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## Ergonomic requirements for computer input devices

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# Ergonomic requirements for computer input devices


## Abstract

Intense work on computers and the associated use of various input devices may lead to disorders in the musculoskeletal system of the hand, arm, shoulder and/or neck, particularly in individuals already suffering from painful disorders of the upper extremities which have other causes. In this case, ergonomically designed input devices are intended to reduce the exposure to stresses and to prevent further disorders associated with their use. Although standards exist containing requirements for these devices, their provisions are in some cases formulated in general, descriptive terms with no quantifying data. It is therefore difficult to derive specific recommendations from them. For this reason, the VBG (institution for statutory accident insurance and prevention in the administrative sector) has launched a literature study in order to gather current knowledge on the ergonomic design of input devices and on testing of them against biomechanical and physiological criteria. A comprehensive survey of the international literature yielded results for keyboards, mice, trackballs, styli and tablets and hand/arm rests. In addition, a checklist was drawn up for keyboards and mice in consideration of biomechanical and physiological criteria. Should disorders arise, it provides assistance in the ergonomic assessment and improvement of the workplace for selection of the input devices.

## Ergonomische Anforderungen an Eingabemittel für Geräte der Informationstechnik

## Kurzfassung

Intensive Computerarbeit und die damit zusammenhängende Benutzung von diversen Eingabemitteln können zu Beschwerden im Muskel-Skelett-System der Hand, des Armes, der Schulter und/oder des Nackens führen, insbesondere wenn bereits schmerzhafte Erkrankungen der oberen Extremität anderer Ursache vorliegen. In diesem Fall sollen ergonomisch gestaltete Eingabemittel helfen, Belastungen zu reduzieren und das Auftreten weiterer Beschwerden bei der Bedienung von Eingabemitteln zu vermeiden. Zwar sind Normen zu Anforderungen an diese Geräte vorhanden, jedoch sind die darin enthaltenen Aussagen teilweise allgemein umschreibend ohne quantifizierende Angaben formuliert. Daher ist es schwierig, aus ihnen konkrete Empfehlungen abzuleiten. Aus diesem Grunde hat die Verwaltungs-Berufsgenossenschaft (VBG) eine Literaturstudie initiiert, um den aktuellen Wissensstand zur ergonomischen Gestaltung von Eingabemitteln und zu ihrer Überprüfung anhand biomechanischer und physiologischer Kriterien zusammenzustellen. Eine umfangreiche Recherche der internationalen Literatur lieferte Ergebnisse zu den Themen Tastatur, Maus, Trackball, Griffel mit Tablettnutzung und Hand-/Armauflage. Außerdem wurde für Tastatur und Maus eine Checkliste nach biomechanischen und physiologischen Kriterien erstellt. Bei auftretenden Beschwerden bietet sie eine Hilfe zur ergonomischen Beurteilung und Verbesserung des Arbeitsplatzes in der Wahl der Eingabemittel.

## Ergonomie des périphériques d’entrée d’ordinateurs

## Résumé

Le travail sur écran intensif, qui implique l’utilisation de divers périphériques d’entrée, peut conduire à des troubles musculosquelettiques de la main, du bras, de l'épaule et / ou de la nuque, en particulier dans le cas des personnes déjà atteintes d’affections douloureuses du membre supérieur ayant d’autres origines. Dans de pareilles situations, l’utilisation de périphériques d’entrée ergonomiques doit permettre de réduire les contraintes et d’éviter la survenue d'autres troubles. Il existe des normes relatives à ces appareils, certaines des spécifications que celles-ci contiennent étant cependant formulées de façon générale et sans indication quantitative. Il est par conséquent difficile d’établir des recommandations concrètes à partir de celles-ci. C’est pourquoi la Verwaltungs-Berufsgenossenschaft (VBG, Caisse mutuelle d’assurance accident de l’administration) est à l’origine d'une vaste étude des publications internationales traitant de ce thème, dont l’objectif était de rassembler les connaissances actuelles en matière d’ergonomie des périphériques d’entrée et de vérification de celle-ci à l’aide de critères biomécaniques et physiologiques. Les recherches effectuées ont donné des résultats dans les domaines suivants : clavier, souris, boule roulante, pointeur et tablette graphique ainsi qu’appui de la main / du bras. En outre, une check-list basée sur des critères biomécaniques et physiologiques a été établie pour le clavier et la souris. En cas de survenue de troubles, elle constitue une aide pour l’évaluation de l’ergonomie du poste de travail et son amélioration par le choix de périphériques d’entrée appropriés.

