Means with SD in brackets)

Measures	**Lever Size**	**Vertical Spatial Orientation (90°)**		**Diagonal Spatial Orientation (45°)**		**Horizontal Spatial Orientation (0°)**		**Significant Differences between Spatial Orientations**	
		Ext.	**Int.**	**Ext.**	**Int.**	**Ext.**	**Int.**	**Ext.**	**Int.**
Peak Torque	Large	29.4 (6.3)	31.8 (7.9)	28.3 (5.5)	24.0 (5.0)	28.3 (7.1)	23.4 (7.1)	**NS**	**90°;45°** (p=.0000) **90°;0°** (p=.0000)
	Medium	21.2 (4.6)	22.6 (5.6)	19.6 (3.1)	18.9 (4.0)	19.6 (4.1)	19.4 (4.0)	**NS**	**90°;45°** (p=.0046) **90°;0°** (p=.0046)
	Small	10.6 (2.9)	12.3 (2.9)	10.1 (2.7)	10.8 (2.7)	10.1 (2.9)	11.4 (2.6)	**NS**	**NS**
Total Work	Large	29.8 (8.0)	35.7 (8.9)	31.5 (7.3)	27.4 (6.9)	32.7 (9.1)	29.5 (8.2)	**NS**	**90°;45°** (p=.0004) **90°;0°** (p=.0004)
	Medium	20.9 (5.0)	24.6 (6.1)	21.8 (5.7)	22.3 (5.7)	24.0 (6.5)	23.6 (6.2)	**NS**	**NS**
	Small	10.2 (3.5)	13.3 (3.9)	10.4 (3.4)	11.5 (3.5)	12.5 (4.2)	12.9 (3.8)	**90°;0°** (p=.0303)	**NS**
Average Power	Large	19.1 (4.6)	22.9 (5.1)	20.2 (4.5)	17.7 (4.2)	20.4 (8.2)	18.7 (4.8)	**NS**	**90°;45°** (p=.0001) **90°;0°** (p=.0001)
	Medium	14.0 (3.9)	16.2 (4.1)	13.5 (2.0)	13.8 (3.1)	14.7 (3.8)	14.7 (3.6)	**NS**	**90°;45°** (p=.0447)
	Small	6.6 (1.7)	8.2 (2.3)	6.7 (1.8)	7.5 (2.1)	8.1 (2.7)	8.3 (1.9)	**90°;0°** (p=.0159) **45°;0°** (p=.0159)	**NS**

NOTE: NS denotes No Significant difference.

Total Work responses using the large lever mirror the trends of the Peak Torque responses (Table IX). The vertical position enables the operator using a large lever to produce, on average, 1.25 times more internal rotation Total Work output than do the diagonal and horizontal working planes. On the other hand the medium control did not show any work-related differences. Use of the small lever showed that external rotation differed between vertical and horizontal orientations. When positioned in the horizontal plane, it resulted in 1.23 times greater external work production than in a vertical spatial orientation. Once again the significant differences with regard to the large lever were during internal rotation while the differences with the small lever occurred during external rotation. As in the instance involving peak torque, this can be related to control size as the large lever was easier to grip and therefore it is more likely that the subjects were able to use the leverage offered by the larger control.

On average, the use of the large lever in a vertical plane allowed the operator to produce 1.25 times more power than in the diagonal and horizontal planes. The medium lever produced 1.20 times more power in the vertical plane than in the diagonal plane (Table IX). The small lever showed significant increases of 1.22 times more power during external rotation, in contrast to the large and medium levers, which only elicited significant differences during internal rotation. Meyer **et al.** (2000) found that the position of a large wheel did not significantly influence the power output produced, an observation supported in the present study which found that spatial orientation did not produce significant changes in power output for any of the Knob-type controls.

In summarising these responses it is noteworthy that spatial orientation only had a significant influence with the Lever-type controls, and then only under certain conditions. The Knob-type controls elicited no significant differences in any of the three spatial orientations. This is an important ergonomic finding as it suggests that knobs can be situated vertically, diagonally or horizontally, without fear of strength decrement due to spatial orientation; certainly when the spatial orientation of Knob-type controls is at 0°, 45° and 90° to the human operator and when the valve sizes are 25mm, 35mm and 50mm respectively. However, it must be remembered that these spatial orientations are not particularly awkward and it is possible that a strength decrement will occur if such controls are situated in awkward positions, i.e. under, behind or above fixed equipment. If the natural orientation of the wrist and hand are altered there will be a concomitant effect on mechanical advantage (Rebiffe, 1967; Chaffin, 1973; Oborne, 1995; Grandjean, 1998; Mital and Kumar, 1998). It is clear that in the present study the changes in spatial orientation did alter the mechanical advantage offered with regard to Lever-type controls in certain instances, whereas for the Knob-type controls there were no mechanical advantages. For the large and medium Lever-type controls the vertical spatial orientation seemed to have offered the user the best mechanical advantage. However, such advantage was only significant during the internal rotation phase of the maximal turning effort. In contrast, manipulation of the small lever only elicited significant differences during the external rotation motion and was best when in the horizontal plane. As discussed previously, the contrasting responses between the large and medium lever on the one hand and the small lever on the other can be related to the size of the controls.

Rotational Factors

In work-simulating testing on the CYBEX ® 6000 there is no alignment of the fulcrum of the dynamometer with the centre of the joint being tested such as is characteristic of clinical laboratory tests. The essence of this difference is that work-simulation more closely resembles the “real” working environment. Furthermore the valve turning test, as conducted in the present study, enables monitoring of the turning action in two directions, i.e. internal and external rotation, which simulates the closing and opening when taken in the context of a working situation for a right hand dominant operator. In the same way that control design and spatial orientation can impact torque, work and power, so hand dominance could influence the responses to internal and external rotation of the various controls in the three selected positions. Statistical analyses on internal and external rotation was done by means of a related t-test, one sample analysis ($p \ 0.05$). Since the responses for peak torque (Nm) and average power (W) echo the responses for total work, only the latter response is discussed.

Work values showed significant differences during testing in the vertical plane, regardless of control type (Table XIX). Internal rotation values were significantly larger than the external rotation values, as subjects were more easily able to use body weight in order to elicit a larger torque. In the vertical position internal rotation was executed more as a pull towards the body, while external rotation was a push away from the body. However, work values for the large Lever-type control in diagonal and horizontal spatial orientations were reversed; with external rotation significantly larger responses were recorded, because of the restriction caused by the change in the plane. In the vertical spatial orientation the shoulder and elbow movement was free of restrictions and the operator was able to use body weight and make use of the leverage offered by the control during the internal rotation phase. However, in the diagonal and horizontal planes the movement was restricted due to the elbow being forced in closer to the body because the lever position had been altered. This movement limited the range of motion, which in turn had an impact upon the internal rotation. These findings support Corlett **et al.** (1986) who suggested that anatomical restrictions will limit range of motion, thereby decreasing the potential forces exerted. With regard to external rotation, the restriction disappeared as the movement was now a push away from the body and therefore not restricted, thereby allowing the external rotators to operate with more force. This was evident in the differences between internal and external rotation responses using the large Lever-type control in all spatial orientations. In the vertical plane the operator was able to do 1.20 times more work in internal than in external rotation. In the diagonal plane this changed; external rotation was now 1.15 times more than internal rotation. Finally in the horizontal spatial orientation there was 1.11 times more strength in external rotation. The medium and small levers followed the same trend set by the large lever in the vertical plane, i.e. the internal rotators produced more work than the external rotators. However, for the medium lever no significant differences were seen in diagonal and horizontal spatial orientations. The small lever on the other hand did elicit significant differences in the diagonal plane, but not in the horizontal orientation. In the diagonal plane the small lever followed the trends set by all the knob controls; the internal rotators producing 1.10 times the work output of the external rotators, Table X.

TABLE X: Total Work (J) during maximal turning efforts.

Control		**Vertical Spatial Orientation (90°)**			**Diagonal Spatial Orientation (45°)**			**Horizontal Spatial Orientation (0°)**		
Type	**Size**	**Ext.**	**Int.**	**p**	**Ext.**	**Int.**	**p**	**Ext.**	**Int.**	**p**
Lever	Large	29.8	35.7	0.0000	31.5	27.4	0.0000	32.7	29.5	0.0000
	Medium	20.9	24.6	0.0000	21.8	22.3	NS	24.0	23.6	NS
	Small	10.2	13.3	0.0000	10.4	11.5	0.0388	12.5	12.9	NS
Knob	Large	8.9	11.8	0.0000	9.7	12.5	0.0000	9.2	10.9	0.0000
	Medium	4.7	6.3	0.0000	5.0	6.8	0.0000	4.8	6.3	0.0000
	Small	2.0	3.6	0.0000	1.4	3.2	0.0000	2.0	3.1	0.0000

NOTE: NS denotes No Significant difference (p 0.05)

The reason for the strength differences shown between the large, medium and small lever may be that the large Lever-type control had an effort arm of 120mm while the medium and small Lever-type controls had effort arms of 85mm and

70mm respectively. The medium Lever-type control had an effort arm 70.8% of the large Lever-type control while the small Lever-type control had an effort arm 58% of the large Lever-type control. The effort arm differences suggest that the operator was not able to use the leverage advantage as the anatomical restrictions caused by the changes in spatial orientation nullified the advantage, especially during internal rotation.

For the Knob-type controls the internal rotation values are significantly higher than the external rotation values for total work output, regardless of spatial orientation (Table X). Once again the reasoning is anatomical. Firstly the turning of a Knob-type control is done by the forearm and wrist, and does not involve use of the shoulder as is the case when controls offer leverage. Therefore the musculature involved is much smaller and the restrictions experienced by the large lever are not encountered. Turning a Knob-type control internally involves pronation, while turning externally involves supination of the forearm. As the turning of the Knob-type control took place with the arm in an extended position and not with the elbow flexed 90°, pronator teres increases in involvement due to an increased length tension relationship (Perrin, 1993). Supination of the forearm is achieved through the contraction of the supinator muscles and biceps brachii, particularly when the elbow is in a flexed position. However, in the present study the elbow was extended rather than flexed and this would have advantaged the length tension relationship of pronator teres, but disadvantaged biceps brachii during supination. This explains why for all knob controls internal rotation (pronation) values were larger than external rotation (supination) values of Total Work regardless of spatial orientation. These results are mirrored for Peak Torque and Average Power.

CONCLUDING REMARKS

Peak Torque

When a muscle is stimulated to contract it produces a force, which can be measured about a joint axis of rotation as a moment of force (torque). In the present study it was clear from Figure 15 that when the subjects used the Lever-type controls they were able to produce greater torque than when using the Knob-type controls, regardless of the spatial orientation of the dynamometer. In addition, size of control was seen to play a role, regardless of the orientation of the control or whether the control was lever or knob type design.

When the subjects used the large control they produced more torque than when using the medium and small control, and when using the medium control produced more torque than when using the small control (Figure 15). This trend is consistent with findings by Fransson and Winkel (1991), Fleming **et al.** (1997) and Milerad and Ericson (1994), who suggest that large controls should be used for tasks requiring forceful exertion and small controls for the manipulative functions.

