

# Effective Designs of Non-Keyboard Computer Input Devices

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## I. INTRODUCTION

With the prevalence of computer usage in society today, the incidence of work related musculoskeletal disorders (MSD) has correspondingly increased, particularly in the upper limbs including neck, shoulder, arms and wrists [20]. For computer workers, a myriad of possible contributing factors for these musculoskeletal injuries have been identified including seated work, awkward positions, static work, inactivity, overuse, lack of breaks, stress on bone and connective tissue, pressure on blood vessels and nerves, gender, age and psychological stress [20]. In a sense, a computer input device can be considered as an exercise machine. It stresses and strains certain muscles repeatedly. However, similar to exercise machines, overuse can lead to pain and even permanent injury.

So what do these injuries tell us about the natural posture and movement of the human form? What are the limits to the stress applied to human muscles? And if we know these limits of muscles and form, can we design a computer input device that would cause less injury? This paper is a literature review of research that attempts to address such issues. Since there are so many different factors that potentially contribute to MSD of computer workers, this paper will narrow its scope to mainly non-keyboard input devices (NKID) which include the mouse, joystick, trackball, touchscreen and touchpad. However, it should be noted that most research lump keyboard and mouse into one object, the computer input device, since both constrain posture for static tasks. Thus research on just NKID specific injuries are sparse.

In this paper, Section II gives an overview of MSD is and a brief overview of possible risk factors, which will be elaborated in Section IV with an emphasis on how it relates to NKID usage. Section III-A describes how common NKIDs are in use and III-B talks about the loads exerted on muscles and the posture users take. Section V describes some popular hypotheses relating some risk factors to MSD as well as experimental results to support them. Section VI compares the differences in NKID designs, mainly in

how it affects wrist movement (lateral along direction of arm) and ulnar deviation (radial about the wrist.) Section VII gives design recommendations followed by conclusions in Section VIII.

## II. MUSCULOSKELETAL DISORDERS

Musculoskeletal disorder, also known as repetitive strain injury, is an umbrella term that incorporates various soft tissue and inflammatory joint conditions. This would include tendonitis, tenosynovitis, nerve entrapment syndromes (e.g. radial, ulnar, etc.), epicondylitis, muscular sprain and strains, carpal and radial tunnel syndrome, bursitis and rheumatoid and arthritic conditions [18]. All of these conditions have similar symptoms including pain, tingling discomfort, numbness and swelling in the joints and muscles, usually in the upper limbs (neck, shoulders, arms, hands/wrists). Other symptoms include lack of movement and pain in the shoulder and neck regions [21].

Some past research have identified the following risk factors [7]:

**Physical:** heavy, static or monotonous work, extreme or constrained postures, repetitive movements, unsuitable workplaces and equipment, forces, exposure to vibration or cold environment

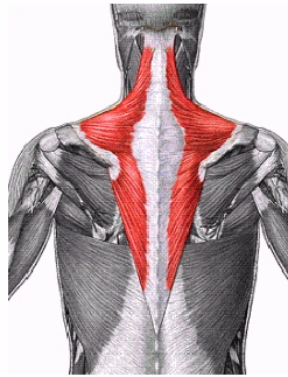
**Psychosocial:** work organisation, interpersonal relationships, short cycle tasks, poor work control, piece rate payment system, poor management, unsatisfactory training, lack of breaks

**Personal:** gender, age, seniority, exercise habits, lifestyle, psychological characteristics and capacities

Perhaps the most influential risk factor for NKID are physical, namely the prolonged static and constrained posture when used. Postures arise from a combination of device design and workstation configuration. Duration and intensity of use depend upon the nature of tasks and it is organised. Other issues, psychosocial and personal, also have a bearing as well.

## TRAPEZIUS

Posterior muscle of neck and most superficial muscle of the back. The trapezius has multiple origins on thoracic and lumbar vertebrae, the lower four ribs and the iliac crest. It inserts on the acromion and spinous processes of the scapula and the clavicle. Its actions include extension of the head, adduction and vertical movements of the scapulae.