## Especificaciones ergonómicas referentes a teclados, ratones y otros accesorios para equipos de computación

## Resumen

El trabajo intensivo en la computadora y la utilización de los diversos accesorios relacionados con dicha actividad pueden originar trastornos del sistema musculo-esquelético de la mano, del brazo, del hombro y/o de la nuca, especialmente cuando ya existan trastornos dolorosos de las extremidades superiores, debidos a otras causas. En estos casos, accesorios ergonómicos pueden ayudar a reducir el esfuerzo y a prevenir ulteriores molestias. Si bien existen normas referentes a las especificaciones para semejantes accesorios, estas, en parte, solamente presentan información muy generalizada y no cuentan con indicaciones cuantificadas. Es por eso, que se hace difícil derivar de ellas recomendaciones concretas. La Berufs-genossenschaft Administración (VBG por sus siglas en alemán) patrocinó un estudio de la información disponible, a fin de recopilar el estado actual de los conocimientos referentes al diseño ergonómico de accesorios para equipos de computación y a su verificación por medio de criterios biomecánicos y fisiológicos. La amplia pesquisa de la literatura internacional arrojó resultados referentes a los siguientes accesorios: teclado, ratón, trackball, tableta gráfica y reposa muñeca. Además, se elaboró un lista de comprobación para teclado y ratón, basado en criterios biomecánicos y fisiológicos. A la hora de presentarse molestias, dicha lista brinda ayuda para la valoración ergonómica, así como para mejorar el puesto de trabajo en lo referente a la selección de accesorios apropiados.

## Contents

# 1 Introduction

Many activities are performed at computers in the modern workplace. A Danish study indicated that 62% of all workers use computers [1]. In a study of workplaces at a German inland revenue office in North-Rhine Westphalia, computers were used for 30% of working hours [2]. *Woods* et al. [3] even speak of a rate of computer use on average of six hours per day, of which input devices are used during around two-thirds of the time [3; 4].

The input devices used include keyboards, mice, trackballs, and so forth. Various standards apply to the design of these input devices, as discussed in Sections 2.2 and 3.1 (see pages 14 and 25).

The muscular force that needs to be exerted to operate computer input devices is not great, yet the monotonous, repetitive motions and static postures in non-neutral positions held for long periods of time represent factors that have negative health implications [2; 5 to 7].

The German Verwaltungs-Berufsgenossenschaft – VBG (Institution for Statutory Accident Insurance and Prevention in the administrative sector) initiated a study of the literature on the subject of the "Ergonomic requirements for computer input devices". The aim of this study was to determine the most recent state of scientific research with regard to the ergonomic design of various computer input devices in order to compile a list of criteria for them based on physiology and biomechanics. This list of criteria will be discussed with regard to the relevant standards.

# 2 Method

## 2.1 Literature study

A study was performed of international literature encompassing scientific research published in English and German over the last twenty years. The papers were retrieved via the Internet and databases, in particular those of the German Federal Institute for Occupational Safety and Health (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin – BauA), the German Institutions for Statutory Accident Insurance and Prevention (Berufsgenossenschaften, BGs), CiteSeer, Compendex, Forschungsportal.net, Google Scholar, INSPEC and PubMed. The search terms used in German and English included various input devices and their combination with computers, office workplaces, (data) input devices, ergonomics, peripheral equipment, keyboard slope, (alternative) computer design, stress and strain, performance and comparison studies. Search results in the three-digit range were reviewed; search terms were refined for results yielding more than 1,000 hits. The search term "keyboard", for example, produced 3,520 hits at Google Scholar, but this figure was reduced to 244 in combination with the term "computer".