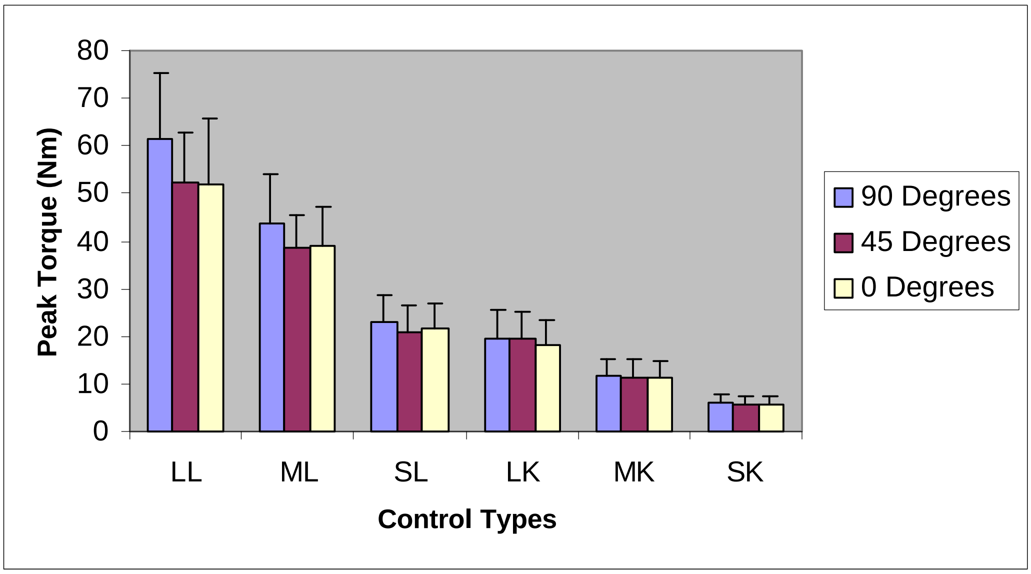

Figure 15: Peak Torque (Nm) trends, summed external and internal rotation values, for all controls in spatial orientations 90°;45°; 0°. Significant differences are indicated in Table IX.

With regard to the direction of motion, internal rotation produced higher torques than the external rotations, regardless of control design, when the spatial orientation of the dynamometer was vertical (Table IV). However, in diagonal and horizontal spatial orientations the trend changed; internal rotation was stronger with the Knob-type controls and the small Lever-type control only. The other two Lever-type controls showed that external rotation exceeded internal rotation. It is argued that this was because all the subjects (n=30) were right-hand dominant and that as the spatial orientation of the dynamometer became progressively more horizontal, subjects were able to exert more force in external rotation using body weight. This scenario was only true for the Lever-type controls, as they provided the operator more purchase for a pushing action.

Clearly size of lever is important, as external rotation diminished with a decrease in the size of the control.

Total Work

As mentioned in Chapter II, Perrin (1993) cautioned that there is a misconception that peak torque at slow velocities reflects strength, and at higher velocities reflects power. Determination of torque, work and power are independent of the testing velocity. In the present study one velocity, namely 60°.s^{-1} was used and this did manage to produce work and power responses. Table IV displays the isokinetic results viz. Peak Torque (Nm), Total Work (J) and Average Power (W) for all controls in the three spatial orientations.

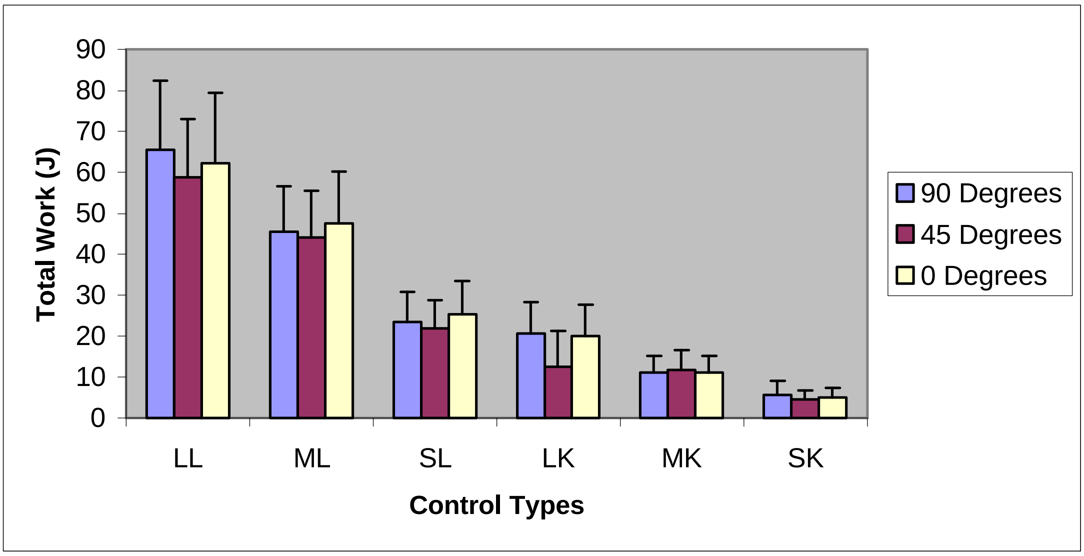

Figure 16: Total Work (J) trends, summed external and internal rotation values, for all controls in spatial orientations 90°; 45°; 0°. Significant differences are indicated in Table IX.

As expected, the trend in Figure 16 illustrated that the Lever-type controls allowed the operators to produce more Work output than when using the Knob-type control, regardless of spatial orientation, and that size once again played a role, allowing more work to be done with the larger controls, regardless of spatial orientation and control design. The same trend is seen for Total Work Output as for Peak Torque (Table IV). Work values for internal rotation were higher than for external rotation in the vertical plane, regardless of control design.

In the diagonal plane once again the Knob-type controls and the small lever exhibited higher internal rotation than external rotation work. The large lever permitted more work in external rotation. In contrast, the medium lever elicited a nominal advantage in internal rotation (Table IV).

Average Power

The summary data on Average Power (Table IV) shows that the Lever-type controls facilitate higher responses than Knob-type controls, regardless of spatial orientation, and that the size of the control played an important role in determining the amount of Average Power output the operator was able to generate. Larger controls, regardless of design, generated most power, followed by the medium size and lastly the smallest controls (Table IV and Figure 17). The power generated in external rotation on the Lever-type controls in the vertical plane was distinctly less than that produced in internal rotation. This trend was progressively reversed as the spatial orientation of the dynamometer shifted from a vertical to a horizontal position. The Knob-type controls did not show this trend, as internal rotation remained more powerful, regardless of spatial orientation (Table IV). In the cases of the medium and small levers, internal and external rotations were only marginally different (Table IV). Comparisons revealed that spatial orientation had very little effect on the power outputs, regardless of control type as the results were very similar. This was expected, given peak torque results.

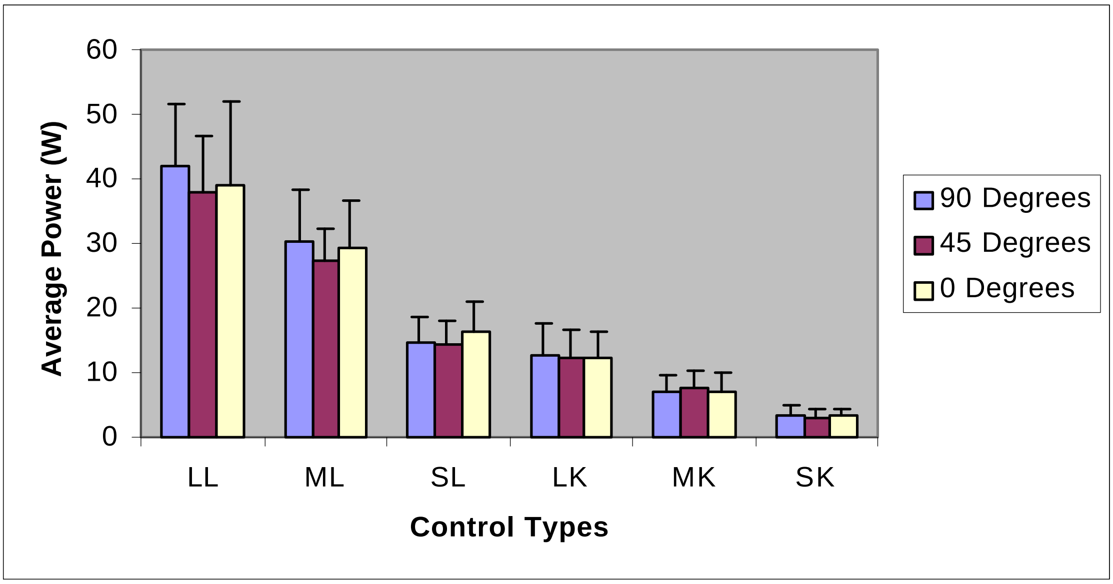

Figure 17: Average Power (W) trends, summed external and internal rotation values, for all controls in the spatial orientations 90°;45°; 0°. Significant differences are indicated in Table IX.

In general it can be seen that Peak Torque, Total Work and Average Power responses using the Lever-type controls outperformed those involving the Knob-type controls, and larger controls outperformed smaller controls. In addition the results show that spatial orientation had very little impact on the outcome of the isokinetic responses.

CARDIOVASCULAR RESPONSES

Note: The details of the statistical analysis relating to H_o2(a) and H_o2(b) can be found on page 165 (Appendix C).

In their study of cardiorespiratory and subjective strain during actuation of large hand wheels, Meyer **et al.** (2000) noted the importance of including physiological responses during repetitive hand wheel turning. The present study attests to the importance of this by measuring heart rate and blood pressure prior to testing and immediately post-task..

The cardiovascular responses (Table V) show that exertional heart rates increased over pre-exertion values under all conditions, regardless of control size, shape or spatial orientation. Post-task systolic blood pressure was elevated under all conditions, regardless of control design or spatial orientation over the pre-exertional resting level of 126.6 (±6.0) mmHg. The smallest increase (4.9 mmHg) occurred during use of the small knob in the diagonal plane, while the largest increase (15.4 mmHg) occurred during exertion on the large lever in the vertical plane. In contrast, diastolic blood pressure did not show the same increases. The largest increase (2.6 mmHg) was experienced during use of the small lever in a vertical orientation. In contrast to systolic blood pressure, diastolic blood pressure showed a decrease of 2.4 mmHg when using the large and medium levers in the horizontal plane. In general it was observed that systolic blood pressure showed sharp increases under certain conditions, while diastolic blood pressure remained fairly constant, regardless of control design or spatial orientation.

Heart Rate

Control Types

It is clear that the influence of control types on heart rate and blood pressure was minimal. Firstly, as expected, the anticipatory heart rate was not affected by the control design. The same is true for exertional heart rate except for work in the horizontal plane. In this plane significant differences were encountered between efforts made with the large and medium Lever-type controls and all the Knob-type controls, and between the large and small Lever-type controls. In addition, significant differences were elicited between the medium Lever-type control and all Knob-type controls.

All exertional heart rates (EHR) were significantly higher than the anticipatory heart rates (AHR), regardless of spatial orientation and control design (Table XI, page 95). There were no differences in anticipatory heart rate for all conditions and the heart rates returned to baseline within one minute of completing the activity as no residual exertion was evident. Exertional heart rate did show significant differences due to control design in the horizontal plane (Table XI). As no significant differences were experienced in vertical and diagonal spatial orientations, it can be assumed that the horizontal plane provided a working situation in which the extra leverage offered by the large and medium Lever-type controls enabled the operator to work harder, producing a higher exertional heart rate, as opposed to when working with the small Lever-type control and all the Knob-type controls (Table XI).