## EXTENSOR DIGITORUM MUSCLES



This is a superficial muscle on the posterior surface of the antebrachium. It has an origin on the lateral epicondyle of the humerus. It inserts on the distal phalanges of the fingers excluding the thumb. It is the prime mover of extension of the fingers.



*Figure 1. Left:(a)Trapezius muscle, Right:(b) Extensor digitorum and specifically the communis muscle [16][19]*

### III. CHARACTERISTICS OF NKID USE

#### A. Amount of Workplace Usage

It is apparent from everyday experience and general observation that the use of NKID is the most commonly used input device other than the keyboard. In particular, the mouse is by far the most common input devices for desktops at 97% and laptops at 64% in the organizations surveyed in 2002. Touchpad and trackball on laptops used at 31% and 28% of organizations respectively [21]. Point-and-click is gaining on keyboard typing. In fact, most websites on the internet is set up such that navigation can be made by a simple click of the mouse. Graphical user interface in most software also tend to designed with point-and-click navigation/usage.

#### B. Physical Loads in NKID Use

A literature survey of the physical loads and static postures caused by NKID revealed a similar pattern. The majority of the muscular disorders in the neck or shoulder regions were located in the trapezius muscle (Figure 1a) and the disorders in the forearm or hand were located in the forearm extensor muscle, specifically extensor digitorum communis (Figure 1b) [20]. For example, Cooper and Straker found that mouse users experienced higher muscular loading on the anterior deltoid muscle and lower loading on the upper trapezius muscle, compared with keyboard users [4]. Jensen et al. (1998, 1999) also found that muscle loads in the neck or shoulder are normally relatively low and static during computer work [12].

In terms of posture, Cook and Kothiyal (1998) found that computer mouse users worked with their shoulders outwardly rotated more often than

keyboard users (81% of the time, compared with 65% of the time, respectively). Computer mouse users tended to have unilateral movements – they flex, abduct and externally rotate the shoulder on one side of the body only. They also found that mouse users were more likely than keyboard users to have musculoskeletal symptoms possibly due to the distance of the mouse from the centre of the keyboard, and proposed that removal of the numeric keyboard for mouse users is helpful in reducing this reach distance [2]. In a separate study, Karlqvist et al (1996) found that mouse technique changed posture and movements compared with non-mouse usage with wrist ulnar deviation was significantly greater during mouse use (17.6°) compared with non-mouse use (1.8°)[15].

### IV. NKID RISK FACTORS FOR MSD

Possible contributing factors to musculoskeletal disorder may include seated work, awkward positions, static work, inactivity, overuse, lack of breaks, stress on bone and connective tissue, pressure on blood vessels and nerves, gender, age and psychological stress [20]. The following will elaborate on how those factors may be aggravated through use of NKID.

#### A. Posture

Postures for NKID use vary depending on individual technique and anthropometry, device design, workstation configuration. Mackinnon and Novak (1997) identified three potential mechanisms through which postures during NKID use might contribute to the development of MSD: increased pressure on nerves at entrapment points, increased neural tension and use of muscles while contracted [17]. In particular, using NKID involve postures that

cause wrist extension, ulnar deviation and other non-neutral joint positions [3]. For example, wrist injury may arise from the narrowing of the carpal tunnel during wrist extension and deviation, causing increased pressure on the median nerve and other structures [17].

### *B. Workstation Configuration*

The dimensions and arrangement of the user workstation has a large effect on device placement and user posture. In regards to NKID placement, it is preferable to allow a near neutral posture [14][15]. When the mouse is positioned away from the midline of the body, users end up working with their arm unsupported, their shoulder abducted and externally rotated and the arm in forward flexion [15][4][2][1].

Arm and wrist support was also found to be beneficial. Aarås et. al. (1997) found that the muscle load on upper part of the musculus trapezius was significantly less when sitting with supported forearms compared to sitting without forearm support [1].

### *C. Duration*

Several studies have documented a relationship between upper extremity pain and the period of time an operator uses a keyboard or mouse. For example, Hagberg (1995) found that computer operators that use the mouse regularly reported higher levels of discomfort in the shoulder-scapular, wrist and hand-finger regions compared to low frequency users [8]. Karlqvist et. al. (1996) similarly reported an association with neck and upper extremity symptoms and extent of mouse use. They found that more than 5.6 hours of mouse time per week had increased risk of shoulder symptoms [15].

