2. GUIDELINES FOR COMPUTER WORKSTATIONS

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INTRODUCTION

Guidelines for office computer workstations are present in many forms, from recognised international and national standards, to ergonomic texts, to guidelines either in written booklet format or, more recently, information provided electronically via occupational health and safety websites (OSHA, 2001). The currency of published guidelines is of concern, given the recent changes in computer hardware and the increasing amount of research regarding workstation configurations and equipment.

STANDARDS

Within Australia, the National Code of Practice for the Prevention of Occupational Overuse Syndrome (NOHSC, 1996b), and the Guidance note for the Prevention of Occupational Overuse Syndrome in Keyboard Employment (NOHSC, 1996a) provide recommendations for assessment and control strategies, aimed at preventing injuries related to computer use. These documents refer regularly to the Australian Standards for computer based work, (AS3590: Screen-Based Workstations: Parts 1-4), which were published in 1990. Part 1 of these standards refers to Visual Display Units, Part 2 to Workstation Furniture and Part 3 to Input devices. Since the development of these guidance notes and standards, there have been many advances in computer hardware, resulting in an increased use and range of alternate input pointing devices (eg trackball), changes in monitor size and resolution and the introduction of alternative keyboards. NOHSC are currently reviewing these guidelines as part of their review of manual handling standards and associated documents.

Some parts of these Standards have been updated or superseded. AS3590.2: Screen-Based Workstations Part 2: Workstation furniture, has been partially superseded by AS/NZS 4442:1997, Office desks and AS/NZS 4443:1997 Office Panel Systems. These standards provide information on design issues related to office chairs and desks. There has, however, been no replacement of Part 3, Input devices or Part 1, Visual Display Units. The range of new and alternate input devices such as the computer mouse, trackballs, alternate keyboards or other peripheral input devices are not reflected in these standards. The traditional office desk is designed to accommodate the keyboard, with no consideration given to non-keyboard input devices such as the computer mouse (Karlqvist, 1998). Also lacking is information regarding LCD displays and the opportunities they create.

GUIDELINES

Many guidelines for work practice in the area of computer based work have been produced by either statutory bodies within Australia or internationally, or by other interested parties, such as university research centres (Hedge et al., 2002), or equipment manufacturers. These are available in either printed format, or recently more commonly from electronic sources.

Australian Guidelines

The current office workstation guidelines provided by WorkCover NSW (Health and Safety in the Office) were printed in 1993, based on AS 3590: 1990 (Standards Australia, 1990). Accordingly, they have similar problems with currency of information owing to the age of the documents. The checklists provided for use in risk assessment do not contain questions regarding any input device use other than the keyboard (Worksafe, 1991). More recent (although not all are up to date) Australian publications are available either in booklet or electronic form. These include publications by Comcare Australia (1996), Victorian WorkCover (2001) and Workplace Health and Safety, Queensland (1994).

International Guidelines

Many of the large Occupational Health and Safety organisations overseas are now providing guidelines for computer workstation arrangements via their websites. The Occupational Health and Safety Administration in the USA is one such organisation, which provides guidelines for workstation assessment and setup which can be used to provide recommendations for good practice within industry. The most current guidelines appear to incorporate recent literature (OSHA, 2001). These are available electronically and contain guidelines as well as checklists that can be used for workstation assessment. Many other university, industry and health organisation websites include information on computer workstations. These vary in quality, currency and research basis. Often the date of publication is not available, nor are the references used to guide the recommendations provided.

There is a need for Australian Occupational Health and Safety agencies to either provide more current guidelines or refer to other agencies where such guidelines can be found.

COMPUTER USE

Use of a computer requires physical interaction between the user, the keyboard and non-keyboard input devices. Visual interaction occurs between the computer monitor, source documents, and in the case of non-touch typists, the keyboard. As computer based work is often performed while sitting, postural support is required for the back, legs and arms.

The focus of this paper is the interaction between the user and input devices, and body support with respect to seating and workstation set up. The published Australian guidelines will be used as the basis for this discussion. Recommendations that incorporate recent published findings will be made.

THE "IDEAL" WORKING POSTURE.

Workstation setup

Most publications present diagrams representing workstation settings. Many figures depict the upright, floating posture promoted in the 1980's and early 1990s (Worksafe, 1991). In these figures, the computer user is shown to be sitting with the hips, knees and elbows at approximately 90º flexion and no arm support was provided (floating posture). The user's eyes are level with the top edge of the screen and their feet positioned flat on the floor (WorkCover, 1993).

Recent findings have demonstrated that this may not be the "ideal workstation posture". Indeed, there is growing consensus that there is no one ideal posture or setup for computer workstations, but that users need to be guided with regard to a range of "safe" or comfortable work postures which may be adopted throughout the working day.

A range of safe postures from current literature will be presented for sitting, keyboard position and workstation heights, the position of the computer monitor and the position of input devices other than the keyboard.

Sitting posture: The chair

The upright posture, ie upright back, head and neck posture with the thighs horizontal and the lower legs vertical has been prescribed as a "healthy sitting posture" since the 1880's (Kroemer, et al., 2001). This upright posture of an elongated 'S' shape of the spine and lordosis of the lumbar spine is still recommended by many owing to the low lumbar disc pressures which were reported to result from sitting in this position (Andersson, 1986; Kroemer & Grandjean, 1997).

Although this posture was, and is still recommended in many publications, questions have been raised as to the validity of this recommendation based on a reported reduction in disc pressures. It is questioned whether a decrease in disc pressure is the best measure of "good" sitting posture. The discs are subjected to compressive and shear pressures during sitting. Dolan and Adams, (2001) subjected lumbar discs in cadavers to sustained compressive loading in which the disc height was reduced by 20%. The decrease in pressure in the nucleus of the disc was reported to be a result of a decrease in the water content of the nucleus and inner annulus. The decrease in disc pressure within the nucleus corresponded with increases in pressure in the outer annulus. So, although the measured pressure within the disc may decrease, the pressure has effectively been shifted to the annulus, thereby not effectively decreasing the risk to the back (Dolan & Adams, 2001).

It was recognised as early as the 1980s that even though people were "set up" to work in an upright posture, they did not maintain this posture for long periods (Grandjean et al., 1984). Two main alternatives to the upright posture have been recommended. Grandjean et al., (1984) reported that people preferred a more open trunk angle of 97º-121º, preferring to lean back in their chairs rather than to sit upright at 90º. The benefits of this posture have been supported by studies of intradiscal lumbar pressures, with a decrease in disc pressure and relaxation of the back muscles demonstrated when the backrest angle was between 90º and 110º (Nachemson and Ekfstrom 1970, cited in Kroemer & Grandjean, (1997). A hypothesised problem with this posture during computer use is a subsequent increase in neck flexion in order to see the screen, a possible precursor for neck pain (Carter & Banister, 1994). However this concern has not been empirically justified.

A second alternative to upright sitting was proposed by Mandal et al., (1981), who suggested a forward tilting seat pan. In this posture, the thighs and pelvis incline forward while the trunk stays upright. The spine retains its normal standing lordotic posture, as the pelvis rotates forward, thereby decreasing intradiscal pressure (Dainoff, 1994).