TABLE XI: Heart Rate (bt.min^{-1}) responses for control type and spatial orientations. (Means with SD in brackets)

Control		Orientation	AHR	EHR	$^{\text{EHR-AHR}}/_{\text{AHR}}\%$	EHR (%age-pred. max)
Type	**Size**					
Levers	**Large**	Vertical	74 (12)	102 (12)	37.8	51.3
		Diagonal	73 (12)	103 (12)	41.1	51.8
		Horizontal	73 (13)	108 (13)	47.9	54.0 **(52.4)**
	Medium	Vertical	75 (14)	102 (13)	36.0	51.3
		Diagonal	75 (13)	102 (14)	36.0	51.3
		Horizontal	75 (14)	105 (16)	40.0	52.3 **(51.6)**
	Small	Vertical	73 (12)	93 (11)	27.4	46.7
		Diagonal	71 (11)	95 (10)	33.8	47.7
		Horizontal	71 (13	97 (11)	36.6	48.7 **(47.7)**
Knobs	**Large**	Vertical	74 (15)	95 (14)	28.4	47.7
		Diagonal	72 (11)	98 (15)	36.1	49.2
		Horizontal	72 (12)	95 (14)	31.9	47.7 **(48.2)**
	Medium	Vertical	75 (14)	96 (14)	28.0	48.2
		Diagonal	72 (13)	95 (14)	31.9	47.7
		Horizontal	74 (12)	95 (14)	28.4	47.7 **(47.9)**
	Small	Vertical	75 (13)	94 (12)	25.3	47.2
		Diagonal	75 (15)	94 (14)	25.3	47.2
		Horizontal	75 (15)	95 (13)	26.7	47.7 **(47.4)**

Note: AHR denotes: Anticipatory Heart Rate.
EHR denotes: Exertional Heart Rate.
Age-predicted maximum heart rate = 199. (220yr-21yr).
Values in **bold font brackets** are the means for the specified control over all three spatial orientations.

In order to establish the extent of the increases in the heart rate the following equation was used:

$$^{\text{EHR} - \text{AHR}}/_{\text{AHR}}\ \%$$

Where: AHR denotes: Anticipatory Heart Rate.
EHR denotes: Exertional Heart Rate.

On average the increases range from 25.3%, small knob in vertical and diagonal orientations, to 47.9%, large lever control in horizontal orientation. In a similar way exertional heart rate was expressed as a percentage of the subjects' mean age-predicted maximum heart rate (Table XI).

Although the subjects in the present study were forced physically with a whole body type activity, the results indicate that four maximum efforts with one hand turning action does place the cardiovascular system under pressure. Regardless of plane of motion, the Lever-type controls had subjects working at 50.5% of their age-predicted maximum heart rate and the Knob-type controls had subjects working at 47.8% of their age-predicted maximum heart rate. Taken in context of an industrial working day, where it is argued that in an eight-hour shift work demands should not exceed 50% of maximum heart rate, they reflect reasonably high outputs. In a study by Meyer **et al.** (2000), turning wheel valves was described as hard work by the workers. In addition it is pointed out that due to fouling of valves, 90% required an initial 400Nm to open them (Meyer **et al.,** 2000).

Spatial Orientation

No significant differences were encountered for anticipatory or exertional heart rate with respect to changes in plane of motion.

Blood Pressure

Control Types

In any form of exertion blood pressure is likely to change, more so in respect of systolic than diastolic blood pressure (McArdle **et al.,**1991). This was evident in the present study which revealed that changes in control type exerted no significant effect on diastolic blood pressure, but did have an effect on the systolic blood pressure (Table XII). When using the large lever in the vertical plane, systolic pressure was significantly different from that when using the medium and small Knob-type controls. An increase in systolic pressure was also evident with large and medium Lever-type controls and the medium Knob-type control in the diagonal plane, when compared to the pressures elicited by exertion on the small knob type control (Table XII).

It is clear that the responses using Lever-type controls were significantly different from those elicited by the Knob-type controls. These differences are probably due to the amount of leverage offered by the control, for where the effort arm was larger, a significant difference was encountered as the subject was able to work harder, the result being a slightly higher systolic blood pressure. Of interest is the fact that in the horizontal plane the control types did not elicit any significant differences in either systolic or diastolic blood pressure. This did not echo the exertional heart rate responses in the same plane. However, this was not entirely unexpected as the awkwardness of the working posture could have nullified the effect of control design which was evident in the vertical and diagonal planes.

TABLE XII: Blood Pressure (mmHg) responses, resting (Rest) and exertional (Exer), for control types during all the spatial orientations.

Control			**Systolic Blood Pressure**		**Diastolic Blood Pressure**	
Type	**Size**	**Orientation**	**Rest**	Exer.	**Rest**	Exer.
Lever	Large	Vertical (90°)	126	142	76	76
		Diagonal (45°)	126	138	76	75
		Horizontal (0°)	126	137	76	74
	Medium	Vertical (90°)	126	140	76	74
		Diagonal (45°)	126	141	76	75
		Horizontal (0°)	126	141	76	74
	Small	Vertical (90°)	126	139	76	79
		Diagonal (45°)	126	138	76	76
		Horizontal (0°)	126	136	76	76
Knob	Large	Vertical (90°)	126	136	76	78
		Diagonal (45°)	126	137	76	79
		Horizontal (0°)	126	139	76	79
	Medium	Vertical (90°)	126	134	76	76
		Diagonal (45°)	126	139	76	78
		Horizontal (0°)	126	138	76	77
	Small	Vertical (90°)	126	134	76	75
		Diagonal (45°)	126	131	76	78
		Horizontal (0°)	126	135	76	76

With regard to systolic and diastolic blood pressure, the present study shows significant differences between the resting and exertional systolic blood pressure ,while experiencing no significant differences between the resting and exertional diastolic blood pressure. These findings correspond with numerous others showing increases in systolic but not diastolic blood pressure during exercise. This type of finding is important in an ergonomics context as it shows that turning a valve can, as easily as picking up a heavy object, cause blood pressure to rise. Therefore, people with a history of coronary heart disease should be cautioned in respect of such activities.

It is clear that maximal-effort valve turning, regardless of spatial orientation and control design, causes the operator significant strain, evident in elevated exertional heart rates and systolic blood pressure. Such tasks can involve short but hazardous cardiovascular strains, about which workers may be unaware (Meyer **et al.,** 2000). Therefore, from an industrial point of view it is important that these workstations be manned by operators who are in good physical condition.

Spatial Orientation

Changes in the plane of motion did not produce any significant differences in systolic nor diastolic blood pressure.

PSYCHOPHYSICAL RESPONSES

The Psychophysical responses in the present study support the general trend established by the isokinetic and cardiovascular responses, in that while spatial orientation had no impact on the responses, control design did affect responses under certain conditions.

Ratings of Perceived Exertion

During any form of physical activity most people have a perception of the amount of effort they are exerting. Therefore the present study used the 15 point rating scale of Perceived Exertion (RPE) devised by Borg (1970) and responses were recorded in respect of “local factors”, reflecting sensations of strain in the muscles and joints of the hand and arm, and “central factors”, reflecting sensations primarily associated with the cardio-respiratory system (Pandolf, 1978). Statistical analyses showed that differences were only encountered for local RPE and not central RPE, and then only in responses to changes in the design of the control.

Experiments using the Borg RPE scale on whole-body, continuous work have demonstrated close correlation between the RPE scores and heart rates (Mihevic, 1981). However, in the present study the activity under investigation was of short duration, with an isolated muscle-group. It is therefore not surprising that the correlation between the Central RPE scores and heart rates was r=0.14, and between Local RPE scores and heart rates was r=0.17.

Borg (1970) had suggested that multiplying the RPE by 10 would approximate heart rate. The following two figures show the disparity between heart rate (HR) and 10· RPE (given by 10· RPE~HR).

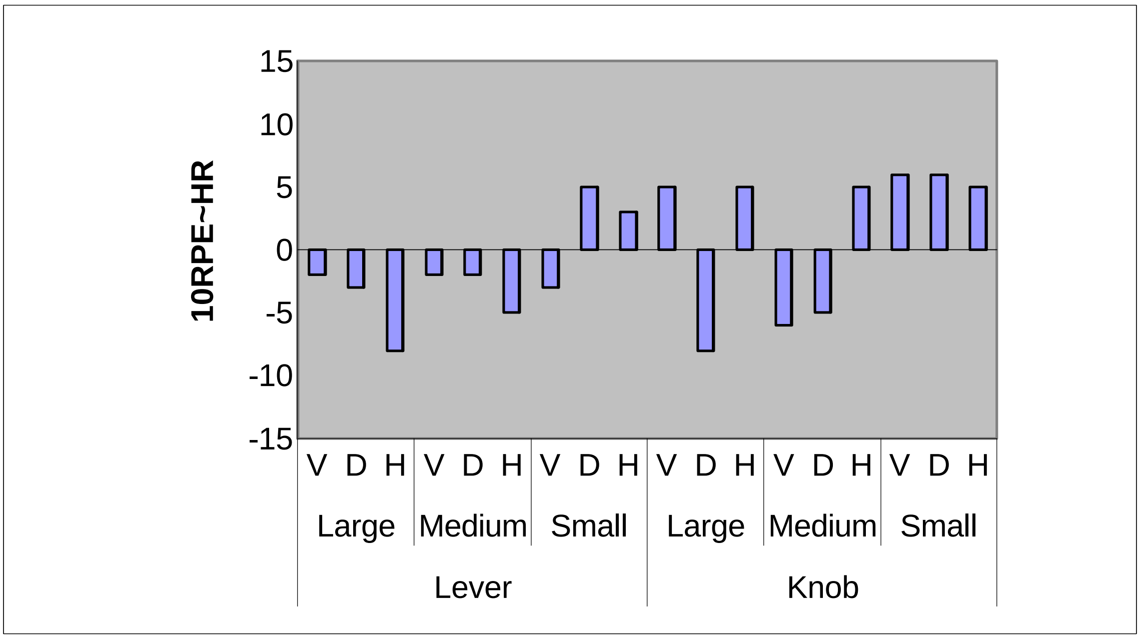

Figure 18: Central RPE disparity between heart rate and 10· RPE.

Disparity between HR and 10· RPE (Central) is shown in Figure 18 and the consistent ascendance of 10· RPE (Local) over HR is shown in Figure 19. Central RPE was in most cases within ± 6bt.min^{-1} and from Figure 18 it is evident that there was relatively greater congruence between the two variables when using large and medium levers.

Cumulative trauma disorders (CTDs) of the upper extremities, particularly the hands and wrist, are associated with three general occupational risk factors; repetition, force and awkward posture. In the present study all the conditions exhibited the latter two factors with only four repetitions required from the subjects. The general trend established was that the disparity between the HR and 10· RPE increases as the type of control changes from a Lever-type to a Knob-type control and also as the size of the control decreases (Figure 19). In addition the high rating could be due to the subjects rating higher on the perceived discomfort as opposed to the perceived exertion. High ratings of perceived discomfort were recorded for the hand and wrist, the exact area used during the local RPE observations (See following section).

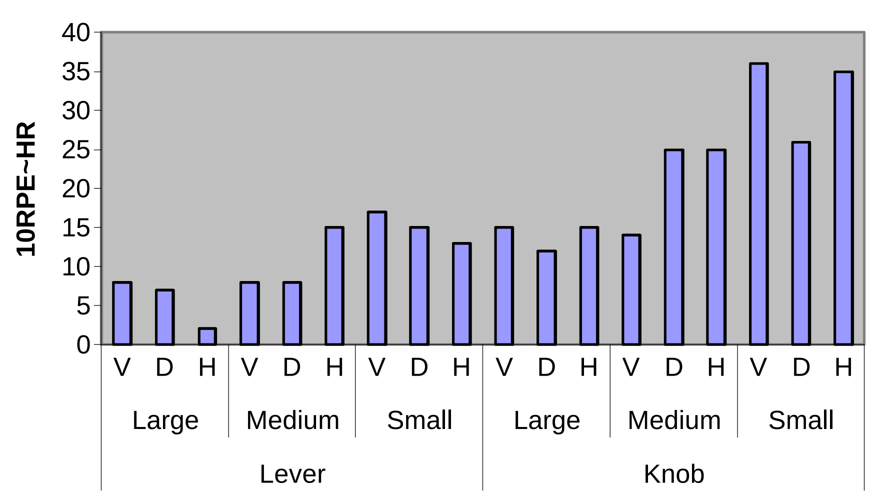

Figure 19: Local RPE disparity between heart rate and 10· RPE.

Perceived Discomfort

As important as determining perception of exertion during the execution of an activity, is the determination of perceived discomfort experienced by the subjects. In the present study, perceived discomfort was divided into two categories, i.e. “Overall” Perceived Discomfort (OPD) and “Local” Perceived Discomfort (LPD).

