Utilizing advancements in data acquisition and control in the design of computer workstations

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Abstract
Musculoskeletal disorders (MSDs) of the neck, shoulders, lower back, and legs are on the rise as a result of increased usage of computers. In this paper, we outline the development of an "intelligent" workstation that can accommodate a range of users so that repetitive strain injuries may be minimized, if not eliminated. The workstation that has been designed and built has height and tilt adjustability for the desktop and footrest, and height adjustability for the monitor support. The user's computer can be programmed to control the workstation based on ergonomic criteria so that cumbersome manual adjustments are avoided for ease of use and operator comfort.

Keywords workstation, musculoskeletal disorders, computer users, furniture.

1. Introduction

The use of computers is growing exponentially worldwide. In 2002, there were 663 million units of personal computers in use worldwide with an average "density" of 106 personal computers in use per 1000 people (Computer Industry Almanac, 2003). In order for people to achieve their optimal performance, it is necessary that the work places and workstations provide effective support in their jobs so that they can work without discomfort or injury. The basic philosophy is to design workstations so that they are safe, comfortable, convenient and productive (Helander, 1997). In other words, tools, equipment and workstations should support people (i.e. designed for people) to do their work in order to achieve the objectives for which they are responsible (Rouse, 1991).

The high prevalence of computer work in almost every industry has given rise to many musculoskeletal disorders (MSDs) of the neck, shoulders, lower back, and legs. A recently concluded conference for the Prevention of Musculoskeletal Disorders in Operation of Computer Input Devices (PROCID) in Sweden (2001) outlined research on basic mechanisms of epidemiology, intervention and rehabilitation (Kadefors and Läubli, 2002). Such conferences and the numerous studies in this area are a clear sign of the increasing incidence of musculoskeletal disorders in workplaces. Many researchers (Berqvist et al, 1995; Gerr, et al., 2002; Hagberg and Sundelin, 1986; Smith 1980) have reported the adverse effects of computer usage, especially in the neck, shoulder, and elbow regions, due to static muscle loading (Karlqvist, Hagberg and Selen, 1994) and upper extremity postures (Higgs and MacKinnon, 1995). These disorders known as repetitive strain injuries or cumulative trauma disorders generally occur in the upper limbs, low back and neck regions.

Cumulative trauma disorders (CTD), also called repetitive motion injuries (RMI) or repetitive strain injuries (RSI) cost US businesses over US$30 billion each year, more than US$ 1 billion to U.K. businesses and cost Australia and Sweden a significant amount as well. The resulting health consequences and the loss of productivity stemming from the modern office have not escaped the attention of leading occupational and safety practitioners. Even though there is a strong consensus that CTDs are a costly and largely preventable occupational health problem (Armstrong, 1986), some countries have been adopting a reactive approach rather than a pro-active approach towards these problems. Countries such as Sweden, Australia, Japan, Great Britain and the United States have initiated national strategies to overcome CTDs (Putz-Anderson, 1988). A recent survey conducted by the Occupational Health and Safety Council (2002) of Hong Kong, on 688 workers from 96 companies showed that musculoskeletal discomfort was present in various body parts: 56% neck discomfort, 57% shoulder discomfort, 47% upper back discomfort, and 74% eye discomfort. The discomfort ranged from pain, muscle soreness, cramps, numbness, muscle weakness and fatigue. The interesting aspect relates to the working conditions, where 94% of these workers had adjustable chair heights, 98% had backrests, 32% had armrests. In addition, 60% of the workers adopted a leaning forward or backward posture when looking at the computer monitor, and only 43% of the people had their keyboard set at elbow height. This survey is a clear indicator of the need for the right height adjustment and the necessity of the workstation to provide dynamic postures. Nanthavanij and Venezia (1999) have developed a computer program giving a pragmatic set of recommendations. The program has been validated with Thai subjects and provides information such as necessary height of seat, height of keyboard home row, height of center of monitor, horizontal distance from seat back to keyboard home row, footrest height, and so on. Lutz and Hansford (1987) discussed many ways in which CTD can be significantly reduced. These included adjustability of equipment height to allow people of different sizes to work comfortably, tilting work fixtures toward a worker to reduce body interference with equipment so as to avoid extreme body postures, minimizing reach distances, and eliminating sharp edges on equipment and/or products. In most cases, such elaborate recommendations are only achieved through the use of thick objects such as telephone directories, wooden boards, foot stools, and so on. The US Center for Disease Control/National Institute for Occupational Safety and Health website (CDC/NIOSH, 2002) provides a very illustrative example of using wooden blocks to adjust the table height in order to reduce the stress on a worker's back, neck and shoulders.