Alternate chair types such as chairs with saddle seats (Gale, et al., 1990) or kneeling surfaces have been designed on the basis of the recommendations of Mandal et al., (1981). However their use is not nearly as widespread as the traditional, adjustable office chair. The main criticism of kneeling chairs is the necessity to weightbear through the legs, causing discomfort in some users (Kroemer et al., 2001).

Use of these chairs also reduces the likelihood of changing lower limb positions, resulting in lack of variability in working posture and can result in discomfort. Difficulty has also been reported with getting on and off the chairs, especially when a conventional office desk is being used. There may also be a greater degree of trunk lateral rotation than with the conventional office chair as the legs are constrained in a kneeling-type chair. These alternate chairs are seen within workplaces, with the saddle type chairs being very popular amongst specific groups such as dentists and hairdressers, occupations with very different postural demands to keyboard work.

Fitballs or Swiss Balls are becoming more popular for use as an alternate to conventional seating in the office environment. These balls originated in Europe in the 1960's for use in the area of physical rehabilitation. No research could be found which documents the effectiveness of these balls as an alternative seating option for use in the office work environment. Concerns regarding fitballs include their instability, which may increase the risk of falling within the workplace, the possibility of fatigue from sustained exercising, and the lack of support for the back, buttocks and thighs (Workcover, Victoria, 2002).

Chairs have become more adjustable, with most office chairs adjustable for height and tilt in both the backrest and seat pan. These adjustments enable the user to comply with the recommendations for both increased seat tilt and lumbar angle, enabling the user to adjust the chair according to comfort and work tasks. Although chairs are now designed to be very adjustable, many workers still do not adjust the basic settings of lumbar support height or chair height (Coleman et al., 1998). The multiple adjustment capability may render chair too complicated for the average user (Dainoff, 1994).

The range of seated postures presented (upright, backward leaning and forward tilt) all have documented advantages and disadvantages for computer users, often according to the task itself or the way it is performed by the individual. An upright posture is seen as suitable for touch typing (typing with or without the arms supported), the forward tilt posture more suitable for reading and writing and the backward leaning posture for when mostly screen work is required (Carter & Banister, 1994). There is a trend towards computer based workstations that can be adjusted to accommodate work in the standing position, another option to enable postural variability during the work day.

Recommendations

As a person's tasks may vary, so should their working posture. Each workstation, desk and chair should have the ability to be easily adjusted to enable work in a variety of postures. Training in how and when to adjust the workstation should be mandatory for computer users. The use of lumbar support, the ability to support the feet preferably on the floor, or at least on a footrest, and the ability to frequently vary one's working posture in sitting and between sitting and standing are the main factors for a healthy working posture.

THE MONITOR

Visual and musculoskeletal discomfort have been associated with the computer monitor. Neck symptoms generally relate to static or awkward postures such as neck extension if the monitor is too high, flexion if the monitor is too low or neck rotation if the monitor is not directly in front of the computer user. Visual symptoms such as discomfort, dry eyes or visual strain are also associated with computer monitor position (Dellman et al., 2002; Turville, et al., 1998).

a) Height

There is little consensus regarding 'correct monitor height'. Recommendations range from 15° above, to 45° below gaze inclination (Dellman & Berndsen, 2002). There is agreement regarding the importance of being able to define a "good" or range of healthy postures for the neck (Sommerich, et al., 2001; Straker & Mekhora, 2000). However, this has yet to be defined.

Difficulties arise in making a decision regarding "good" posture for a number of reasons. Until recently, there has been little consistency in neck posture definitions, resulting in different measurements being taken and making comparisons between studies difficult (Ankrum, 2000). Inadequately described working postures and the use of different postures and equipment between studies further compound the issues. As with other areas of ergonomics, the issue of large individual differences has been reported (Straker, 2000; Burgess-Limerick, et al., 1998).

Various recommendations for monitor height exist. The main recommendations are for a high position: (the top of the screen equal with eye height); a mid position: (the bottom of the screen level with the desk surface); or a low position: (the bottom of the screen just visible below the keyboard). Ultra-high and ultra-low positions have also been recommended (Straker, 2000).

The rationale behind various monitor positions reflects both the biomechanical concerns of these working postures, and the functioning of the oculomotor system. The main arguments for the recommended heights are presented below.

High

The high recommendation is generally found in conjunction with the "upright sitting posture" in many standards and guidelines. These guidelines recommend that the monitor should be arranged so that the top line of the screen is level with or below eye level, so that it can be read without bending the head down or back (OSHA, 2001; NOHSC, 1991). The high monitor position results in a viewing angle of 0°-15° below the horizontal (Straker, 2000). The Australian Standard AS3590.2 states that forward head tilt is fatiguing after long periods, so should be limited to a maximum of 15°. However, the Standard also states that the most comfortable viewing zone is 32° to 45° below the horizontal, but do not specify the upright posture from which these angles are measured (Standards Australia, 1990). An upright posture has been shown to reduce cervical and thoracic erector spinae activity (Straker & Mekhora, 2000; Turville et al., 1998; Sommerich et al., 2001) although the significance of this finding is debatable. The rationale behind a high monitor position is to reduce the neck muscular load, by maintaining a "neutral" head posture. However, there is little agreement as to the definition of "neutral".

There are a number of documented concerns with this height. It is proposed that higher monitors increase visual stress (Villaneuva et al., 1996). Preferred gaze angles are reported to be lower than the 0° -15° required of this monitor position (Mon-Williams, et al., 1999). As a result, a high monitor requires the user to raise the eyes, either causing visual discomfort (Burgess-Limerick et al., 2000) or causing the user to adopt postures involving atlanto-occipital extension which may cause musculoskeletal discomfort (Burgess-Limerick et al., 1998). There are consistencies within the epidemiological literature to support this argument, with neck discomfort reported to be associated with 'eye level' monitor heights (Bergqvist et al., 1995).

Mid

The mid position, where the bottom of the screen is at desk height is advocated by a number of authors. In this position, the viewing angle is from 15°-30° below the horizontal (Straker, 2000). The bottom of the screen is positioned as near as possible to the rear section of the keyboard (Kroemer et al., 2001).

Low

In the low monitor position, the bottom of the screen is just visible over the keyboard. This generally results in the monitor being at a viewing angle of 30°-45° below the horizontal (Straker, 2000). These recommendations have been made on the basis of user preference and concern regarding stress on the visual system (Kroemer et al., 2001).

The mid and the low positions will be discussed together, as there are similar concerns for both heights with respect to the effect on the neck and visual system. There have been documented advantages and disadvantages of a lower monitor position.

As monitor heights are lowered, there is a corresponding increase in the head flexion (atlanto-occipital angle) relative to the neck (Burgess-Limerick et al., 1998; Villaneuva et al., 1996). An increase in cervical extensor muscle activity has also been reported (Turville et al., 1998; de Wall, et al., 1992; Straker & Mekhora, 2000; Sommerich et al., 2001; Psihogios, et al., 2001). The sustained muscle activity while viewing the monitor is reported to result in fatigue associated with the continuous activation of low threshold muscle fibres, proposed to contribute to the development of tension neck syndrome (Sommerich et al., 2001; Hagberg et al., 1995). There is, however, no evidence to support this suggestion. An increased load on the cervical vertebrae with forward inclination of the head has also been reported, with significantly more shrinkage of the spine found with a gaze at 20° or 40° below horizontal compared with horizontal gaze (Bonney & Corlett, 2002). A recent study which examined postural differences between symptomatic and asymptomatic subjects found trends towards increases in head tilt and neck flexion amongst the symptomatic subjects (Szeto, et al., 2002).