The scheme used for perception of overall body discomfort appears in appendix B (p161). For the observation of OPD, subjects were instructed to indicate the anatomical region experiencing the most discomfort, and to rate the intensity of the discomfort on the scale. Statistical analyses of these observations showed that spatial orientation had no significant effect on the outcome of the observations, while control design did impact in certain areas. These areas were the hand and the wrist, the two areas predominantly used in the production of the four maximal turning efforts.

Due to the nature of the study, OPD ratings were dominated by responses relating to the hand. Of all the OPD responses recorded for specific conditions, the average percentage for the hand ranged from 74.4% (medium knob in a horizontal orientation) to 96.8% (small knob in a vertical orientation). The area experiencing the next highest responses was the wrist (Table XIII).

TABLE XIII: Overall Perceived Discomfort (OPD) responses for all controls and spatial orientations.

Control			**Hand**		**Wrist**		**Forearm**		**Upper-arm**		**Shoulder**	
Type	**Size**	**Orientation**	%	INT	%	INT	%	INT	%	INT	%	INT
Lever	Large	Vertical	88.2	4	5.8	2	2.9	2	0.0	0	3.1	4
		Diagonal	80.0	4	5.7	2	2.9	4	2.8	6	8.6	4
		Horizontal	81.3	4	3.1	5	9.3	3	6.3	3	0.0	0
	Medium	Vertical	77.0	5	12.8	2	2.6	4	0.0	0	7.6	2
		Diagonal	81.1	5	10.8	4	8.1	3	0.0	0	0.0	0
		Horizontal	77.0	5	5.1	2	12.8	3	2.6	3	2.5	4
	Small	Vertical	83.3	5	2.7	2	8.4	3	5.6	3	0.0	0
		Diagonal	85.7	5	5.7	5	5.7	2	0.0	0	2.9	4
		Horizontal	85.7	6	5.7	4	8.6	3	0.0	0	0.0	0
Knob	Large	Vertical	82.9	5	8.6	4	5.7	4	2.8	1	0.0	0
		Diagonal	80.0	5	8.6	4	5.7	3	5.7	4	0.0	0
		Horizontal	77.0	6	10.1	4	10.2	2	2.7	6	0.0	0
	Medium	Vertical	82.9	6	11.4	4	5.7	4	0.0	0	0.0	0
		Diagonal	85.3	6	11.8	4	2.9	5	0.0	0	0.0	0
		Horizontal	74.4	6	12.8	5	7.7	4	0.0	0	5.1	2
	Small	Vertical	96.8	7	3.2	6	0.0	0	0.0	0	0.0	0
		Diagonal	90.9	7	3.1	2	3.0	2	0.0	0	3.0	1
		Horizontal	85.7	7	8.6	5	5.7	4	0.0	0	0.0	0

NOTE: % denotes the percentage of the total number of observations for a specific site for the specified control and spatial orientation.
INT denotes the mean intensity of discomfort.

Table XII shows that the rating of discomfort gradually increased from large lever, through lever and Knob-type controls, to small Knob-type control at the end. These data follow the same pattern as the isokinetic responses for Peak Torque, Total Work and Average Power. The subjects perceived less discomfort with the Lever-type controls and could therefore perform better. In a similar fashion the rating of perceived local and central RPE increased with a move from the Lever-type to the Knob-type controls and changes in size from largest to smallest.

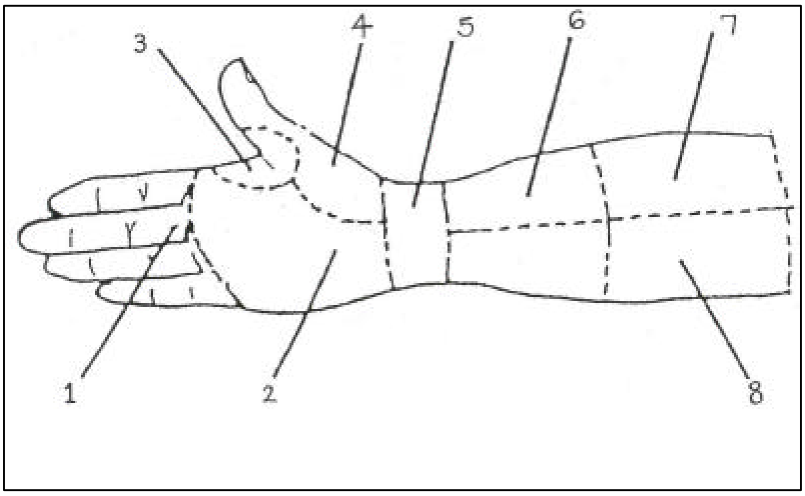

Figure 20: Localised Perceived Discomfort (LPD).

Rating of Localised Perceived Discomfort (LPD), Figure 20, was deemed essential in the present study due to the nature of the tasks. The expectation had been that most of the LPD would relate to the hand, wrist and forearm. The results (Table XIV) show that this assessment was correct; OPD was dominated by the hand and wrist, regardless of control design or spatial orientation. Localised Perceived Discomfort simply required subjects to identify areas experiencing discomfort: subjects were not required to rate the discomfort. Statistical analyses of these responses high-lighted the trends already established, that spatial orientation had no impact on the outcome of the results while control design did, under certain conditions. The areas that did encounter significant differences due to control design were the areas of fingers and the palm of the hand (Figure 20).

TABLE XIV: Localised Perceived Discomfort (LPD) observations: Frequency of citations (%).

Control			Total	% in area 1	% in area 2	% in area 3	% in area 4	% in area 5	% in area 6	% in area 7	% in area 8
Type	**Size**	**Orientation**									
Lever	Large	Vertical	56	19.6	39.3	10.7	21.4	3.6	1.8	1.8	1.8
		Diagonal	45	22.2	53.3	6.6	8.8	4.5	0.0	2.3	2.3
		Horizontal	46	21.7	50.0	10.9	8.7	2.2	0.0	2.2	4.3
	Medium	Vertical	56	23.2	48.2	8.9	12.5	3.6	0.0	1.8	1.8
		Diagonal	62	25.8	41.9	12.9	12.9	3.3	1.6	0.0	1.6
		Horizontal	60	31.7	45.0	6.6	10.0	0.0	1.7	1.7	3.3
	Small	Vertical	61	26.2	36.1	9.8	23.0	0.0	1.6	0.0	3.3
		Diagonal	63	33.3	30.2	19.0	15.9	1.6	0.0	0.0	0.0
		Horizontal	61	39.3	36.1	13.2	9.8	0.0	0.0	1.6	0.0
Knob	Large	Vertical	55	45.5	23.6	9.1	16.4	3.6	0.0	0.0	1.8
		Diagonal	58	44.8	19.1	8.6	22.4	1.7	1.7	1.7	0.0
		Horizontal	68	39.7	23.5	13.3	17.6	2.9	0.0	1.5	1.5
	Medium	Vertical	61	41.1	24.6	11.5	18.0	1.6	0.0	1.6	1.6
		Diagonal	62	38.7	19.4	17.7	19.4	3.2	0.0	0.0	1.6
		Horizontal	68	39.7	22.1	16.2	17.6	2.9	0.0	0.0	1.5
	Small	Vertical	80	30.0	27.5	20.0	22.5	0.0	0.0	0.0	0.0
		Diagonal	78	30.8	28.2	19.2	21.8	0.0	0.0	0.0	0.0
		Horizontal	79	30.4	30.3	19.0	16.4	1.3	0.0	1.3	1.3

Note: Total denotes the total number of discomfort ratings recorded for the specific control and spatial orientation.

The dominant area of discomfort in respect of the large and medium lever control type was the palm (Area 2) regardless of control design (Table XIV). The small lever experiences most discomfort in the palm area (Area 2) during efforts made in the vertical plane, but this shifted to the area of the fingers (Area 1) for efforts made in diagonal and horizontal spatial orientations. With regard to the Knob-type controls, the fingers experienced the highest percentage of discomfort regardless of control design and spatial orientation, Table XIV. This could be because in many cases the subject’s hands fitted over the edge of the circular surface and experienced the edges cutting into the fingers during forceful actions.

In contrast, the efforts made using the large and medium Lever-type controls elicited discomfort across the palm of the hand (Area 2). This was due to the fact that the palm was now on the edge, putting localised pressure into the hand as the fingers totally encompassed the handle. However, this was not true of the smallest lever, regardless of spatial orientation. In the vertical plane the action involved a push/pull motion and therefore discomfort was experienced in the palm of the hand (Area 2). However, in diagonal and horizontal orientations the awkward position and the small surface area of the handle caused the subjects to grip with their fingers, thereby causing discomfort to be experienced in the fingers (Area 1). It is clear that fingers and palm of the hand (Areas 1 and 2) dominated the LPD with combined percentages upwards of 57.5%, regardless of control design or spatial orientation.

Selection Ps

The present study deemed it important to observe the perceptions of the subjects both before and after the task with regard to control design. For this reason subjects were instructed to rank the six controls from “best” (1) to “worst” (6), both before testing commenced and again after testing, Table XV.

TABLE XV: Pre- and post-test control design selection ps.

Control Type	**Lever**			**Knob**		
Size	**Large**	**Medium**	**Small**	**Large**	**Medium**	**Small**
Pre Test Selection	1	2	5	4	3	6
Post Test Selection	1	2	4	3	5	6

Exertions involving the large and medium levers exceeded those on all other controls and this work output was reflected in the subjects' ps for the controls, as these controls were rated "best" and "second best" on completion of pre- and post-testing selection ps. In addition the small knob elicited the lowest physical responses and during the p selection phase was voted the "worst" control in both pre- and post-testing p selection (Table XV). However, the rating of the remaining three controls differed from pre- to post-testing p selection. The medium knob was seen during the pre-testing as the "third best" control, but dropped to the "second worst" control in the post testing selection. The reason for this is that it looked and felt good to the subjects at the start but as soon as a forceful exertion was required, the control pressed excessively into the subjects' fingers and hands, which was not evident with the large knob. Therefore the large knob moved up a position from 4th to 3rd. It is of interest to note that the small lever improved its rating from 5th to 4th. Many subjects thought before the testing that the small lever would be difficult to handle due to the smallness of size. Although the small lever was identified as being too small and not allowing forceful actions to be generated during isokinetic testing, it did not cause pain to the subjects as did the medium knob.

ERGONOMIC IMPLICATIONS

Predictive Data

The ability to estimate responses before an operation has taken place has industrial relevance. It has already been shown by numerous authors and confirmed in the present study, that large controls are consistent with forceful actions while the smaller controls are more suited to fine-tuning manipulation. However, it is the intermediate controls which fall into a grey area. In the present study the outputs using the large lever and large Knob-type controls exceeded those of the medium and small controls in torque, work and power, regardless of spatial orientation. Therefore the present study deemed it possible to be able to predict the responses of the controls in the grey area by comparing their outputs to those of the large controls.