However, in a more recent study, Cook et. al. (2000) found no relationship between self-reported duration of mouse use and MSD symptoms in a cross-sectional survey of 270 users. They were unable to explain the discrepancy between this finding and those of the stated earlier studies other than to note the problem with relying on self-reported surveys rather than controlled experimentation [3].

### *E. Individual Characteristics*

Age and gender have also been noted to make a difference when it comes to MSD. In terms of age, it is obvious that the elderly may have weaker muscles and tire quicker. In terms of gender, it was found that females displayed MSD symptoms in the neck/shoulder and forearm/hand regions nearly twice as often as men. Hagberg reported findings from a

study looking at musculoskeletal health of computer mouse users in the Swedish workforce with regard to gender and psychosocial factors. In all eleven economic activities examined, a statistically significant number of females exceeded males with neck symptoms [7].

### *F. Psychological Stress*

Thorn (2005) showed through experiment that psychological stress in users resulted in an increased trapezius motor response and less muscle rest. He suggested that stressful working conditions increased the risk for muscular overuse which led to more neck/shoulder complaints [20].

## V. THE BIOLOGY LEADING TO MUSCLE PAIN

Since MSD includes such varied conditions affecting both muscles and joints, this paper chose to focus on muscle pain since there has been some research in this area. In particular, the muscles where a majority of the muscular disorders are located: the trapezius muscle (in neck/shoulder area) and the extensor digitorum communis (EDC) muscle (in forearm down to fingers).

The traditional theory for MSD is that for prolonged workloads with high muscle contraction hampers blood macrocirculation due to increased intramuscular pressure. This may reduce the supply of oxygen and nutrition to the muscles while trapping lactic acid in the muscle (which is known to cause muscle aches in athletes). However, Thorn maintains that this explanation

However, as mentioned in Section III, the use of NKID and computer work in general tends to be a low and static workload. Thus this traditional explanation has been challenged as insufficient to explain pain in surface muscles such as the trapezius and EDC since they experience less intramuscular pressure. One of the more contemporary theories being examined is the Cinderella hypothesis, which postulates that groups of muscle fibres or motor units (MU) are continuously active during monotonous workloads, leading to MU overuse and an MSD known as myalgia. Hägg (1991) postulated that some of the low-threshold MU will be overused if the contraction is sustained too long without periods of total relaxation [9]. Thorn (2005) demonstrated that there is continuous and sustained MU activity in the trapezius and EDC muscles during standard word processing computer tasks, which seems to support the Cinderella hypothesis. He also found an increased trapezius motor response to psychological

stress, such as a stressful work environment, which increases the risk of MSD [20].

Another theory is known as the nitric oxide/oxygen ratio hypothesis. According to this hypothesis, neck myalgia is caused when low-level contractions in the trapezius muscle are combined with psychological stress or prolonged head-down neck flexion at work. Both psychological stress and prolonged head-down neck flexion can increase sympathetic nerve activity which leads to arterial vasoconstriction [5]. This causes reduced blood flow and O<sub>2</sub> to muscles as well as reduced removal of NO residual from muscles. The increase in NO/O<sub>2</sub> ratio affects the production of adenosine triphosphate (ATP), required by cells for energy, and leads to a build up of lactic acid in connective tissues to cause myalgia [13].