Benefits of a lower posture are also documented. The preferred gaze angle when fixating on a near target is steeply downward. This is due to the arrangement of the extra-ocular muscles and vergence requirements imposed by near targets. As a result, a lower monitor position based on the structure of the visual system has been recommended (Mon-Williams et al., 1999) Most visual discomfort associated with computer work is related to extra-ocular fatigue caused by vergence requirements. There are also reports that lower positions reduce musculoskeletal strain, such as a decrease in trapezius muscle activity reported with a low monitor position (Turville et al., 1998). Burgess-Limerick et al., (2000), reported that visual displays higher than 15° below the horizontal eye caused atlanto-occipital extension. This results in a forward head posture, with flexion at the cervical joints and extension at the atlanto-occipital joints, a posture which has been associated with headaches (Watson, cited in Burgess-Limerick et al., 1998). A lower monitor is reported to achieve more preferable gaze angles while adopting postures which do not involve extended atlanto-occipital joints (Burgess-Limerick et al., 1998). The small suboccipital muscles, which extend the atlanto-occipital joints, are thought to provide stability to the cervical spine as well as counteracting flexor torque imposed by gravitational acceleration. Extension of these short muscles is likely to cause significant decrement in their force-generating capacity. Owing to the short length of these muscles, even small changes in posture affect the length tension relationship of these muscles, which may in turn affect the stability of the cervical spine (Burgess-Limerick et al., 2000). As lower monitor positions increase the potential for glare problems, the position of the monitor with respect to glare sources must be considered.

b) Lateral monitor position

There is agreement on the lateral position of the monitor. Postural adjustments occur following small lateral changes of the visual target. As positions of neck rotation are associated with visual discomfort, the monitor should be placed directly in front of the user, if the visual task is largely screen based (Straker, 2000).

c) Monitor distance

The 'correct' distance of the monitor from the user is dependent on user characteristics such as age and visual capacity, the height of the monitor and the clarity and size of the visual image on the screen (Straker, 2000). If the monitor is lower, it can be placed closer to the user. Recommendations for distance from the monitor to the user range from 500mm to 1000mm (WorkSafe, 1991; Dellman & Berndsen, 2002; Sommerich et al., 2001; HFES, 2001), with a distance of around 750mm recommended for the 'mid' position (Straker, 2000). If the image size can be increased, there is no limit to the distance from the user to the display. An increase in distance reduces visual discomfort thereby decreasing the detrimental effects of high displays.

d) Glare Control

Eye discomfort has been associated with computer use, with inadequate lighting, lack of or inadequate optometric corrections and glare being reported as contributory factors (Aaras et al., 1998).

Increased lighting levels by use of both direct and indirect lighting is reported to give better luminance conditions and visual comfort compared with only direct light (Aaras et al., 1998). Glare either direct from a source (eg window or bright lamp) or indirect (or reflected) from the monitor screen can be a cause of visual discomfort, eye fatigue and annoyance (Kroemer et al., 2001; OSHA, 1997). Indirect lighting, where most of the light is reflected back into the room from the ceiling and walls is a way of avoiding glare (Kroemer, 2000). Glare can also be reduced by increasing the distance of the desk from the window (above 1.5metres) and orienting the workstation so that the monitor screen is at 90^{o} to the windows (Aaras et al., 1998; OSHA, 1997). Window treatments such as blinds, tinting or curtains can also be used to reduce glare (Kroemer, 2000). Optometric corrections are also reported to be important in the reduction of visual discomfort and eye symptoms (Aaras et al., 1998).

Recommendations

Although there is no consensus on correct monitor height, there is agreement that individual differences and task requirements should be considered with respect to monitor height (Mon-Williams et al., 1999; Sommerich et al., 2001; Straker, 2000; Kroemer et al., 2001).

Workstation assessment should include consideration of visual information such as preferred gaze angle, type and use of glasses. Users should be provided with the means and appropriate education to enable them to place their monitor in the most comfortable position for their task and personal preferences. Workstations should enable the user to adjust their monitor between a viewing angle of 0^{o} and 45^{o}, at a distance of between 600 and 1000mm. If the monitor is the main visual source, it should be placed directly in front of the user. The use of LCD displays enables people to position their monitor at greater eye - display distances at normal desk depths.

HORIZONTAL WORK SURFACE

Position of the Keyboard

Traditionally, the keyboard was positioned close to the edge of the desk to enable the forearms to be close to horizontal and the wrists to be straight (WorkCover, 1993; Carter & Banister, 1994). The hands were positioned to "float" or "hover" over the keyboard (Barry, 1995). Touch-typing was introduced in 1888, and was being taught in many US schools by 1901 (Barry, 1995). Touch typists are taught to, and generally adopt this "floating" posture.

Based on a study of preferred settings and postures for computer workstations, Kroemer & Grandjean, (1997), recommended placement of the keyboard at a distance of 100-260mm between the desk edge and the home row of keys. A distance of more than 120mm from home row of keys to the desk edge has been shown to be associated with a lower risk of hand arm symptoms and disorders (Marcus et al., 2002). Although not specified by the authors, increased distance of the keyboard from the desk edge is usually associated with resting the forearms on the work surface. A lower risk of symptoms in this study was also associated with supporting of the arms on the desk surface or chair arm rests (Marcus et al., 2002). This is consistent with the findings from a recent field study of the effect of forearm support in intensive computer users in a newspaper call centre (Cook & Burgess-Limerick 2002). The mean distance of the keyboard from the desk edge before intervention was 95mm, increasing to a mean of 165mm following a period of adjustment to the forearm support posture. Position of the keyboard at the minimal distance of 100mm could result in only the wrists being rested on the work surface. The suggestions by Horie et al.,(1993) that resting on the wrists may increase carpal tunnel pressure, indicate that a greater distance from the desk edge is preferable to encourage resting of the forearm rather than just the wrist (Horie et al., 1993).

Desk height

The purpose of the desk is to provide a working surface on which equipment or tools required to complete the task are arranged. The height of the work surface should allow sufficient knee clearance, and allow for an 'appropriate' keyboard height (Carter & Banister, 1994). Although there is consensus that the work surface height should be adjustable, there are discrepancies around the recommended range of adjustability. The work surface may be adjustable in terms of height, angle, or sections within the work surface may be adjustable, such as a keyboard platform.

The height of the work surface should be dependent on the anthropometry of the user and the task being performed. Other factors, such as the sitting posture of the person (ie whether they are inclined or sitting upright) and user preference should also be considered. Although there is a difference in the range of heights given for adjustable workstation furniture, there is general agreement (within a range) that the workstation should be at or slightly below elbow height.

OHSA, (1997), in their document "Working safely with Video Display Terminals", recommends a "lower -than - normal" work surface, so that the operators work with the elbows by the side and the forearms parallel to the floor to enable the hands to move easily over the keyboard (OSHA, 1997).