Lever-Type Controls

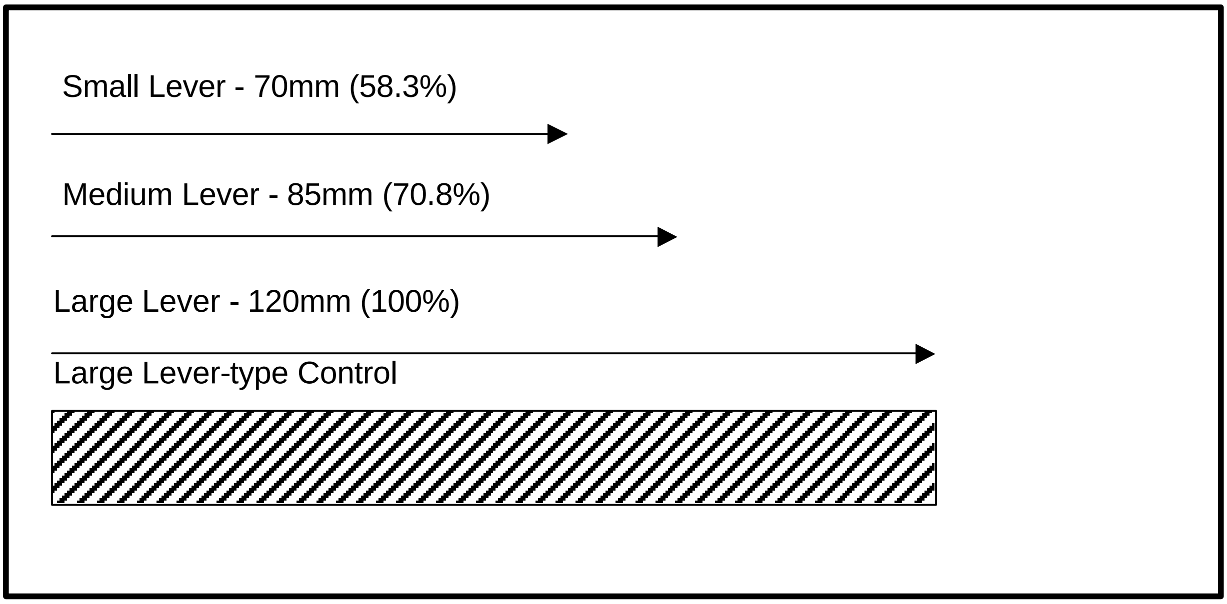

FIGURE 21: Lever-type control effort arms (mm) and as percentages of the large Lever-type control's effort arm (Diagram is drawn to scale).

Figure 21 shows the medium lever to have an effort arm 70.8 % that of the large lever, and the small lever 58.3% that of the large lever. It can therefore be predicted that the peak torque, total work and average power produced by the medium and small levers will be 70.8% and 58.3%, respectively, of the results achieved by the large lever. Tables XVI to XVIII show the actual responses and relate these to the outputs of the large lever in the form of over (+) and under (-) predictions.

TABLE XVI: Predicted Peak Torque values (Nm) relative to those obtained on the large lever (effort arm length 120mm) in the three test planes (vertical 90°, diagonal 45°, horizontal 0°).

Lever Characteristics	Orientation	Peak Torque (Nm)				Accuracy of prediction $[1.00-(^{A}/_{P})]\cdot 100$	
		Ext.		Int.			
		Pred.	Act.	Pred.	Act.	Ext.	Int.
LARGE: **(ea 120mm)** **($^{ea}/_{120}$)%=100**	Vertical	-	29.4	-	31.8	N/A	N/A
	Diagonal	-	28.3	-	24.0	N/A	N/A
	Horizontal	-	27.6	-	24.4	N/A	N/A
MEDIUM: **(ea 85mm)** **($^{ea}/_{120}$)%=70.8%**	Vertical	20.8	21.2	22.5	22.6	-1.9	-0.4
	Diagonal	20.0	19.6	17.0	18.9	+2.0	-11.2
	Horizontal	19.5	19.6	17.3	19.4	-0.5	-12.1
SMALL: **(ea 70mm)** **($^{ea}/_{120}$)%=58.3%**	Vertical	17.1	10.6	18.5	12.3	+38.0	+33.5
	Diagonal	16.5	10.1	14.0	10.8	+.38.8	+22.9
	Horizontal	16.1	11.2	14.2	11.4	+30.4	+.9.7

*Note: These columns express % over (+) or under (-) prediction.

Peak torque predictions responses show that the medium Lever-type control achieved more than was expected, since in all situations barring one, external rotation during diagonal spatial orientation, were under-predicted (Table XVI). External rotation in the diagonal plane showed an over-prediction of only two percent. In contrast, outputs on the small lever showed over-predictions exceeding 22% in five out of the six cases and of nearly 10% in the remaining case, which involved internal rotation in the horizontal plane. In general it can be seen that with regard to peak torque production, the medium lever allowed the user to produce torque values exceeding the expected results. In contrast, the values obtained from usage of the small lever were below the expected results. Similar trends were experienced for Total Work(Table XVII) and Average Power (Table XVIII).

TABLE XVII: Predicted Total Work values (J) relative to those obtained on the large lever (effort arm length 120mm) in the three test planes (vertical 90°, diagonal 45°, horizontal 0°).

Lever Characteristics	**Orientation**	**Total Work (J)**				**Accuracy of prediction $[1.00-(^A/_P)]\cdot 100$**	
		Ext.		**Int.**			
		Pred.	**Act.**	**Pred.**	**Act.**	**Ext.**	**Int.**
LARGE: (ea 120mm) ($^{ea}/_{120}$)%=100	Vertical	-	29.8	-	35.6	N/A	N/A
	Diagonal	-	31.5	-	27.4	N/A	N/A
	Horizontal	-	32.7	-	29.5	N/A	N/A
MEDIUM: (ea 85mm) ($^{ea}/_{120}$)%=70.8%	Vertical	21.1	20.9	25.2	24.6	+1.0	+2.4
	Diagonal	22.3	21.8	19.4	22.3	+2.2	-14.9
	Horizontal	23.2	24.0	20.9	23.6	-3.4	-12.9
SMALL: (ea 70mm) ($^{ea}/_{120}$)%=58.3%	Vertical	17.4	10.2	20.8	13.2	+41.4	+36.5
	Diagonal	18.4	10.4	16.0	11.5	+43.5	+28.1
	Horizontal	19.1	12.5	17.2	12.9	+34.6	+25.0

*Note: These columns express % over (+) or under (-) prediction.

TABLE XVIII: Predicted Average Power values (W) relative to those obtained on the large lever (effort arm length 120mm) in the three test planes (vertical 90°, diagonal 45°, horizontal 0°).

Lever Characteristics	**Orientation**	**Average Power (W)**				**Accuracy of prediction $[1.00-(^{A}/_{P})]\cdot 100$**	
		Ext.		**Int.**			
		Pred.	**Act.**	**Pred.**	**Act.**	**Ext.**	**Int.**
LARGE: (ea 120mm) ($^{ea}/_{120}$)%=100	Vertical	-	19.1	-	22.9	N/A	N/A
	Diagonal	-	20.2	-	17.7	N/A	N/A
	Horizontal	-	20.4	-	18.7	N/A	N/A
MEDIUM: (ea 85mm) ($^{ea}/_{120}$)%=70.8%	Vertical	13.5	14.0	16.2	16.2	-3.7	0.0
	Diagonal	14.3	13.5	12.5	13.8	+5.6	-10.4
	Horizontal	14.4	14.7	13.2	14.7	-2.1	-11.4
SMALL: (ea 70mm) ($^{ea}/_{120}$)%=58.3%	Vertical	11.1	6.6	13.4	8.2	+40.5	+38.8
	Diagonal	11.8	6.7	10.3	7.5	+43.2	+27.2
	Horizontal	11.9	8.1	10.9	8.3	+31.9	+23.9

*Note: These columns express % over (+) or under (-) prediction.

As mentioned previously, there is a discrepancy between the predicted values of the small and medium lever. This is probably due to the fact that the small lever has a surface area of 900mm^2 and the operators find it difficult to hold the small lever without it getting "lost" in their hands (the medium lever has a surface area of 2 100mm^2). The average surface area of the subjects' dominant hand was 16471.43mm^2; thus the larger surface area of the medium lever provided a surface that fitted comfortably into the subjects' hands, allowing maximum use of the leverage. This argument was used earlier in Chapter IV to explain the discrepancy between the large Knob-type control and the small Lever-type control, which have similar effort arms but very different surface areas.

Knob-Type Controls

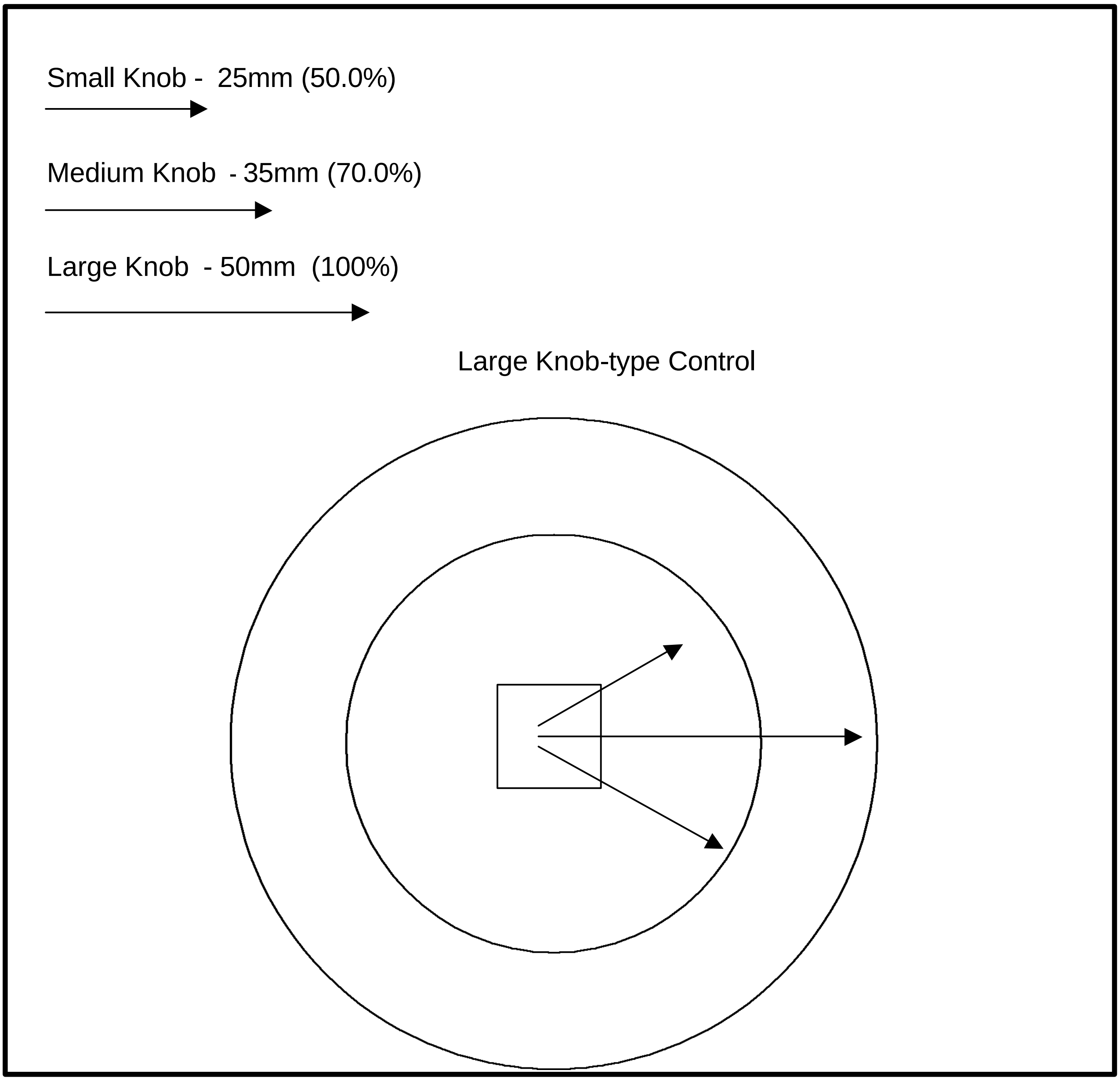

FIGURE 22: Knob-type control effort arms (mm) and as percentages of the large Knob-type control's effort arm (Diagram is drawn to scale).

Figure 22 shows that the small and medium Knob-type controls have respectively 50.0% and 70.0% the effort arm of the large Knob-type control and therefore should produce 50%, in the case of the small knob, and 70%, in the case of the medium knob, of the Peak Torque, Total Work and Average Power generated by the large knob (Tables XIX to XXI).