In keeping with its objectives, the literature study was limited to the input devices of keyboards, mice, trackballs, touch-screen displays, joysticks and pen-and-tablet devices. Yet studies were only found that were sufficient and suitable for a well-founded evaluation for the search terms keyboard, mouse, trackball and pen-tablet. Whereas there were numerous published studies on touch-screen displays and joysticks, the majority pertained to activities that are not performed at office workplaces.

In reviewing the literature on keyboards and mice, it was stated that hand or wrist supports play an important role in the ergonomic design of the overall workplace and that the ergonomic assessment of an input device would be heavily influenced by such objects accordingly. This subject was thus also included in the study of the literature.

One criterion for weighting a paper was, hence, the relevance of the studied object at the primary level. Studies whose contents provided no information on the subject of “ergonomic requirements for computer input devices” were not mentioned in this report.

At a secondary level, the remaining studies were assessed according to six additional criteria:

- number of human subjects *n*
- data recording
- study design
- activity/task
- control group and/or comparison group
- statistical analysis

Based on these criteria, the studies were given scores from 1 (not very good) to 3 (very good). A score of 3 was given in this process if all six criteria were met satisfactorily, 2 if at least three were met satisfactorily and 1 if fewer than three were met satisfactorily. The conditions by which the individual criteria were considered as fulfilled were formulated as follows:

**Number of human subjects *n***

The number of test subjects *n* required to satisfy this requirement were defined as dependent of the methodology used for the study. Studies that relied on technical measuring methods required a minimum of 15 test subjects. Studies that relied only on survey questionnaires required a minimum number of subjects of $n = 50$.

**Data recording**

The assessment of a study in terms of its data recording and measurement depended on the study's objectivity. A study based on a technical measurement, such as electromyographic (EMG) measurement, was thus given a higher score than a study that only recorded subjective perceptions by way of questionnaires. Moreover, direct measurements, as in measuring body postures or joint positions by way of an electrogoniometer, were given a higher score than indirect measurements of angles using video images.

### Study design

It is important for technical measuring methods that the test subjects are able to forget as much as possible that measurements are being performed so that the subjects assume postures that are natural, which is to say, postures the subjects would assume under everyday working conditions. For a given study to receive the score of "good" (2), the duration of the study had to be at least 15 minutes.

Intervention studies in which survey questionnaires were used to analyse the subjective opinions of test subjects were required to have a sufficient interval between the surveys before and after the intervention. This time interval depended on the topic of the study and on the applied evaluation criteria, and this interval was thus assessed individually for each study.

### Activity/task

This criterion was met if the study was performed with a suitable task description. In order to make relevant statements on the input devices pertinent to the research question of this study, it was deemed essential to test the activity or movement in a typical workplace setting.

### Control/comparison group

It is possible to distinguish between intervention studies and comparison studies. For intervention studies, such as those aiming to study the effects of an ergonomic keyboard, control groups are essential. The presence of control groups is the requirement for meeting this particular criterion.

Studies that compare two different input devices, for instance, do not require control groups in this strict sense. The presence of comparison groups suffice to meet this criterion.

### Statistical analysis

Meeting this criterion required that a statistical analysis be performed and presented in a comprehensible fashion.

Yet an evaluation of a study as less than good did not prevent the study's information from being used, especially if the information was about subject areas for which only a small number of studies were found. The evaluation procedure is merely meant to aid in weighting the information in an intelligible fashion.

## 2.2 Review of standards and checklists

To obtain an overview of the requirements currently applicable for input devices, the various standards and checklists for the German, European and trans-Atlantic regions were reviewed at first.

Certain subjects, such as the rules for the slope of keyboards, the response of the keys and the position of the mouse, were compared with one another to resolve possible discrepancies and subsequently to compare or augment them with the contents of the studies found. The standards and checklists reviewed are presented in Table 1.