Comcare (1996) recommends that the top surface of the desk is just below elbow height with WorkCover (1993) recommending an elbow position of at least 50mm above the work surface. Recommendations with respect to work surface height for keyboard tasks vary. Guidelines acknowledge that the keyboard thickness and slope are crucial in determining the height of the work surface (OSHA, 1997).

The recommended range of adjustability for office desks varies between publications. The Australian/New Zealand Standard on Office Desks (1997), recommended a range of adjustability of 610mm-760mm from the floor whereas WorkCover, (1993) recommended a wider range of adjustablility of 580mm-730mm. Kroemer, et al., (2000) recommended similar range of between 600mm-700mm. Grandjean, et al., (1983) reported that preferences for higher than recommended workstation heights of 710mm-870mm in a sample of 68 VDT operators. Similarly, the recommendations in Kroemer & Grandjean, (1997) are for a range, between 700mm and 850mm.

Where the desk is not height adjustable, or where there is insufficient room on the work surface for the computer and keyboard, other options for workstation design are often considered. These include use of an adjustable keyboard extender or tray, or use of a split desk (OSHA, 1997). The Australian/New Zealand Standard on Office desks includes these as alternatives to the preferred option of a height adjustable desk (AS/NZS, 1997). Although these alternatives have the advantage enabling adjustment of the keyboard to a correct height, they also have many disadvantages. Split desks and keyboard trays often have limited space on which to use a mouse (Comcare Australia, 1996). The range of tasks which can be performed on the work surface may be limited by having surfaces of different heights. The adjustment mechanism located under the shelf may be hazardous to the knees and may create inadequate clearance for the thighs below the work surface (Kroemer et al., 2001). Keyboard platforms which slide out from under the desk can have similar problems and can also increase the reach distance to other equipment on the desk (NOHSC, 1991). Most importantly, keyboard shelves and split desks reduce the range of potential postures for keyboard and input device because of the fixed location of the keyboard and associated input device. This runs counter to the principle of maximum postural variability.

Desk shape

The conventional office desk has tended to be straight, with a few alternate designs documented in the standards for use if the worksurface is to be used for a variety of tasks other than keyboard use. The Australian Standard on office desks specifies that there should be sufficient space for writing and for resting the hands and arms (AS/NZS, 1997), however the standards do not indicate support for the arm using the mouse. The study conducted by Aaras et al., (1998, 2001) on forearm support, used a concave desk as a means of providing forearm support.

The use of alternate shaped desks has been further explored by Karlqvist, (1998). This study compared muscle activity, perceived exertion, wrist postures and personal preference in a small study (n=10) which compared conventional desk use with three shaped computer desks. The exact design of the conventional desks was not specified, and no details are given as to whether the participants were able to support their forearms on the desktop. The alternate desks on which participants could support their arms resulted in lowest perceived exertion and lower muscle activity than the other desks. These shaped desks also resulted in less external rotation, and less time spent in external rotation of the shoulder when using the mouse. No effect of table design or forearm support was found for wrist extension during mouse use (Karlqvist, 1998; Cook & Burgess-Limerick, 2002). This was consistent with the findings of Woods et al., (2002) who compared no support, wrist support and forearm support during mouse use using both a straight and an L-shaped desk (n=20). Forearm support by the L -shaped desk resulted in lower levels of muscle activity in the left shoulder and right forearm, with slightly higher levels for the right shoulder and hand. There were no differences between wrist extension and radial deviation angles when forearm support with a straight desk was compared with a L-shaped desk.

Simoneau et al., (2001) examined a number of factors, including the effect of elbow height with respect to wrist height during keyboard use. A significant reduction in wrist extension was found when the keyboard was positioned 5cm above the elbow. This finding has not been previously reported. The authors expressed concern with using this recommendation for workstation setup due to the large body of literature associating desk position above elbow height with musculoskeletal symptoms. High desk heights causing postures of shoulder elevation are associated with neck and shoulder discomfort (Kroemer & Grandjean, 1997; Cook et al., 2000). The concluding recommendation made by Simoneau et al., (2001) was for the elbow and wrist to be positioned at equal heights, with the keyboard set at a negative slope of 7.5^{o} or 15^{o}.

Recommendations

The distance between the keyboard and desk edge should provide enough space to allow support of the forearms on the worksurface. The actual distance will depend on anthropometry and personal preference. Correspondingly, the work surface needs to be large enough to accommodate all equipment used and tasks performed. The height of the work surface should be adjustable in height and also have enough space to enable forearm support (ie desk at approximately elbow height). A curved or shaped work surface – or one that has an extension on the side of mouse use – may provide better support than a straight desk. There should also be adequate clearance for the thighs beneath the desk. The edges of the desk should be rounded as angled edges may result in discomfort from contact stress. Keyboard trays or split desks are not recommended. The decrease in desk space required for the LCD displays, allows sufficient eye display distances and forearm support at usual desk depths.

WORKING POSTURE

There are three main schools of thought represented in the guidelines. The first promotes typing in the floating position with the elbows at 90^{o}, requiring a lower workstation height (WorkCover, 1993; Comcare Australia, 1996; OSHA, 1997). The second promotes work in a reclined position, adopting a more open elbow angle and a higher workstation (Grandjean et al., 1983; Carter & Banister, 1994). The third promotes forearm support, either with or without a reclined chair posture (Aaras et al., 2001; Cook & Burgess-Limerick, 2001; 2002). In the studies reported by Cook & Burgess-Limerick, (2001, 2002), the worksurface height was adjusted so that when either the forearms or wrists were supported, the elbow was at 90^{o} and there was no shoulder elevation.

a) Floating posture

The floating posture, as outlined above has been the traditional method in which people were instructed to type. It continues to be advocated in some publications, and is still used by many people today. The workstation is recommended to be just below elbow height when working with a floating posture. High workstations have been associated with neck discomfort (Bergqvist et al., 1995) and shoulder discomfort (Hoekstra et al., 1996), due to the associated shoulder elevation, flexion and abduction required to maintain the hands at the keyboard.

b) Arm support

Lack of forearm support has been associated with increased hand/arm disorders (Bergqvist et al., 1995; Karlqvist et al., 1996; Karlqvist et al., 1998). Beneficial effects of supporting the arm were reported as early as the 1980s (Schuldt et al., 1987; Erdelyi et al., 1988). However, the benefits of forearm support during computer use were not described until much later.

The provision of forearm support during keyboard and mouse use has been demonstrated to reduce neck and shoulder muscle activity in both laboratory and field settings (Aaras et al., 1998; Aaras et al., 2001; Cook & Burgess-Limerick 2001; 2002; Woods et al., 2002). In the workplace, a reduction in musculoskeletal discomfort in the neck and shoulders (Aaras et al., 1998; Aaras et al., 2001; Cook & Burgess-Limerick 2002), and wrists and forearms (Cook & Burgess-Limerick 2002) was reported following provision of forearm support. Forearm support has been also demonstrated to reduce extremes of ulnar deviation as well as time spent in extreme postures of ulnar deviation (Cook & Burgess-Limerick 2001; 2002).