## VI. COMPARING DIFFERENT NKID

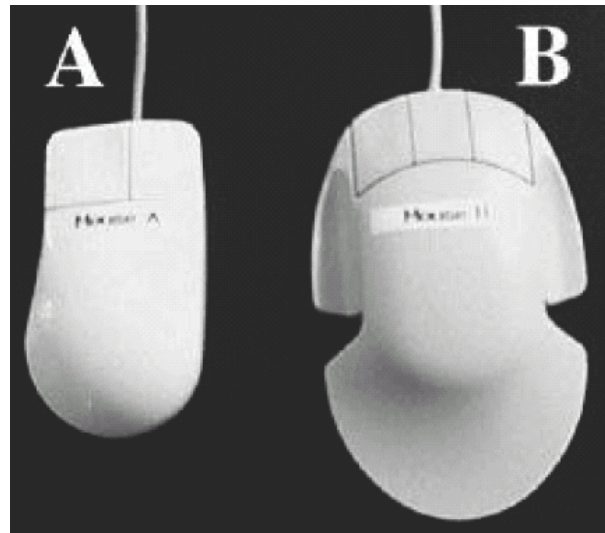
As mentioned in Section IV-A, posture is one of the main risk factors for MSD with excess wrist extension and ulnar deviation as likely causes for carpal tunnel syndrome. It is apparent that different NKID devices would require different operating postures. For example, a computer mouse would require a downward twist of the forearm while a joystick adopts a more forearm neutral position. However, different mouse shapes and sizes can also yield a significant change. Hedge et. al. (1999) compared the two mice in Figure 2 and found that mouse design had a significant effect on a user's wrist extension posture and task performance, but no significant difference in ulnar deviation [10].

In a few studies done on such NKID comparison, it was found that there was little difference in posture between mouse and trackball, but a greater effect from device location. The mouse had high ulnar deviation (greater than 10°) during use, while trackballs had more extreme wrist extension (greater than 30°). Trackballs reduced the loading on shoulder muscles, but increased undesirable wrist posture [14]. The physical mechanism for using the increasingly popular touchpad on laptops is very similar to the trackball, so it is suspected that results will be similar.

The track-point mouse (a small joystick in the middle of a keyboard) commonly found on laptop computers was found to require less shoulder activity than a standard mouse, but increased hand, finger flexion and forearm muscle load [6].

A joystick mouse gives a more neutral forearm position compared to a standard mouse which requires pronation of the forearm, which leads to a lower muscle load when using a joystick. Aarås et. al. (1997) found in a study that a joystick resulted in

lower pain intensity and frequency in the wrist/hand, forearm, and shoulder/neck area [1]. The drawback is that using a joystick tends to have task performance and precision issues.



**Figure 2.** Mouse A (Microsoft Corp.) is static & standard, Mouse B (Humanscal, Whale mouse) has adjustable length[10]

Ichikawa et. al. (1999) studied pen-tablet devices. The mouse was subjectively found to have lower load to the wrist, elbow, arm and shoulder [11].

In general, there was so much individual variability in the postures adopted when using these devices that it was difficult to recommend any particular input device for prolonged use.

## VII NKID DESIGN GUIDELINES

Based on the known risk factors and comparison of different designs, some recommendations for design proposed for the Health and Safety Executive 2002 [21] are given below:

- Should be comfortable to hold and operate, thus it should have varying sizes or be adjustable to fit different user anthropometry.
- Handedness should be a consideration to accommodate left-handed users as well. Also, right-handed users can use it to vary their posture.
- The design should promote a straight wrist posture while avoiding excess finger flexion (close buttons position) and static loading of the arm and shoulder (low force buttons).
- General features expected from a computer input device including precision and accuracy, intuitive use and configuration, minimal maintenance, etc.

### VIII. CONCLUSION

These studies reviewed as well as anecdotal evidence from daily life have shown that there is a correlation between our computer input devices to an increasing number of musculoskeletal disorders. The studies have also pointed out specific reasons, or risk factors, that lead to such MSD through NKID use, including posture, workspace configuration, duration, individual characteristics and psychological stress. Some biochemical hypothesis proposed to explain muscle aches in particular basically involve overstimulation of muscles causing some chemical imbalance to induce a build up in lactic acid, known to cause muscle aches. In examining different NKID designs, it was found that most devices have benefits and drawbacks and there was no clear winner. It must be noted that no studies were found comparing the use of the increasingly popular touchpad on laptops to a standard computer mouse. However, it was thought that the physical movement of the touchpad paralleled that of the trackball. Based on all this research, design guidelines were proposed for NKID devices.

In a way, the technologies that humans have haphazardly developed are now testing the limits of human physiology. Likely the most important guideline that any designer can have is feedback from its users for future improvements through iteration.

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