Table 1:
Overview of the reviewed standards and checklists

| **Standard/checklist** | **Content: input devices** |
|---|---|
| DIN EN ISO 9241-400 [8] | Input devices generally |
| DIN EN ISO 9241-4 [9] | Keyboards |
| DIN EN ISO 9241-5 [10] | Hand/arm supports |
| DIN EN ISO 9241-9 [11] | Various input devices other than keyboards |
| ISO/FDIS 9241-410 [12] | Various input devices |
| Working at computer screens from the German occupational medicine manual "Handbuch der Arbeitsmedizin" [13] | Keyboard, mouse |
| BG information publication on computer screen and office workplaces "Bildschirm- und Büroarbeitsplätze" (BGI 650). VBG [14] | Keyboard, mouse |
| Guidelines to the selection and purchase of work-station furniture and equipment. Human Resource Management Division (HRM), New Zeeland [15] | Keyboard, mouse |

Table 1: continued

| Standard/checklist | Content: input devices |
|---|---|
| Health and safety regulations. Workstation risk assessment questionnaire. Health and Safety Executive (HSE), England [16] | Keyboards |
| Ergonomics for the Prevention of Musculoskeletal Disorders. Swedish National Board of Occupational Safety and Health, Sweden [17] | Keyboards |
| Guidelines on office ergonomics, CSA-Z412. Canadian Standards Association (CSA) International, Canada [18] | Various input devices |

## 2.3 Definitions and explanations

### 2.3.1 Definitions and glossary

The meaning of several terms and designations used in this report are explained in greater detail and defined clearly below.

**Keyboard slope**

The keyboard is tilted along its longitudinal axis away from the screen or monitor – positive slope (Figure 1) – or towards the screen or monitor – negative slope (Figure 2).

Figure 1:
Positive keyboard slope

Figure 2:
Negative keyboard slope

### Lateral keyboard angle

The half sections of the keyboard are elevated in a tent-like shape (Figure 3).

Figure 3:
Raised, split keyboard

### Outward turn of the keyboard halves

The halve sections of the keyboard are turned outward along the keyboard's vertical axis (Figure 4).

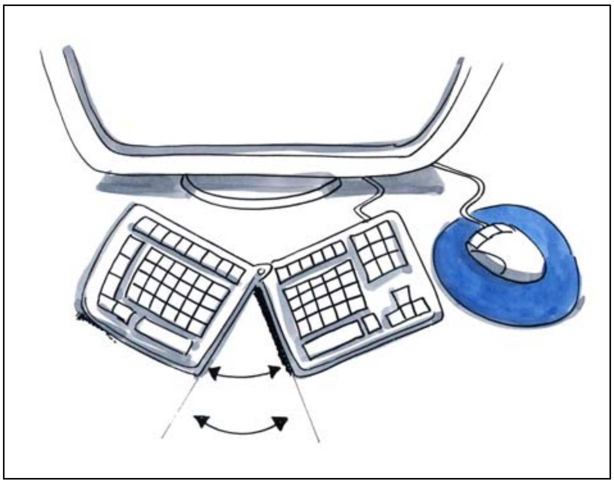
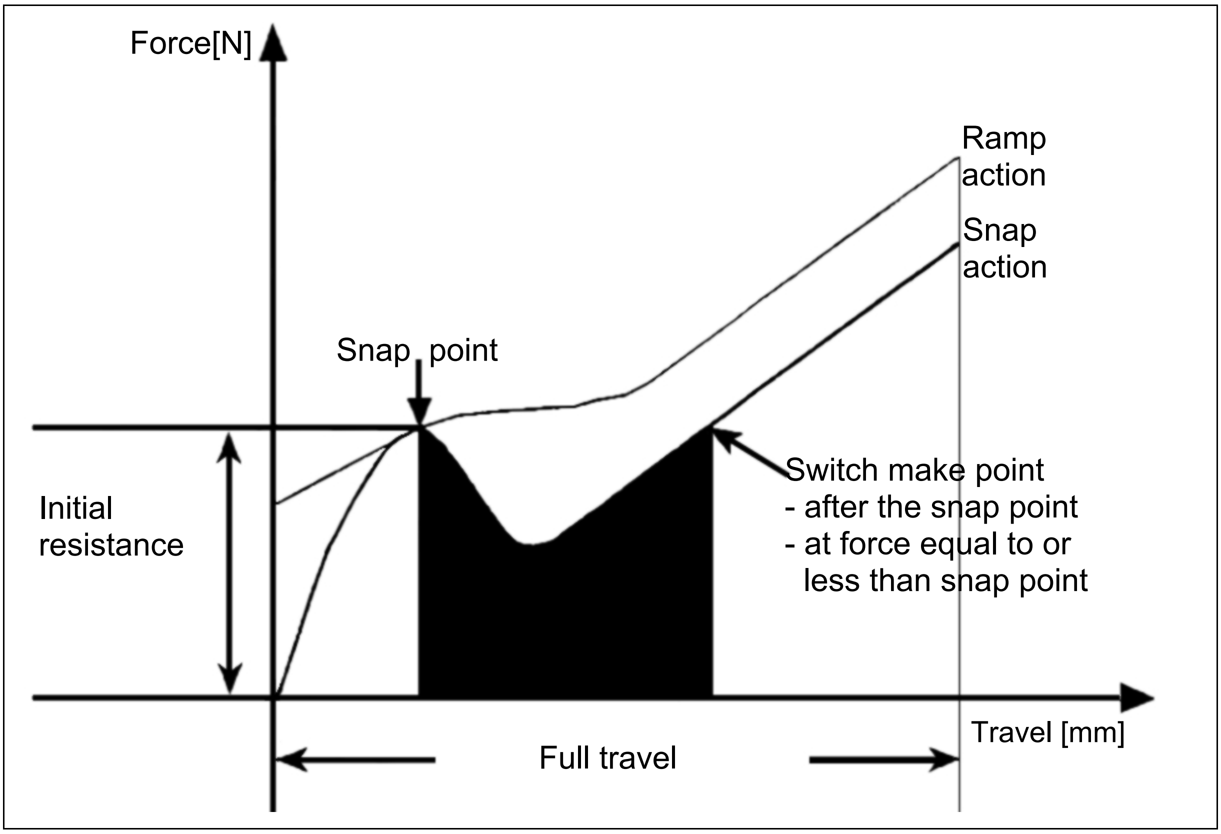