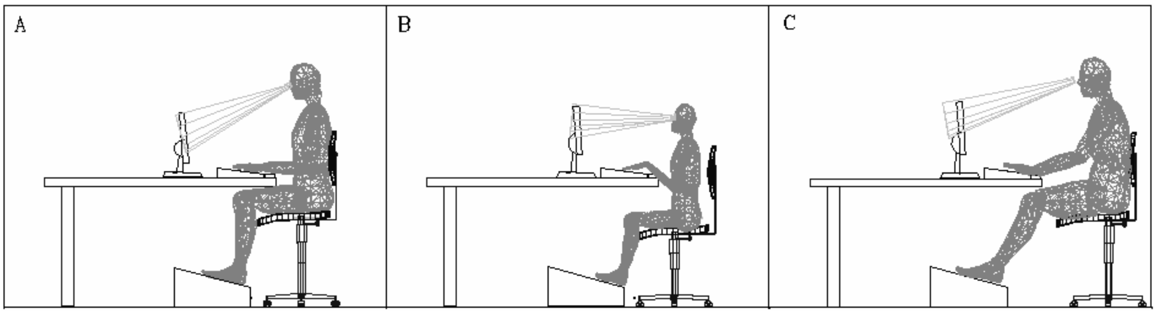

Figure 1. Effects of poor posture due to lack of adjustability in computer workstations (A). average person (B) small person and (C) large person. The primary visual range, below the resting position of the eye is also shown. Note the awkward wrist and neck postures in (B) and the slouching in (C).

A number of different standards institutions have been very active in this area (The American National Standard for Human Factors Engineering, ANSI/HFES, 1988; British Standards, BS 5940, BS 7179, 1980; Committee European de Normalisation, CEN 1990; International Standards Organisation, ISO-9241, etc). The American National Standard for Human Factors Engineering of Visual Display Terminal Workstations (ANSI/HFES Standard #100-1988) brought worldwide attention to the fact that the needs of the human user were not being fully addressed in the design of office furniture. These standards serve more as a guideline for people to adopt, and those that exist are static measurements for improved posture. The implementation of these standards relies solely on the user to interpret and adjust the relevant parameters that he/she may or may not have control. In order to adhere to the standards and directives, nearly all manufacturers are producing adjustable chairs to increase their market share in a multi-billion dollar furniture industry. Chair adjustments range from seat heights and inclinations to back support depths and thickness. Even though some adjustability is built-into the chairs, the adjustments are hardly used. With the general lack of adjustability on the computer table, the operator is locked-in to one static posture resulting in discomfort and pain when seated for long periods. Figure 1 clearly shows some of these awkward postures. Computer users will try to use their body to compensate for the necessary height matching of the eyes, hands, and feet. In the long-term, such awkward postures can result in disorders of the neck, shoulders, back. Only a few companies have recognized the need for adjustable work surfaces and offer a few different variations of tables. Products with adjustable surfaces can be found from companies such as the Mayline group (www.mayline.com/showcase/adjwrk.html), Zydeco (www.mcergo.com/adjust_met.htm), Anthro (www.keyalt.com/furniture/anthro.htm), Workrite stations (http://www.wrea.com/Lifts/Lifts.shtml) and so on. Rare, but some other adjustments to furniture include VDT table heights, monitor heights, monitor tilt angles, keyboard angles, and some others. Figure 2 shows how adjustable furniture can help one achieve good posture. The adjustment mechanisms include manual cranks, counterbalanced tables, and electric motors. However, there are various problems associated with such furniture. Firstly, most operators are not aware of the height to which the furniture should be adjusted. Secondly, once the furniture is adjusted, the operator is reluctant to change the setting, as the user may not be able to achieve a previous setting, which may have had a higher degree of comfort. In other words, the person-furniture system is without memory. Thirdly, with such adjustments, the furniture-user is presented with an infinite number of adjustment possibilities. Due to the complexity of the needed adjustments, nearly 99.9% of the users of adjustable furniture make only one adjustment prior to use. Thereafter, they refuse to change any of the settings on these expensive "ergonomic aids" making the adjustable features redundant, if not useless.