As for other recommendations on workstation setup, forearm support is not suitable for all people, with up to 20% of the participants in the study described by Cook & Burgess-Limerick (2002) withdrawing from the forearm support posture, either from discomfort of dislike of this work position. These findings and the group who did not experience a reduction in symptoms in the Aaras et al., (2001), study indicate that working with forearm support may not be the posture of choice for all keyboard users. This reinforces the importance of consideration of subjective preferences in workstation setup (Bendix & Bloch, 1986) as well as the importance of acknowledging individual differences.

c) Wrist support.

An alternate means of supporting the arm is to support the wrists. The wrists can be supported by the work surface, or by wrist or palm rests. Controversy surrounds the concept of supporting the wrists with respect to the angle of the wrists, the proposed increases in carpal tunnel pressure due to the position of the wrist, the effect of direct external pressure over the carpal tunnel, and reported discomfort.

Horie et al., (1993) reported an increase in intracarpal tunnel pressure when the wrist was supported in comparison with a "floating" posture. This research has only been published in abstract form, with other authors questioning the methodology and wrist position in this study (Albin, 2000). Although these findings may have been inconclusive, the hypothesis that supporting the load of the upper extremity via the wrists may increase intracarpal tunnel pressure has biological plausibility. A comparison of the anatomical structures of the wrist and forearm suggest that supporting the load of the upper extremity over the larger surface area of the forearm has merit over support using the relatively small surface area of the wrist.

Recommendations

Current research indicates that forearm support is a beneficial working posture for the majority of people. Use of a wider base of support is preferable, indicating that forearm support should be the preferred option over wrist support during keyboard use. Education on how to set up the workstation appropriately is also crucial prior to introduction of a different working posture.

KEYBOARD USE

Wrist postures

Ideally, the wrist should be positioned as far as possible within near neutral ranges during keyboard use to reduce the risk of possible injury. Keyboard use has been consistently shown to promote working postures around 19^{o}-23^{o} extension, 18^{o} ulnar deviation and full pronation (Serina et al., 1999; Chen et al., 1994).

Observation of extreme postures during keyboard use has resulted in a number of strategies aimed at reducing wrist angles: the use of wrist rests, the use of negative slope keyboards and the development of alternate keyboards.

Wrist rests

The primary use of the wrist rest is to keep the wrists in a neutral flexion/extension position while keying (Albin, 2000; OSHA, 1997). Despite the widespread use of wrist rests in workplaces, there is a dearth of published data on wrist rests, with most research only published in abstract form. Wrist rests are usually padded and detachable, varying in width, thickness and compressibility (OSHA, 1997). Wrist rests or palm rests are often integrated with, or attached to the keyboard. It is recommended that such wrist rests or supports be matched to the width, height and shape of the front edge of the keyboard (NIWL, 2002; HFES, 2001). Wrist rests can be placed adjacent to and in front of the keyboard, or along the desk edge, providing support to the palm, the wrist or the forearm. Comcare Australia (1996) report that wrist rests are for use during micropauses between actual keying, although the authors recognise that in practice, the wrist rest is often used while keying. The HFES (2001) standard reports that wrist rests may inhibit motion of the wrists during typing so should be considered as an optional feature. Australian guidelines report that wrist rests should not be needed with modern thin keyboards with well rounded desk edges (NOHSC, 1991).

There are a number of concerns expressed about wrist rests. These include the effect on intracarpal tunnel pressure from external contact pressure; whether wrist rests cause an increase in lateral deviation of the wrist (Albin, 2000); and the risk of tendon strain due to mechanical friction on the tendons which pass over the wrists to the fingers. This is stated to be due to the fingers reaching to the keyboard, rather than movement being generated by the whole arm (Comcare Australia, 1996).

Horie et al., (1993) reported an increase in intracarpal tunnel pressure when the wrist was supported in comparison with a "floating" posture. There have been concerns reported regarding the position of the wrist at 30° extension in the Horie et al., (1993) study. This wrist posture is associated with increased intracarpal tunnel pressure, irrespective of the support provided (Albin, 2000). No other published research could be found to substantiate the claim that wrist rest use increases intracarpal tunnel pressure.

There is little published research that examines the effect of wrist rest use on wrist posture. Albin, (1997), reported that wrist rests facilitate more neutral postures in flexion/extension (Albin, 1997). Two laboratory studies (Cook & Burgess-Limerick 2001; 2002) demonstrated ulnar deviation of close to neutral when a wrist rest was used in conjunction with forearm support. These studies were conducted with a firm wrist rest because previous authors have suggested that ulnar deviation is affected by the 'firmness' of the wrist rest, with softer materials associated with greater lateral deviation than firmer (Albin, 2000). No effect was found on wrist extension as a result of wrist rest use, with angles found to be similar to those previously reported. The wrist rest placed at the edge of the desk under the forearm rather than adjacent to the keyboard was found to improve wrist postures and be a preferred by a number of participants in a recent field study (Cook & Burgess-Limerick, 2002). This positioning of the wrist rest is consistent with previous recommendations (Hedge et al., 2002).

Recommendations

The literature indicates that a firm wrist rest used in conjunction with forearm support may increase comfort and decrease harmful wrist postures of ulnar deviation and possibly wrist extension. Preferably, the support should be placed under the forearm rather than under the wrist.

Negative slope keyboard

Negative slope keyboards are reported to be another way of neutralising wrist postures. Hedge & Powers, (1995) reported that wrist extension could be reduced to an average of one degree flexion when a negative slope keyboard support system was used in an experimental study using 12 experienced typists. This negative slope keyboard system rakes the base of the keyboard away from the user, so that the keytops are oriented horizontally, or slightly below horizontal with respect to the hand. This working posture was compared with two alternative postures, typing using a conventional keyboard without support and use of a full motion forearm support system.

Although the authors reported that use of the negative slope keyboard system resulted in reduced wrist extension, there were no differences between the experimental positions for ulnar deviation or elbow angles. The authors recommended that this system be used in conjunction with a palm rest to support the weight of the arms in between bursts of typing. They reported that this system may have the potential to reduce wrist extension in keyboard users (Hedge & Powers, 1995).

Further research on the effect of a negative slope has been published by Simoneau et al., (2001), who investigated the effect of keyboard slope angle and desk height on wrist extension in a laboratory study of 50 female typists. Reductions in wrist extension as a result of negative slope keyboard were not as marked (15° extension at 15° negative slope as opposed to 1° flexion reported by Hedge & Powers, (1995). The differences in wrist angle between the studies was reported as possibly a result of the difference in elbow height versus wrist height measured in the Simoneau et al., (2001) study, but not the Hedge & Powers, (1995) study.

A finding for the negative slope keyboard not previously reported, was a significant increase in ulnar deviation with use of the negative slope keyboard. The lowest measure of ulnar deviation was when the keyboard was positioned with a positive rather negative slope (Simoneau & Marklin, 2001). Both studies were consistent in their finding that a negative slope had no positive effect on neutralising wrist posture in ulnar deviation.

The participants in a recent study used a horizontal wrist rest (Simoneau & Marklin, 2001). This was in contrast to the palm rest placed at the same orientation of the sloped keyboard in the Hedge & Powers, (1995) study. Participants had been instructed to "type so that their wrists were either in contact with or slightly above the wrist rest". However, whether or not participants used wrist support during the study was not documented. When tendon travel as a measure of the repetitiveness of the keyboard task was considered, it was found that use of a negative slope keyboard resulted in significantly more tendon travel of the long finger flexors than when a positive pitch keyboard was used (Treaster & Marras, 2000). A gender difference was also found, with males having significantly greater tendon travel than females.