TABLE XIX: Predicted Peak Torque values (Nm) relative to those obtained on the large Knob (effort arm length 50 mm) in the three test planes (vertical 90°, diagonal 45°, horizontal 0°).

Knob Characteristics	**Orientation**	**Peak Torque (Nm)**				**Accuracy of prediction $[1.00-(^{A}/_{P})]\cdot\ 100$**	
		Ext.		**Int.**		**Ext.**	**Int.**
		Pred.	**Act.**	**Pred.**	**Act.**		
LARGE: (ea 50mm) ($^{ea}/_{50}$)%=100	Vertical	-	8.7	-	10.6	N/A	N/A
	Diagonal	-	8.7	-	10.9	N/A	N/A
	Horizontal	-	8.0	-	9.5	N/A	N/A
MEDIUM: (ea 35mm) ($^{ea}/_{50}$)%=70.0%	Vertical	6.1	5.1	7.4	6.4	+16.4	+13.5
	Diagonal	6.1	5.0	7.6	6.2	+18.0	+18.4
	Horizontal	5.6	4.8	6.7	6.2	+14.3	+7.5
SMALL: (ea 25mm) ($^{ea}/_{50}$)%=50.0%	Vertical	4.4	2.6	5.3	3.4	+40.9	+35.8
	Diagonal	4.4	2.3	5.5	3.4	+47.7	+38.2
	Horizontal	4.0	2.5	4.8	2.0	+37.5	+57.9

*Note: These columns express % over (+) or under (-) prediction.

In all cases relating to the prediction of torque generation by the medium and small Knob-type controls, the figures were over-predicted, Table XIX. Over-predictions for the medium knob ranged from 7.5% to 18%, while for the small knobs they ranged from 37.5% to 57.9%, Table XIX. This is in direct contrast to the predictions for torque values for the Lever-type controls. The same trend as illustrated in Table XIX is evident in Tables XX and XXI with all predictions, barring one, showing over-predictions in excess of 14%. The only exception being for Average Power, the medium Knob-type control during internal rotation in the horizontal plane.

TABLE XX: Predicted Total Work values (J) relative to those obtained on the large Knob (effort arm length 50 mm) in the three test planes (vertical 90°, diagonal 45°, horizontal 0°).

Knob Characteristics	**Orientation**	**Total Work(J)**				**Accuracy of prediction $[1.00-(^{A}/_{P})]\cdot 100$**	
		Ext.		**Int.**			
		Pred.	**Act.**	**Pred.**	**Act.**	**Ext.**	**Int.**
LARGE: (ea 50mm) $(^{ea}/_{50})$%=100	Vertical	-	8.9	-	11.8	N/A	N/A
	Diagonal	-	9.7	-	12.5	N/A	N/A
	Horizontal	-	9.2	-	10.9	N/A	N/A
MEDIUM: (ea 35mm) $(^{ea}/_{50})$%=70.0%	Vertical	6.2	4.7	8.3	6.3	+24.2	+24.1
	Diagonal	6.8	5.0	8.8	6.8	+26.5	+22.7
	Horizontal	6.4	4.8	7.6	6.4	+25.0	+19.0
SMALL: (ea 25mm) $(^{ea}/_{50})$%=50.0%	Vertical	4.5	2.0	5.9	3.6	+55.5	+39.0
	Diagonal	4.9	1.4	6.3	3.2	+71.4	+49.2
	Horizontal	4.6	2.0	5.5	3.1	+56.5	+43.6

*Note: These columns express % over (+) or under (-) prediction.

XXI: Predicted Average Power values (W) relative to those obtained on the large knob (effort arm length 50mm) in the three test planes (vertical 90°, diagonal 45°, horizontal 0°).

Knob Characteristics	**Orientation**	**Average Power (Nm)**				**Accuracy of prediction $[1.00-(^{A}/_{P})]\cdot\ 100$**	
		Ext.		**Int.**		**Ext.**	**Int.**
		Pred.	**Act.**	**Pred.**	**Act.**		
LARGE: (ea 50mm) $(^{ea}/_{50})$%=100	Vertical	-	5.5	-	7.2	N/A	N/A
	Diagonal	-	6.0	-	7.9	N/A	N/A
	Horizontal	-	5.7	-	6.7	N/A	N/A
MEDIUM: (ea 35mm) $(^{ea}/_{50})$%=70.0%	Vertical	3.9	3.1	5.0	4.0	+20.5	+20.0
	Diagonal	4.2	3.2	5.5	4.4	+23.8	+20.0
	Horizontal	6.0	6.2	4.7	4.0	-3.3	+14.9
SMALL: (ea 25mm) $(^{ea}/_{50})$%=50.0%	Vertical	2.8	1.4	3.6	2.1	+50.0	+41.7
	Diagonal	3.0	1.0	4.0	2.1	+66.7	+47.5
	Horizontal	2.9	1,2	3.4	2.0	+58.6	+41.2

*Note: These columns express % over (+) or under (-) prediction.

It is evident that the medium Lever-type control is the most appropriate to enable prediction of peak torque, total work and average power responses. All responses for the other controls showed values that were grossly exaggerated in comparison to the actual data. This is important for any industrial setting as it identifies that a Lever-type control with an effort arm over 85mm could be reliably used to bench mark data for future industrial settings. However, this is not the case with Knob-type controls, as the results are not reliable when used in order to try and predict peak torque, total work and average power in a certain spatial orientation, in any workplace environment.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

In both sporting and working environments there are needs for accurate strength assessments. Using isokinetic dynamometry to conduct such assessments is standard practice in the field of sport science. However, in the field of ergonomics it is less frequently attempted. The work simulation isokinetic strength assessment of the present project should contribute to the growing ergonomic research in the area. In order to obtain background information, the author conducted numerous surveys at various industrial settings in South Africa. South Africa is recognised as an industrially developing country and a large percentage of work done in industry is manual. These manual tasks include pushing, pulling, lifting and valve turning. In the literature there is a copious amount of research concerned with the acts of pushing, pulling and lifting. However, studies of valve turning in relation to control design and positioning, especially in industrially developing countries, are sparse in the literature. Therefore the present study contributes towards filling the gap in the literature on isokinetic strength testing and valve turning, with respect to control design and positioning, in a work-simulated environment.

The study was holistic in that it includes certain cardiovascular responses, viz. heart rate and blood pressure, and psychophysical responses, viz. RPE and perceived discomfort observations. These observations were conducted on 30 male subjects using six control types in three positions. The control types varied in shape (Knob or Lever-type controls) and size (large, medium and small). Control positions were vertical (90°), diagonal (45°) and horizontal (0°) to the operator.

PROCEDURES

The subjects were required to attend two testing sessions of approximately one hour long each and one week apart. On arrival at the first session the subjects were given a letter of information and a verbal explanation about the requirements for the testing, and required to sign an informed consent form. Before the isokinetic, cardiovascular and psychophysical testing some demographic and anthropometric data were collected. During the first session the subjects were tested in nine of the eighteen conditions. The selection process for these conditions was randomised and thus no two subjects, in different testing sessions, were ever tested in the same order. As all the subjects had no previous experience at isokinetic dynamometry, a brief verbal explanation of the working requirements was given before the commencement of the first session. In addition the subjects were all allowed a familiarising practice effort before the first condition. This familiarising practice effort was then not used again. The subject was next required to produce four maximal valve turning efforts for the specified condition. Blood pressure and heart rate were taken before and after the completion of each condition. Perceived discomfort and RPE was recorded after each condition. After nine conditions had been tested the session was complete and the other nine conditions were assessed in the second test session.

RESULTS

Lever-type controls enabled subjects to produce higher values in Peak Torque, Total Work and Average Power than did the Knob-type controls, regardless of position (See Tables IV, VI,VII,VIII and Figures 15, 16 and 17; Chapter IV). These results were expected and are attributed to the larger effort arms of the Lever-type control. Significant differences were encountered between all combinations of control design, except between the large knob and small lever, and between the medium and small knobs.

With regard to the impact of the plane of motion, it was interesting that significant differences were only encountered for the Lever-type controls and not the Knob-type controls (See Tables IX, Chapter IV). It was discerned that the Lever-type controls allowed operators to use their upper body, plus make use of leverage offered by the larger Lever-type controls. In all the cases where significant differences were encountered, the controls in the vertical plane resulted in greater values than the controls positioned diagonally or horizontally.

In the present study the direction of rotation was seen to impact significantly on work output. Internal rotation figures were significantly greater than external figures, regardless of control type, when positioned vertically. This trend was followed throughout, regardless of spatial orientation, for all the Knob-type controls. However, positioning the larger Lever-type control diagonally and horizontally resulted in a reversal in the values, with external rotation being higher than internal rotation.

With regard to cardiovascular responses, exertional heart rates were in all cases significantly higher than anticipatory heart rates. This was expected as the conditions required four maximal valve turning efforts. The only significant difference encountered as a result of changing the control type occurred on the horizontal plane. Systolic blood pressure was significantly influenced by control type when the controls were positioned vertically or diagonally. In contrast, diastolic blood pressure showed no significant difference, regardless of control type or spatial orientation. Although the control design led to significant differences in heart rate and blood pressure under certain circumstances, plane of motion did not. Neither heart rate nor blood pressure showed any significant differences due to changes in the positioning of the controls, and regardless of spatial orientation, or control type, all the tasks required effort levels close to 50% of age-predicted maximum heart rate. It must be remembered that the subjects were young adults: if older adults had been used the percentage would in all probability have been greater. Of ergonomic importance is that industries need to be aware of this so that workers who have previously suffered from cardiac heart disease are kept from tasks which require them to work at high percentages of age-predicted maximum heart rate.

Psychophysical responses showed that correlations between heart rates and RPE were low in comparison to studies in which whole body, long duration aerobic work is usually the stressor. The correlation between heart rate and central RPE was 0.14 while that between heart rate and local RPE was only 0.17.

Overall Perceived Discomfort (OPD) clearly implicated the hand in all conditions, followed by the wrist. The hand discomfort ranged from 74.4% of responses with the medium knob in the horizontal plane, to 96.8% of responses with the small knob in a vertical plane. Localised Perceived Discomfort (LPD) was dominated by fingers (Area 1) and the palm (Area 2), regardless of spatial orientation and control design. Interestingly, on average, higher percentages were experienced in the palm of the hand when the condition required Lever-type controls to be used and in fingers when the requirement was for Knob-type controls. However, it is clear that these two areas dominated LPD with combined percentages upwards of 57.5%, regardless of control design and spatial orientation.

Predictions of Peak Torque, Total Work and Average Power values for Lever-type controls indicate that the medium lever, on average, will enable higher than expected values when compared to the large lever. In contrast the use of the small lever produced values lower than expected. However, the same predictions for the Knob-type controls showed that use of the Knob-type controls produced values lower than expected in all cases barring one. This has important ergonomic implications as it shows that the Lever-type controls are less influenced by the size of the control. It is argued that any Lever-type control larger than 85mm will produce over-predicted values for expected Peak Torque, Total Work and Average Power. On the other hand, the knob controls appear to be more affected by changes in the size of the control. The ergonomic importance of this is that the lever controls can be operated with less strength in order to deliver the required peak torque, total work or average power for the specified task. In other words, industries can safely employ weaker employees if Lever-type controls are in place, knowing they will be able to complete the task.

Analyses of Hypotheses

The experiments undertaken to test hypotheses raised in this study yielded the following conclusions:

$H_o1(a)$: Valve turning isokinetic responses are unaffected by plane of motion, regardless of control design.

In respect of 54 combinations tested (See Table IX), only 12 showed significant differences as follows:

Internal Rotation:

- Torque, work and power outputs were significantly reduced between 90° and 45° and between 90° and 0° when using the large lever.
- Torque output was significantly reduced between 90° and 45° and between 90° and 0° when using the medium lever.

- Power output was significantly reduced between 90° and 45° when using the small lever.