The aim of this project is to design a flexible and adaptive computer workstation that can be adjusted to fit any person while allowing the user to get back any of his or her previous settings with ease. With the rapid advancements in data acquisition and computer control, the planned objective can be implemented at reasonable cost.

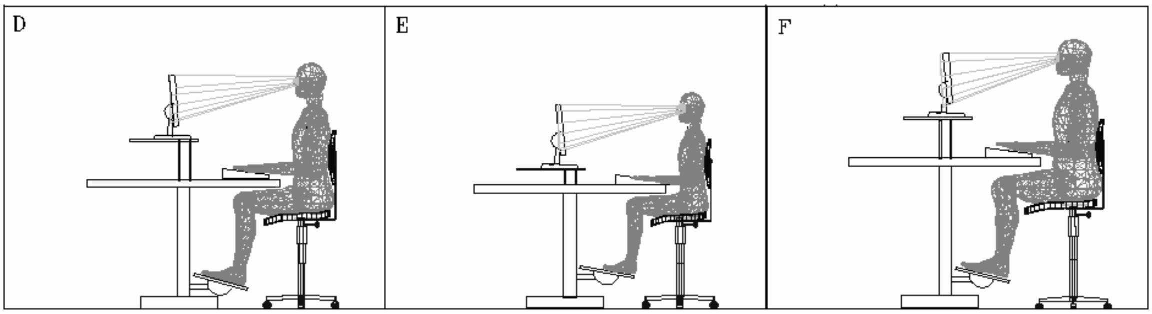

Figure 2. The same persons (average, small and large) as Figure 1 with an adjustable workstation. The primary visual range below resting position of eye is also shown.

Even though standards such as the American National Standard for Human Factors Engineering of Visual Display Workstations (ANSI/HFES, 1988) addresses the various dimensions and angles associated with computer workstations, recent epidemiological research (Marcus et al., 2002) however, shows that workstation recommendations such as OSHA (1997) and ANSI-HFES (1988) alone may not be appropriate. Rather, workstation designs should allow for more flexibility during use and in general provide opportunities for the body to be supported while working. In some cases, the design recommendations are conflicting. For example, a common recommendation for monitor position is for a monitor to be around eye level (high position). More recent recommendations include positioning the monitor somewhere between 15^0 and 45^0 below eye level (low position). Some of these conflicting recommendations are shown in Table 1.

Table 1. Display height recommendations

Source	Display height recommendation
OSHA (1997), Canadian Standard Association (1989), Kroemer et al (2001); Pheasant (1992)	Top of monitor at around eye level so that the line of sight anywhere from 0 to 45^0 below horizontal when one sits “upright”
Ankrum and Nemeth (1995)	Top of screen is at least 15^0 below horizontal eye level
Berqvist et al. (1995)	Much lower than eye level
Kumar (1994)	Monitor center is 35^0 below horizontal eye level to accommodate bifocal users

Fogelman and Lewis (2002) have reported factors associated with self-reported musculoskeletal discomfort in computer users. They found that users who position the monitor too low tend to slouch forward resulting in stress in the neck/upperback, lowerback, and shoulders (see Figure 1C). Similarly, Straker and Mekhora (2000) found that the high position had less head, neck and trunk flexion and less cervical and thoracic erector spinae muscle activity compared to the very low level. Such conflicting recommendations become difficult to implement with fixed surfaces. Even with adjustable surfaces, if the adjustments are cumbersome (for example turning a crank), those adjustments are less likely to be used.