Recommendations

The results of the above studies indicate that although a negative slope keyboard has the potential to reduce wrist extension, it may increase ulnar deviation and increase tendon travel. This working posture also has the potential of reducing potential postural variability due to the fixed position of the keyboard, and therefore is not recommended.

KEYBOARD DESIGN

Conventional keyboards

The traditional QWERTY keyboard was designed over 100 years ago (Nakaseko, et al., 1985). It remains the primary input device of the computer. There are functional and biomechanical criticisms of the QWERTY layout. Functional criticisms include the overloading of the weaker left hand in right handed people, too little typing on the home row of keys, overloading of the left hand and the excessive movement between the rows of keys (Erdil and Dickerson, cited in Amell and Kumar, (2000)). There is concern that letters commonly used in conjunction are spaced apart and that the orientation of the letters in a straight line does not follow the normal position of the fingers (Kroemer et al., 2001).

The use of a conventional keyboard results in full pronation of the forearm and wrist deviation to rest the fingers on the home row of keys. Most computer users hold their wrists in a position of extension. There is widespread support in the biomechanical literature for reducing these awkward postures. This has led to the design of a variety of alternate keyboards, the goal of these keyboards being to position the wrist and forearm in a neutral posture (Marklin, et al., 1999).

A number of studies have been conducted to examine the effect of these alternate keyboards. The effectiveness of these keyboards has been measured with respect to wrist/forearm angles and muscle activity, tendon excursion, musculoskeletal symptoms, productivity and preference/comfort.

Alternate keyboards

Alternative keyboards were developed as early as the 1920's when a split keyboard was proposed as a way of alleviating ulnar deviation. Recent alternate designs have built on and extended this concept. The design of alternate keyboards differ from the conventional keyboard with respect to the slant, slope or tilt angles (Marklin et al., 1999).

Modifications to keyboards fall into three main categories, according to the axes on which the keyboard has been rotated (Barry, 1995).

1. Opening angle (yaw or slant) - rotation of the left and right halves of the keyboard around a vertical axis to prevent ulnar deviation
2. Tenting or lateral angle (roll) - tenting of the two halves of the keyboard to prevent pronation
3. Slope (pitch, tilt) - from front to rear to reduce excessive extension/flexion of the wrist (Barry, 1995) (Treaster & Marras, 2000) (Smutz, et al., 1994).

A range of studies has been conducted which examine the use of alternate keyboards. These studies vary in methodology, sample size and quality, ranging from laboratory studies of short duration with 6 subjects to randomised controlled design studies of 80 subjects over 6 months (Tittiranonda, et al., 1999).

The main improvement in wrist angles due to alternate keyboard use is in the plane of ulnar/radial deviation, with some studies reporting an almost neutral wrist posture when alternate keyboards are used (Simoneau & Marklin, 2001; Marklin et al., 1999). Most studies report that current alternate keyboard designs appear to have minimal influence on improving wrist extension, which has been shown to have more effect on carpal tunnel pressure than ulnar/radial deviation. Zecevic et al., (2000) reported 0^{o} extension with the Microsoft Natural keyboard, lower than reported mean wrist extension in the other cited studies. The lowest wrist extension for alternate keyboards appears to be for the Kinesis keyboard (Chen et al., 1994), however there are concerns with this keyboard regarding productivity. Pronation appears to be most reduced when a vertically inclined or "open" keyboard is used (Zecevic, et al., 2000; Marklin & Simoneau, 2001).

Repetition

Until recently, the risk factors of repetition and force have been less often considered in the literature on alternate keyboards. The synergistic effect of a number of risk factors can be more than the sum of them individually. As the combination of risk factors is of crucial importance to the risk of developing work related musculoskeletal disorders, the measurement of all factors should be considered. Repetition, such as measured by tendon travel should be considered when assessing keyboard design (Treaster & Marras, 2000). As tendon travel has been shown to vary by up to 11% between alternate keyboard designs, the differences over a long period of time may mean the difference between a high risk and low risk job (Nelson et al., 2000; Treaster & Marras, 2000).

Nelson et al., (2000), measured tendon travel and wrist angles in an evaluation of 30 combinations of yaw, roll and pitch (3 minutes per condition) in a laboratory setting with 15 volunteers. An adjustable (Comfort) keyboard was used for all test conditions. Tendon travel was reported to be sensitive to changes in pitch, roll and yaw angles, with up to 13% difference seen between the minimum and maximum tendon travel. Increasing pitch resulted in a decrease in tendon travel, especially when in conjunction with increased roll angles. However, increasing pitch also resulted in an increase in wrist extension. Increasing roll resulted in a decrease in wrist deviation and also in forearm pronation, moving the wrist into a more neutral position mid way between pronation and supination. Treaster et al., (2000), compared a standard keyboard with three alternate keyboards (Microsoft Natural, Kinesis and the Lexmark) with respect to wrist angles and tendon travel. Results were consistent with the Nelson et al., (2000) study, tendon travel was decreased as pitch increased, with the most tendon travel found for negative pitch keyboards. Significant effects on tendon travel were found for gender, with males having greater tendon travel than females (Treaster & Marras, 2000). The authors could not conclude one ideal position because of individual differences in anthropometry and work styles. Another concern was that beneficial decreases in tendon travel were associated with non-desirable increases in wrist extension. The Comfort keyboard was found to have limitations with respect to forearm support due to the depth of the keyboard. The increased depth of this keyboard resulted in an inability of the participants to rest their wrists on the desk surface (Nelson et al., 2000).

Muscle activity

Electromyography has been used to determine muscle activity in forearm muscles in a number of studies on alternate keyboards. In a comparison of the Kinesis keyboard with a standard keyboard, Gerard et al., (1994) reported that significantly less muscle activity was required in the finger flexors and extensors to maintain a resting position or to type using the Kinesis keyboard (Gerard, et al., 1994). In an evaluation of another alternate keyboard, a significant decrease in muscle activity was also reported for the extensor carpi ulnaris during use of Microsoft Natural keyboard, in comparison with a standard keyboard (Szeto & Ng, 2000).

Productivity

The difficulty in learning a new device, and the moderate improvements in typing speed and accuracy, are proposed reasons for alternate keyboards not being widely adopted (Amell & Kumar, 2000). Concerns regarding speed and accuracy of use of alternate keyboards, have been documented (Smith et al., 1998). Consequently, many recent studies have included productivity in terms of typing speed and error rate in their analysis of alternate keyboard designs.

Most documented concerns regarding speed and accuracy are for the Kinesis keyboard (Gerard et al., 1994). As not all studies include productivity data, and studies give variable training time on the alternate keyboards prior to evaluation (eg 3 minutes Chen et al., (1994) vs 10 hours Zecevic et al., (2000), it is difficult to determine the true effect of these keyboards on productivity. However, studies that have included 10 hours of training time, still report a reduced productivity with alternate keyboards when compared to standard.