External Rotation:

- Work and Power outputs were significantly increased between 90° and 0° when using the small lever.
- Power output was significantly increased between 45° and 0° when using the small lever.

Except for the above few instances $H_o1(a)$ is tentatively retained as, in general, valve turning strength was unaffected by plane of motion.

$H_o1(b)$: Valve turning isokinetic responses are unaffected by control design, regardless of plane of motion.

The results forced rejection of this hypothesis as a generalisation: of 270 combinations all but 30 were significantly affected by control design. No significant isokinetic differences were elicited in the following combinations:

- All isokinetic outputs on the small lever were the same as those using the large knob in every case measured.
- All isokinetic outputs using the medium knob were the same as those on the small knob when the planes of motion were vertical and horizontal.

$H_o2(a)$: Valve turning cardiovascular responses are unaffected by plane of motion, regardless of control design. The results force tentative retention of this hypothesis in all cases. No significant heart rate or blood pressure differences (p   0.05) were attributable to the plane of motion involved.

$H_o2(b)$: Valve turning cardiovascular responses are unaffected by control design, regardless of plane of motion. This hypothesis is tentatively retained in respect of all but the following combinations:

- The heart rate elicited by exertion on the large lever was significantly higher than on all other controls, but only when exerting in the horizontal plane.
- Systolic pressures elicited by exertion on the large lever were significantly higher than on the medium and small knobs for motions in the vertical plane.
- Systolic pressures elicited by exertion on the small knob were significantly lower than those elicited by the medium knob and the medium and large levers, during motions in the diagonal plane.

Thus, of 45 systolic blood pressure combinations, only the above 5 were significantly related to control design.

$H_o3(a)$: Valve turning psychophysical responses are unaffected by plane of motion, regardless of control design. Thus the null hypothesis is tentatively accepted. No significant ratings of perceived exertion or perceived discomfort differences ($p \quad 0.05$) were attributable to the plane of motion involved.

$H_o3(b)$: Valve turning psychophysical responses are unaffected by control design, regardless of plane of motion. This hypothesis is retained in respect of all but the following combinations:

- Local RPEs while using the large lever were significantly different to when using the medium and small knob. In addition local RPEs while using the small knob were significantly different to when using the medium and small lever and the large knob.
- Overall perceived discomfort of the hand while using the small knob was significantly different to when using the medium lever and large knob.
- Overall perceived discomfort of the wrist while using the small lever was significantly different to when using the medium knob.
- Localised perceived discomfort for the fingers while using the small knob was significantly different from usage of the large knob and the large and medium lever.

- Localised perceived discomfort of the palm while using the large lever was significantly different to use of the small lever, medium knob and small knob. The medium lever exhibited significant differences, for the same area, for the large, medium and small knobs. The large and medium knobs showed significant differences to the small lever for the palm of the hand.

Thus only the above mentioned conditions exhibited significant differences (p 0.05) with regard to control design.

CONCLUSIONS

The present study has contributed to the field of isokinetics and ergonomics by providing information that has linked two fields that have until now been seen as different entities. In addition, this research has contributed to the literature by using isokinetics in a work-simulating mode. The isokinetic, cardiovascular and psychophysical responses reported here have important ergonomic implications for industry.

RECOMMENDATIONS

1. The sample used in the study (a volunteer student sample) is not representative of the working population of South Africa. It is recommended that a similar study be conducted on a more representative sample drawn from an industrial setting. The present study was delimited to males in an age group of 18-28 years. Again this is not representative of workers in industry. If this recommendation is followed, workers of both sexes, spanning the full age-range encountered in industry, should be included.

2. There is a need incorporate two-handed wheel-valve turning in a similar study in order to determine the differences that may exist isokinetically, cardiovascularly and psychophysically where larger controls have to be manipulated.

3. It is questionable whether Borg-type psychophysical scales are appropriate in isokinetic studies of this nature. The correlations found between heart rate and RPE are very weak when short-burst anaerobic efforts are being rated. Greater rigour should be exercised when choosing psychophysical scales appropriate to the nature of the task under investigation.

4. It is recommended that the results of studies such as this should be communicated to industry in order to highlight the importance of application of research findings, and thereby emphasise the need for ergonomics in industry. The essence of the study is that industries should use Lever-type controls where at all possible.

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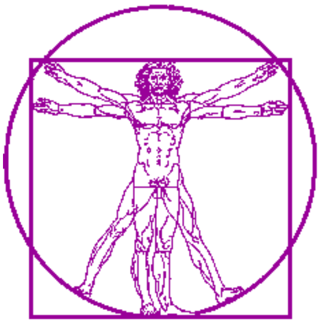
APPENDIX A: STANDARD INFORMATION

Letter of Information

Informed Consent Form



Wood House

Kingswood College

Grahamstown

6139

Tel : 082-9212748

Dear _______________,

Thank you for offering to participate in my Master of Science research thesis entitled:

The effects of control design and working posture on strength and work output: An Isokinetic Investigation.

In this study, I will be investigating the effect of positioning of controls and the design of controls and determining how this affects worker strength and the work output the worker is able to deliver in a simulated working environment.

Before any testing takes place, your demographic data will be collected. This entails taking your weight, height, age and the length and breath of your dominant hand. In addition your grip strength of your dominant hand will be taken with a grip strength dynamometer. After this you will proceed to the CYBEX® room for the strength testing.

You will be asked to do four (4) maximal repetitions for four different types of controls in three different positions on the CYBEX ® 6000. During this phase strength parameters will be observed. At the same time certain cardiac and respiratory responses will be measured, namely blood pressure, heart rate and breathing frequency. You will be one of a pair and testing will follow a certain pattern allowing equal rest breaks for each participant. Each participant will be testing on one control, in one position at all three speeds before the next subject is tested, after which the control and/or the position are changed. All instructions and questions will be verbally administered before and during the testing phase.

During the testing you will be asked to indicate on various scales your subjective ratings to the various tasks. There will be three of these ratings at various times during the testing. The most frequent rating will be the rating of Perceived Exertion (RPE), which you will be required to give after every specific speed for each control at every position. This rating gives us an indication of how you are feeling during the testing. Please remember that this is a localised rating and therefore is a rating of how your hand / forearm is feeling and not if you are cardiovascularly tired. The next rating you will be required to judge is the localisation of discomfort rating. Here you will be shown a diagram of the hand and forearm and you are required to identify a number region that is causing you the most discomfort in this area. This rating will be done after a specific control has been tested. The final rating is the body part discomfort, which is similar to the hand discomfort, but incorporates more body parts. You will be required to identify one (1) body part and to give a rating of discomfort from 1 (just noticeable) to 10 (intolerable). This rating will take place for each control and each position. These instructions will be explained verbally at the start of each session and all questions will be addressed then.

There are no additional risks that may be encountered during the data collection sessions. However, Professor J Charteris (the research supervisor) will be present at all times during the testing to oversee the procedures and to protect your best interests.

This project will have no direct benefit to you, although your involvement will benefit our knowledge of control positioning and design.

Again thank you for your involvement and please do not hesitate to contact me if you have any queries.

Yours sincerely,
Charles van Schalkwyk.
(Master of Science Student)

SUBJECT CONSENT FORM

I,________________________________ having been fully informed of the research entitled:

THE EFFECTS OF CONTROL DESIGN AND WORKING POSTURE ON STRENGTH AND WORK OUTPUT: AN ISOKINETIC INVESTIGATION

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 to my participation, as explained to me verbally and in writing. In agreeing to participate in the research I waive any legal recourse against the researcher, the Department of Human Kinetics and Ergonomics or Rhodes University of any claims resulting from personal injuries sustained. The waiver shall be binding upon heirs and personal representatives. I realise that it is necessary for me to promptly report any signs or symptoms indicating any abnormality or distress. I am aware that I may withdraw my consent and 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.

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

SUBJECT (OR LEGAL REPRESENTATIVE)

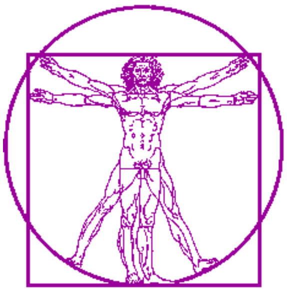
____________________	________________	______
(Print name)	**(Signed)**	**(Date)**

PERSON ADMINISTERING INFORMED CONSENT

____________________	____________________	________
(Print name)	**(Signed)**	**(Date)**

WITNESS

____________________	____________________	________
(Print name)	**(Signed)**	**(Date)**



APPENDIX B: EXPERIMENTAL PROCEDURES

Demographic and Anthropometric Characteristic Recording Sheet

Psychophysical and Physiological Recording Sheet

Randomised Test Conditions

Instructions for use of RPE

Instructions for Body Discomfort

RPE Scale

Overall Perceived Discomfort

Localised Perceived Discomfort

DEMOGRAPHIC AND ANTHROPOMETRIC DATA

DEMOGRAPHIC DATA

Subject Name:…………………………… Age(yrs):………. Code:………

Height (mm):………. Mass (Kg):………….

Hand Breath (mm):………… Hand Length (mm):………

CARDIAC DATA

Blood pressure (mmHg):………… Heart rate (bt.min $^{-1}$)…………..

GRIP STRENGTH DATA

Dominant Hand (kg): 1st…………….

………………. 2nd……………

Max:…………

PREFERENTIAL SELECTION DATA

Please rate the controls in order of p; 1= best and 6=worst.

Before testing:		After testing:	
Large Lever:	☐	Large Lever:	☐
Medium Lever:	☐	Medium Lever:	☐
Small Lever:	☐	Small Lever:	☐
Large Knob:	☐	Large Knob:	☐
Medium Knob:	☐	Medium Knob:	☐
Small Knob:	☐	Small Knob:	☐

PSYCHOPHYSICAL AND PHYSIOLOGICAL DATA SHEET

SUBJECT NAME: ………………………………………..

Control Type: ………………………….

Spatial Orientation			
Heart Rate	1) 2)	1) 2)	1) 2)
RPE (local)			
RPE (Central)			
Breathing Frequency			
Blood Pressure			

LPD: area: 1)……………….. 2)……………….. 3)………………..

OPD: area: 1)……………….. 2)……………….. 3)………………..

Discomfort: 1)……………….. 2)……………….. 3)………………..

Control Type: ………………………….

Spatial Orientation			
Heart Rate	1) 2)	1) 2)	1) 2)
RPE (local)			
RPE (Central)			
Breathing Frequency			
Blood Pressure			

LPD: area: 1)……………….. 2)……………….. 3)………………..

OPD: area: 1)……………….. 2)……………….. 3)………………..

Discomfort: 1)……………….. 2)……………….. 3)………………..

Control Type: ………………………….

Spatial Orientation			
Heart Rate	1) 2)	1) 2)	1) 2)
RPE (local)			
RPE (Central)			
Breathing Frequency			
Blood Pressure			

LPD: area: 1)……………….. 2)……………….. 3)………………..

OPD: area: 1)……………….. 2)……………….. 3)………………..

Discomfort: 1)……………….. 2)……………….. 3)………………..

Control Type: ………………………….

Spatial Orientation			
Heart Rate	1) 2)	1) 2)	1) 2)
RPE (local)			
RPE (Central)			
Breathing Frequency			
Blood Pressure			

LPD: area: 1)……………….. 2)……………….. 3)………………..

OPD: area: 1)……………….. 2)……………….. 3)………………..

Discomfort: 1)……………….. 2)……………….. 3)………………..