2. Functional requirements of a workstation

Many dimensions have been identified as being critical for seated work. One ought to be able to see the work (display), support their hands in the optimal position for handling tasks such as typing, and be able to rest their back, feet and buttocks to support load without undue compression. Depending on the critical factor (that is, eye, hands, or feet) from the standpoint of work that has to be performed, and also from the standpoint of the "weakest" or most uncomfortable body part of the person, one may select furniture settings to achieve some acceptable level of comfort or discomfort. If the work surface height, display height and footrest height are all not adjustable, there is a possibility that some of the body parts could be at risk as a result of some awkward postures.

It is well known that, neutral posture can help reduce repetitive stress injuries. Hence, achieving neutral posture at all body joints is the key functional requirement to minimize discomfort. Studies such as Aaras et al. (2002) have shown the importance of designing products to enhance neutral position during use for the reduction of pain and discomfort. Generally, the keyboard (the g-h keys) and mouse are supposed to be at around elbow height, so that forearm can be at 90 degrees and wrist straight. Similarly, studies such as Delleman and Dul (2002) have provided very specific guidelines for sewing machine workstations such as:

1. the table should be between 5 and 15 cm above elbow height in a seated posture and,
2. the table should have an inclination of about 10 degrees

3. Design parameters

The design parameters of the workstation are monitor position, worksurface location, and footrest height and inclination. The height of the monitor platform can be adjusted to one's liking and the operation is controlled through the computer. The range of monitor adjustment is 5cm to 20cm above the worksurface. The lowest position of the platform is 5cm above the level of the working area of the workstation. This platform can also be moved back and forth manually through 19cm. The furthest position of the monitor is 50 cm from the front edge of the workstation. The keyboard is on the work surface, which is 54cm x 47cm and can be inclined anywhere between 0 and 40 degrees for writing. In addition, the work surface was designed to maximize reach.

The user of the workstation may change their footwear (heel height) everyday (Schulze 2000). This will affect comfort of the feet and ankle. Thus the angle of the footrest is adjustable manually by forcing the footrest to the desired angle. The minimum leg clearance is 84cm x 40cm x 42cm under the table and above the footrest.

4. Data acquisition and control

A PC-based LabVIEW data acquisition card was used to acquire signals and control the workstation. The card had multi-functions, and had the ability to handle analog input and output as well as digital input and output. LabVIEW has a windows-based graphic programming ability. The software has a powerful set of icons. The programmer puts each of the icons in the required sequence and connects each of the icons using lines. As the programmer generates these icon graphs, LabVIEW generates the software code in the background.

A series of motors, solenoids, and limit switches were used for moving the workstation parts and for controlling the movement. The positioning of each part was achieved through the use of rotary potentiometers. The complete electrical system was a closed loop control system. The adjustments were performed at a predetermined speed by the computer so that stopping can be somewhat instantaneous in order to achieve the required setting. Each of the adjustments was uncoupled so that the user can manipulate the system in a hierarchical fashion. The range of movement of each and every component was controlled with the use of limit switches. Gears, lead screw arrangements and toothed belts were used to transmit forces and torques to move the different parts.

5. Control, safety and maintenance

All adjustments are performed using the same user computer even though a manual override option is also available. The moving parts are covered for safety reasons. The edges of the workstation are rounded to avoid "cutting" into skin. The workstation is quite robust and very little maintenance is required. Unless there are failures of components such as limit switches, motors, or potentiometers, regular maintenance will only involve lubrication of moving parts.

6. Conclusions

Even though many ergonomists have recognized that workstation adjustability is important for the well being of people, the implementation of the adjustability concept has not been well executed. It is hoped that an intelligent workstation such as the one designed, developed, and described in this paper will make furniture more person-oriented and dynamic, so that users can “ride” with comfort when working at a workplace.

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