Discomfort

Only one study examined changes in pain severity, clinical findings, functional hand status and comfort over time (Tittiranonda et al., 1999). In comparison with a standard keyboard, use of two alternate keyboards (Microsoft Natural and to a lesser extent the Apple Adjustable) resulted in improved trends in pain severity and hand function after 6 months of use. This was not, however, associated with an improvement in clinical findings. Other studies have considered discomfort during keyboard use in a laboratory setting. However, many of these studies were of short duration. Discomfort was reported to increase in the neck (Marklin & Simoneau, 2001) and overall (Chen et al., 1994; Tittiranonda et al., 1999) for standard keyboard use when compared with alternate keyboards. Decreases in discomfort were also reported when an alternate keyboard with a forearm support was used (Nakaseko et al., 1985).

Preference

Although user preference is an important part of ergonomics, few authors report having measured this variable. Tittiranonda et al., (1999) who conducted a 6-month randomised controlled study on alternative keyboards, reported that for alternate keyboard users, satisfaction was correlated with a decrease in overall pain. This was converse to the findings of the placebo group - subjects who reported their keyboard as "better", reported a worse mean pain severity. In the laboratory studies, a preference for the alternate keyboard over the standard was reported by a number of authors, with Zecevic, et al., (2000) reporting a higher preference for the fixed adjustable and standard keyboards over the open adjustable keyboard. Another study reported a preference for use of an alternate keyboard with a wide forearm support (Nakaseko et al., 1985).

Recommendations

There is no conclusive evidence that alternate keyboards reduce injury or are beneficial to computer users (NIOSH, 1998). However, some alternate keyboards such as the Microsoft Natural have been demonstrated to neutralise wrist extension postures and to significantly decrease pain after 6months of use (Tittiranonda et al., 1999).

NON KEYBOARD INPUT DEVICES: COMPUTER MOUSE

Prevalence

The computer mouse is the most commonly used non-keyboard input device. With the numbers of mouse users increasing rapidly over the past decade, it has become increasingly difficult to find people who use a keyboard as their only input device. In a recent study, only 32 out of a sample of 302 did not use a computer mouse. These were all employees in a newspaper call centre. In the subsequent weeks following the study, the mouse was introduced to these participants as well (Cook et al., 2000). Recent studies have reported that approximately 95% of computer users use the traditional computer mouse, with the remainder using alternate devices such as track-balls, optical pens or touch pads (Karlqvist et al., 2002; Aaras, et al., 2002; Jensen et al., 1998; Woods et al., 2002).

Mouse use can account for up to two thirds of computer operation time, depending on the task performed (Karlqvist et al., 1994). In a recent study of 3475 Danish employees, 40% of respondents reported to use their computer mouse never or seldom, 32% for a quarter of their work time and 28% between half and all their work time. Of the group who did not use a mouse, 624 were call centre employees who used a keyboard only (Jensen, et al., 2002). In the Cook et al., (2000) study, 52% of mouse users (n=270) reported using their mouse 4 hours or more per day.

Awkward postures: Proximal upper extremity

Symptoms in the proximal upper extremity have been associated with postures of shoulder flexion and abduction adopted during mouse, static load on the neck and shoulder muscles and the repetitiveness of the mouse task.

Muscle Activity

The effect of poor posture and static load on the muscles of the neck and shoulders during upper extremity work was well documented prior to the advent of the computer mouse. Westgaard and Aaras (1985) and Maeda (1977) reported the relationship between low level prolonged static muscle load on the neck and shoulders and musculoskeletal injuries. Work requiring positions of shoulder flexion and abduction has been identified as contributing to symptoms in the neck and trapezius region (Hagberg, 1981; Kilbom, 1988; Kilbom & Persson, 1987; Schuldt, et al., 1987b).

In comparison with keyboard use, mouse use is reported to result in increased shoulder muscle activity in the trapezius, (Harvey & Peper, 1997), and anterior deltoid (Cooper & Straker, 1998). Increased trapezius muscle activity has also been reported when the side operating the mouse is compared with the other side (Jensen et al., 1998). Postural effects of mouse use include increased shoulder flexion, abduction and shoulder rotation (Karlqvist et al., 1994). The placement of the mouse with respect to the keyboard has an effect on muscle activity and posture. Shoulder muscle activity and range of motion were increased when the mouse was placed distal rather than adjacent to a standard extended keyboard. Muscle activity was lowest when a keyboard without a numeric pad was used (Cook & Kothiyal, 1998). Non-optimal location of the mouse (shoulder forward flexion and abduction) was reported by 43% of participants in one study (Cook et al., 2000), and by 67% of men and 78% of women in another study (Karlqvist et al., 2002). The study by Cook et al., (2000) reported a relationship between shoulder abduction and neck symptoms amongst mouse users. This posture has been associated with the development of neck /shoulder disorders (Hagberg et al., 1995)

It is hypothesised that the provision of forearm support during mouse use will counteract the effect of extreme postures of shoulder flexion and abduction. A number of authors have reported the positive effects of support on decreasing muscle activity during mouse use. Cooper & Straker, (1998), reported a decrease in right trapezius activity when mouse was compared with keyboard use. They contributed the decrease in trapezius activity to the forearm support adopted during mouse. These findings were consistent with those of Bystrom et al., (2002) with recommendations for shoulder support during mouse use made by other authors (Fernstrom & Ericson, 1997; Woods et al., 2002).

Awkward postures: Distal upper extremity

Mouse users adopt postures of approximately 20° wrist extension, 10° ulnar deviation (Burgess-Limerick et al., 1999; Karlqvist et al., 1999) and almost full pronation during mouse use (Aaras et al., 1998; Cook & Burgess-Limerick 2001). When trial time is considered, mouse use has been reported to involve considerable exposure to extreme ulnar deviation (over 10° ulnar deviation) with some exposure to extreme postures of wrist extension (over 30°) (Burgess-Limerick et al., 1999). In a workplace study of computer aided design operators, electrogoniometric measurements of wrist postures demonstrated that the wrist operating the mouse was extended and ulnarly deviated for 90% of the work time (Jensen et al., 1998). Conversely, a recent study on mouse use and arm support reported a mean of between 20° and 27° radial deviation irrespective of whether or not the arm was supported. Wrist extension in this study was higher than previously reported during mouse use (mean 36° to 46°)(Woods et al., 2002).

Keir et al., (1999) studied the effect of mouse design and task on carpal tunnel pressures and wrist postures (Keir, Bach, & Rempel, 1999). No differences were found in wrist extension or carpal tunnel pressures with respect to mouse design. Carpal tunnel pressures were found to be greater during computer mouse use than when the hand is statically positioned over the mouse. Pressures were also found to be higher when a repeated dragging task was performed in comparison with a similar pointing task. The magnitude of carpal tunnel pressures measured during mouse use (~30mmHg) have been previously associated with altered nerve structure and function in human and animal nerve studies. The results indicate that people using a mouse for long periods of time may be at a higher risk of developing carpal tunnel syndrome, or aggravating existing symptoms. This is consistent with the findings of Franzblau et al., (1993), where an increased rating of hand and forearm pain was reported in a small sample of graphic artists in comparison with office workers.

Strong evidence exists for an association between tendinitis and force, repetition and posture (Bernard, 1997). The postures of wrist extension and ulnar deviation adopted during mouse use, combined with the repetition of the mouse task suggest that an association between tendinitis of the extensors of the wrist and mouse use is possible.