RANDOMISED CONDITIONS

GROUP 1:

SMALL LEVER			MEDIUM KNOB			LARGE LEVER		
90º	0º	45º	45º	90º	0º	90º	45º	0º

MEDIUM LEVER			LARGE KNOB			SMALL KNOB		
90º	45º	0º	45º	0º	90º	0º	45º	90º

GROUP 2:

LARGE LEVER			LARGE KNOB			SMALL LEVER		
0º	45º	90º	45º	90º	0º	90º	0º	45º

MEDIUM LEVER			MEDIUM KNOB			SMALL KNOB		
0º	45º	90º	45º	0º	90º	90º	45º	0º

GROUP 3:

MEDIUM KNOB			SMALL LEVER			MEDIUM LEVER		
90º	45º	0º	45º	0º	90º	0º	45º	90º

LARGE KNOB			LARGE LEVER			SMALL KNOB		
45º	90º	0º	90º	0º	45º	45º	0º	90º

GROUP 4:

LARGE KNOB			SMALL LEVER			MEDIUM KNOB		
90º	45º	0º	45º	0º	90º	45º	90º	0º

MEDIUM LEVER			SMALL KNOB			LARGE LEVER		
90º	0º	45º	45º	90º	0º	0º	45º	90º

GROUP 5:

LARGE KNOB			MEDIUM KNOB			SMALL LEVER		
45º	90º	0º	45º	0º	90º	90º	45º	0º

LARGE LEVER			MEDIUM LEVER			SMALL KNOB		
0º	45º	90º	0º	90º	45º	45º	90º	0º

GROUP 6:

MEDIUM LEVER			LARGE KNOB			SMALL KNOB		
90º	45º	0º	45º	0º	90º	0º	45º	90º

SMALL LEVER			MEDIUM KNOB			LARGE LEVER		
90º	0º	45º	45º	90º	0º	90º	45º	0º

GROUP 7:

MEDIUM KNOB			SMALL KNOB			LARGE LEVER		
90°	0°	45°	45°	90°	0°	0°	45°	90°

MEDIUM LEVER			LARGE KNOB			SMALL LEVER		
90°	45°	0°	45°	0°	90°	0°	45°	90°

GROUP 8:

MEDIUM LEVER			MEDIUM KNOB			SMALL KNOB		
0°	45°	90°	45°	0°	90°	90°	45°	0°

LARGE LEVER			LARGE KNOB			SMALL LEVER		
0°	45°	90°	45°	90°	0°	90°	0°	45°

GROUP 9:

MEDIUM LEVER			LARGE KNOB			SMALL KNOB		
90°	45°	0°	45°	0°	90°	0°	45°	90°

MEDIUM KNOB			SMALL LEVER			LARGE LEVER		
90°	0°	45°	45°	90°	0°	0°	45°	90°

GROUP 10:

MEDIUM LEVER			LARGE KNOB			SMALL LEVER		
90º	45º	0º	45º	0º	90º	0º	45º	90º

MEDIUM KNOB			SMALL KNOB			LARGE LEVER		
90º	0º	45º	45º	90º	0º	0º	45º	90º

GROUP 11:

MEDIUM KNOB			SMALL LEVER			LARGE LEVER		
90º	0º	45º	45º	90º	0º	0º	45º	90º

MEDIUM LEVER			LARGE KNOB			SMALL KNOB		
90º	45º	0º	45º	0º	90º	0º	45º	90º

GROUP 12:

MEDIUM KNOB			SMALL LEVER			MEDIUM LEVER		
90º	45º	0º	45º	0º	90º	0º	45º	90º

LARGE KNOB			LARGE LEVER			SMALL KNOB		
45º	90º	0º	90º	0º	45º	45º	0º	90º

GROUP 13:

LARGE KNOB			LARGE LEVER			SMALL KNOB		
45º	90º	0º	90º	0º	45º	45º	0º	90º

MEDIUM KNOB			SMALL LEVER			MEDIUM LEVER		
90º	45º	0º	45º	0º	90º	0º	45º	90º

GROUP 14:

LARGE LEVER			MEDIUM LEVER			SMALL KNOB		
0º	45º	90º	0º	90º	45º	45º	90º	0º

LARGE KNOB			MEDIUM KNOB			SMALL LEVER		
45º	90º	0º	45º	0º	90º	90º	45º	0º

GROUP 15:

MEDIUM KNOB			SMALL LEVER			MEDIUM LEVER		
90º	45º	0º	45º	0º	90º	0º	45º	90º

LARGE KNOB			LARGE LEVER			SMALL KNOB		
45º	90º	0º	90º	0º	45º	45º	0º	90º

INSTRUCTIONS TO SUBJECT FOR RPE

During the next testing session you will be required to turn various valves at various testing velocities. While we will be measuring strength and work output, and physiological parameters, we will also be objectively assessing psychological parameters. The first of these psychological parameters is Rating of Perceived Exertion (RPE). You will be asked to rate the degree of exertion that you are feeling on a numerical scale. You will have to point to a number on this scale, which corresponds to the exertion you are feeling locally, i.e. the exertion you are feeling in your hand and forearm.

You will be required to give this rating at the end of each testing speed for all controls and positions. You will be required to give two ratings; one for how tired you are feeling cardiovascularly and one for how tired your arm is.

Try to estimate as honestly and objectively as possible and try not to over estimate or under estimate the exertion you are feeling. Remember this is not a competitive assessment and over estimating does not make you better than your fellow subjects.

INSTRUCTIONS TO SUBJECT FOR BODY DISCOMFORT

During the next testing session you will be required to turn various valves at various testing velocities. While we will be measuring strength and work output, and physiological parameters, we will also be objectively assessing psychological parameters. The first of these psychological parameters is the identification of an area on a chart of the hand and forearm which is causing you discomfort. You only need to identify one area, labelled 1 to 8, which is causing the most discomfort.

The second parameter involves the identification of one area on the whole body, which is causing discomfort. The areas are broken up in various segments, which are the following:

Hand
Wrist
Forearm
Upper arm
Shoulder
Whole body.

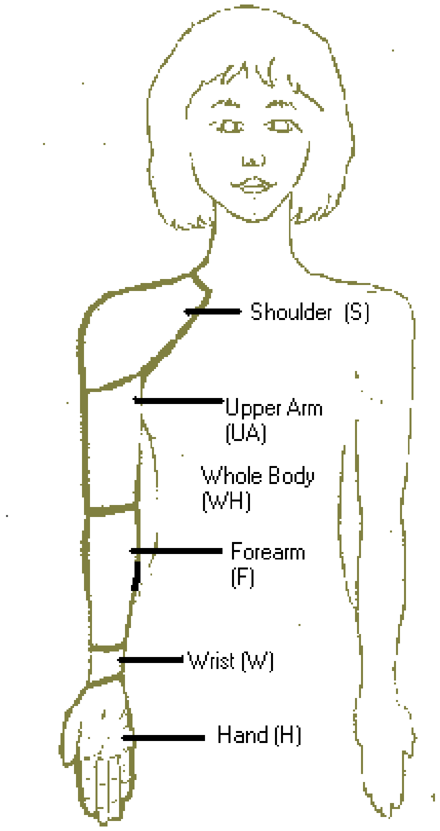
While identifying this one area you will be asked to suggest a rating on a scale of 1 to 10, 1 corresponding to discomfort being “just noticeable” and 10 corresponding to a rating of “intolerable”. Once again try to be as objective as possible and try not to over or under estimate the degree of discomfort. You will be asked for your rating and identification at the end of a control being tested in all three velocities for a specified position.

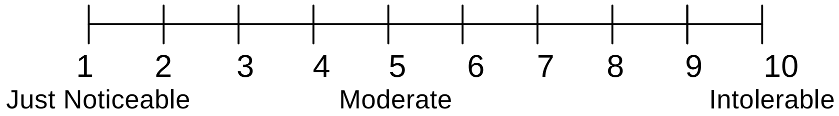
PERCEIVED EXERTION (RPE).

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	

(Borg, 1970)

OVERALL PERCEIVED DISCOMFORT (OPD)

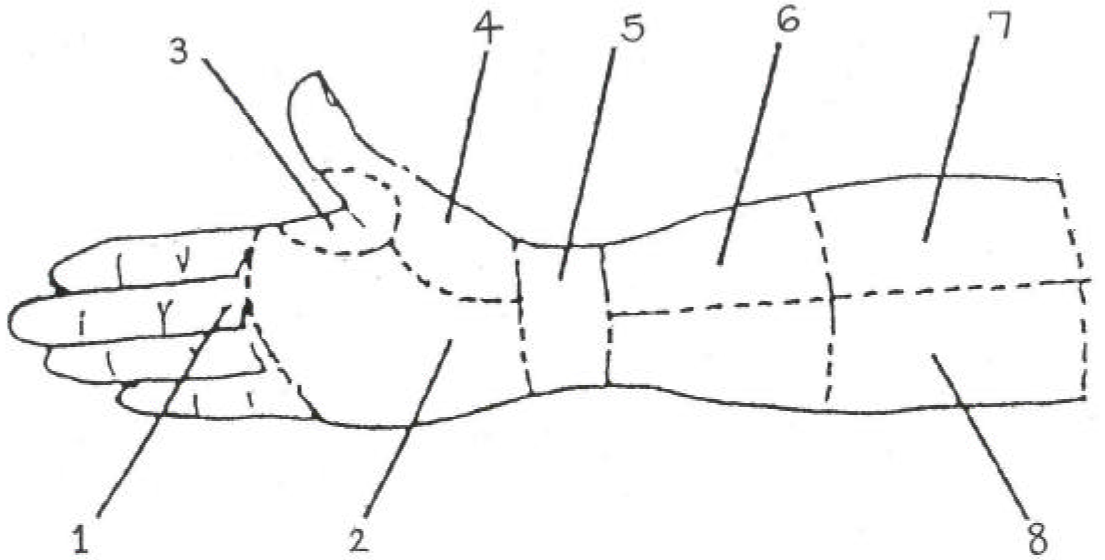




LEVEL OF DISCOMFORT

(Source: Adapted from Schulze and Woods, 1994 and Marley and Fernandez, 1995)

LOCALISED PERCEIVED DISCOMFORT (LPD)



APPENDIX C: RESULTS

ANOVA Tables

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ANOVA TABLES

Multiple factor analysis of variance (Control type over Spatial Orientation) isokinetic responses.

Measure	Variance Analysis Source	SS	DF	MS	F	Sign. Level
Torque External	**Between (CT):** **Within (SO):**	40472.444 52.478	5 2	8814.8449 26.2389	717.919 2.137	.0000 .1190
Torque Internal	**Between (CT):** **Within (SO):**	34143.437 596.904	5 2	6828.6874 298.4519	447.787 19.571	.0000 .0000
Work External	**Between (CT):** **Within (SO):**	56634.037 184.070	5 2	11326.807 92.035 01	509.746 4.142	.0000 .0164
Work Internal	**Between (CT):** **Within (SO):**	49340.948 364.804	5 2	9868.1896 182.4019	389.601 7.201	.0000 .0008
Power External	**Between (CT):** **Within (SO):**	22786.526 32.848	5 2	4557.3052 16.4241	611.757 2.205	.0000 .1113
Power Internal	**Between (CT):** **Within (SO):**	20308.259 151.559	5 2	4016.6519 75.7796	478.578 8.929	.0000 .0002

Multiple factor analysis of variance (Control type over Spatial Orientation) of physiological responses.

Measure	**Variance Analysis Source**	**SS**	**DF**	**MS**	**F**	**Sign. Level**
Heart Rate 1	**Between (CT):** **Within (SO):**	733.72778 147.51111	5 2	146.74556 73.75556	.948 .477	.4493 .6212
Heart Rate 2	**Between (CT):** **Within (SO):**	8362.3481 539.5815	5 2	1672.4696 269.7907	10.394 1.677	.0000 .1880
Diastolic Blood Pressure	**Between (CT):** **Within (SO):**	597.07593 33.79259	5 2	119.41519 16.89630	1.781 .252	.1150 .7774
Systolic Blood Pressure	**Between (CT):** **Within (SO):**	2870.5481 4.6926	5 2	574.10963 2.34630	6.758 .028	.0000 .9728

NOTE: Heart Rate 1 depicts Anticipatory Heart Rate
Heart Rate 2 depicts Exertional Heart Rate

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