Figure 4:
Outward angle of the keyboard halves

### Key displacement

Key displacement (also referred to as key lift) is the distance that a key potentially moves when struck. Figure 5 (see page 17) shows two possible curves of the finger force needed depending on the key displacement of the keyboard. Characteristic points over the course of key movement are marked and explained below.

Figure 5:
Force/displacement characteristics, according to DIN EN ISO 9241-4 [9]




**Ramp action (keyboard)**

"*Kinaesthetic sensation when pressing the keys in which the force needed to press the keys rises once the key is moved*" [9] (Figure 5).

**Snap action (keyboard)**

"*Sudden drop in the force needed to move the key further*" [9]
(Figure 5).

**Trackball**

A trackball is a cursor-moving device in which a movable ball sits in a fixed housing; the ball is meant to be moved by the fingers in any direction to move the on-screen cursor (Figure 6, see page 18).

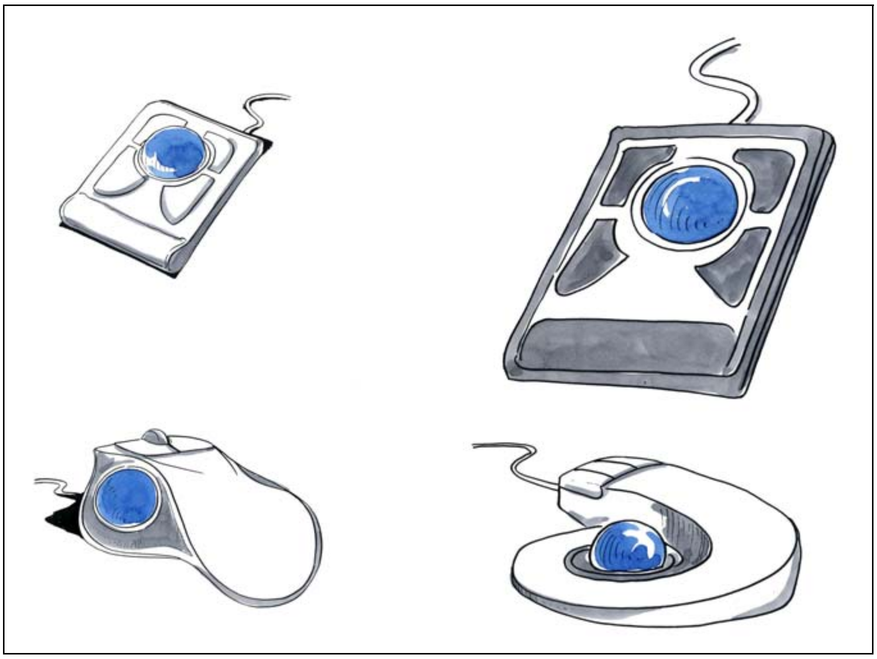


Figure 6:
Trackballs

### 2.3.2 Anatomy and physiology

Several anatomical and physiological terms used in this report are defined and described below. First is a description of the movements of the arm and hand in accordance with the neutral zero method. The neutral zero method takes