Repetition

Associations have been made between highly repetitive work and an increased risk of hand/wrist disorders. Silverstein et al., (1986) report highly repetitive work as being work tasks with cycle times below 30 seconds or where work is performed for more than 50% of the cycle time. Kilbom et al., (1994) suggests limits for the number of movements made by the hand, arm and fingers which indicate a risk for musculoskeletal disorders. The number of movements of the arm (2.5/minute), elbow (10/minute) and wrist (10/minute) observed in a study of CAD operators, exceeded the limits for repetitive work suggested by Kilbom et al., (1994). Jensen et al., (1999), compared trapezius muscle activity of computer-aided design operators with that of production workers. It was reported that CAD work was associated with more static muscle activity patterns and less EMG gaps on the mouse side. Continuous upper trapezius muscle activity was reported during mouse use, in conjunction with more repetitive muscle activity patterns on the mouse side (Jensen, et al., 1999). Fast, repetitive finger movements during mouse use has been reported to activate co-contraction in the neck and upper limb muscles (Sandsjo, et al., 2002).

Although this data suggests that mouse use is classified as repetitive, the EMG levels reported are lower than those previously associated with highly repetitive tasks (Jensen et al., 1998). Rather than activity levels, Jensen et al., (1998) suggest that repetitive movements without postural variation may result in prolonged activation of the neck and forearm muscles resulting in a risk of developing musculoskeletal symptoms.

The cognitive demands of many mouse related tasks and the stress of many work environments need to be considered in conjunction with the postural demands when considering the risk related to mouse use.

Effect of other work demands

A number of publications have demonstrated the effects of other work demands – such as stress and memory – on physiological responses while working with a computer mouse. Finsen et al., (2001), compared a computer aided design task requiring short-term memory demands with a task without memory demands. Memory demand was reported to initially increase heart rate, blood pressure, forearm extensor and finger flexor muscle activity (physiological effects of stress), with a subsequent decrease over time, possibly due to adaptation (Finsen, et al., 2001). Although a significant increase in muscle activity was found after the task was reintroduced, there were no corresponding increases in cardiovascular variables. The increase found in muscle activity in extensor carpi radialis had been reported previously during an attention related task (Waersted & Westgaard, 1996).

Similar responses of increased muscle activity and force during mouse use have been reported when participants were placed under stress (time pressure and verbal provocation) demonstrating the modifying effect of other risk factors (Wahlstrom, et al., 2002; Birch, et al., 2000).

As stress has been demonstrated to increase trapezius tension, Forsman et al., (1999) proposed that the same motor units engaged in activation during mouse use also may be evoked as a result of stress. Cognitive demands in conjunction with computer mouse work that already requires prolonged or repetitive muscle contractions, may constitute an increased risk of developing musculoskeletal disorders (Finsen et al., 2001).

ALTERNATE INPUT DEVICES

There are numerous alternate input devices, such as pens, light pens or guns, horizontal or vertical tablets, joysticks, trackballs, touch displays, speech control, touch gloves and knee controls (Coll et al., 1994), and trackpoints (Fernstrom & Ericson, 1997). The published research on alternate input devices is limited. Recent research has indicated that alternate input devices present advantages and limitations in comparison with the mouse, depending on the aspect studied (Fernstrom & Ericson, 1997).

The most commonly used alternate input device after the mouse is the trackball, with a number of studies comparing mouse and trackball use with respect to upper extremity posture, shoulder load (Karlqvist et al., 1999) and wrist postures (Burgess-Limerick et al., 1999). Aaras et al., (1999) also examined the effect of use of an upright mouse on posture and pain.

Muscle Activity

When muscle activity was considered, trackball use was found to be associated with lower right trapezius muscle activity than mouse use. This was consistent with a finding of decreased shoulder elevation with trackball use. The lowest trapezius muscle activity was for trackball use with the arm supported. The authors relate this to the active use of the shoulder during mouse use, in comparison with a trackball that requires mainly finger activity to move the "ball". No significant differences were found between the devices for either productivity or subjective ratings (Karlqvist et al., 1999).

Similar decreases in shoulder muscle activity were reported with trackpoint or trackball use (when the device was positioned in the centre of the keyboard) when compared with mouse use (Fernstrom & Ericson, 1997; Harvey & Peper, 1997). A perceived advantage of the centrally positioned input device is the avoidance of extreme postures of shoulder flexion and abduction as a consequence of the location of the mouse away from the midline of the body. Although this was demonstrated in both the above studies, the results of the Fernstrom et al., (1997) study indicated that trackpoint use resulted in increased forearm muscle activity (extensor carpi ulnaris) when compared with mouse use (Fernstrom & Ericson, 1997). Although not measured in this study, the authors reported that users positioned the hand near the trackpoint in the middle of the keyboard, ulnarly deviating their hand to use the rest of the keyboard. The limitations of all of the above studies include short study duration, small sample sizes and the laboratory setting.

Awkward postures

Trackball use was found to result in increased wrist extension and decreased ulnar deviation when compared with mouse use for some users (Burgess-Limerick et al., 1999). Another study reported similar, although less marked differences for wrist extension and no differences between trackball and mouse use for ulnar deviation (Karlqvist et al., 1999).

The conventional mouse results in work with a pronated forearm (Aaras et al., 1998). An upright mouse (Renaissance) has been demonstrated by Aaras & Ro, (1997) to result in a more neutral forearm posture, with decreased activity of the extensor digitorum communis and extensor carpi ulnaris (ie decreased pronation, wrist extension and ulnar deviation). In a longitudinal study over three years with 67 participants, use of the upright mouse in conjunction with forearm support resulted in a significant decrease in neck, shoulder, forearm and wrist/hand pain after 6 months of use (Aaras et al., 1999). When followed up, no significant changes in pain or confounding factors had occurred between 12 and 36 months. The authors advocate the importance of using a more neutral forearm posture and forearm support when using a computer mouse (Aaras et al., 2002).

Recommendations

Mouse use is a relatively new, but steadily increasing phenomenon. The relationship between mouse use and musculoskeletal disorders has been recognised, resulting in a rapid increase in publications over the past few years which address risk factors related to the use of alternate input devices. There is consensus amongst the published research, that the forearm should be supported during use of alternate input devices, irrespective of which device is used. Any peripheral input device should be used as close as possible to the keyboard to reduce awkward shoulder postures. Where possible, a shorter keyboard should be used instead of the standard keyboard so that the mouse can be positioned closer to the body midline.

At present, there is no conclusive evidence to support use of any particular alternate input device to the mouse, with the mouse by far the most commonly used non-keyboard input device in the workplace. Use of alternate devices to the mouse may be appropriate for individuals with wrist or forearm discomfort associated with prolonged mouse use. The size of the mouse should be considered as a mouse that is too large may contribute to hand pain. The large inter-individual differences observed during both mouse and keyboard use indicate that research should identify a range of "safe" input devices from which users can choose, depending on their anthropometry, work postures and preferences. Accordingly, each user should be evaluated individually to determine the appropriate device for use. Where possible, non-hand input alternatives should be considered.

SUMMARY

The aim of this paper was to discuss current standards and guidelines in light of recent research on computer workstations. Recommendations have been provided for workstations including use of the computer keyboard, the monitor and other peripheral input devices such as the computer mouse.

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