measurements of all joint motions from a uniformly defined zero point. This neutral zero position corresponds to the joint posture that a healthy person would assume in an upright stance with arms hanging at the sides, with thumbs directed forward, with feet parallel to each other and with head and eyes pointed forward. Generally, movements in two directions are possible in a plane from the neutral zero point.

The illustrations below depict the neutral position at 0º and the physiological range of motion as expressed in degrees; the illustrations also describe the direction of motion. Shown in each are the neutral position at 0º and the range of motion.

#### Finger abduction and adduction

These terms describe spreading the fingers of one hand apart and drawing them together, respectively.

### Range of motion of the hand

Figure 7 displays the sideward motions of the hand towards the thumb or the little finger. Figure 8, in contrast, displays the wrist stretched towards the back of the hand and the wrist bent forwards towards the palm.

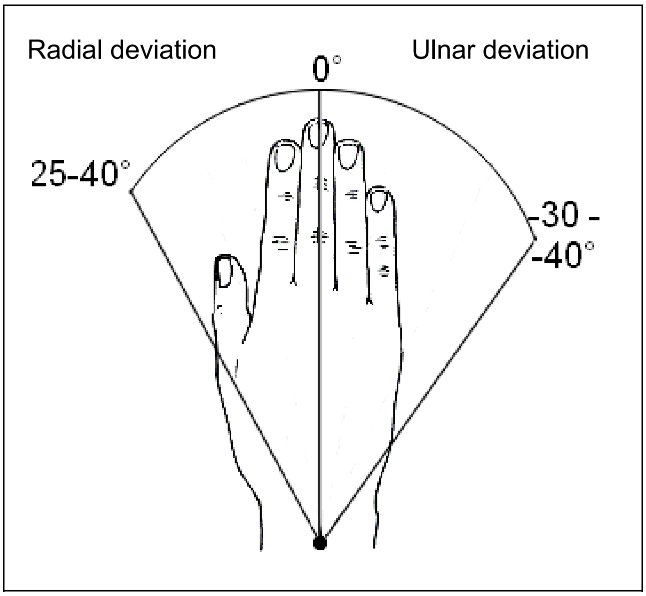



Figure 7:
Radial deviation: in the direction of the thumb (towards the radius);
ulnar deviation: in the direction of the little finger (towards the ulna)

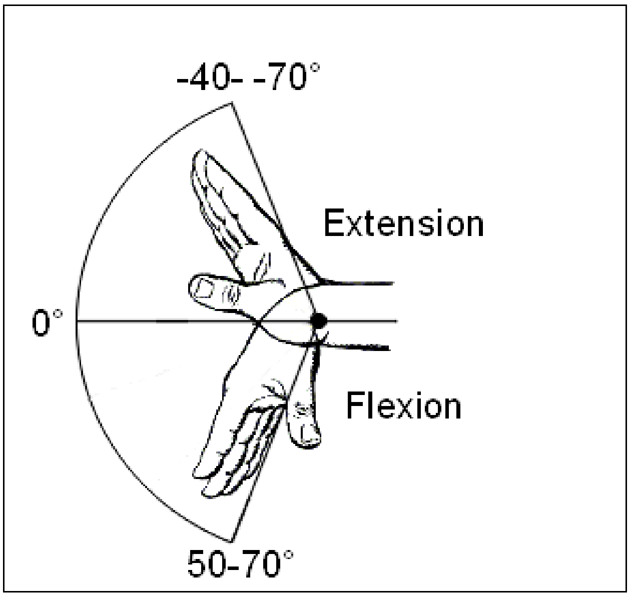
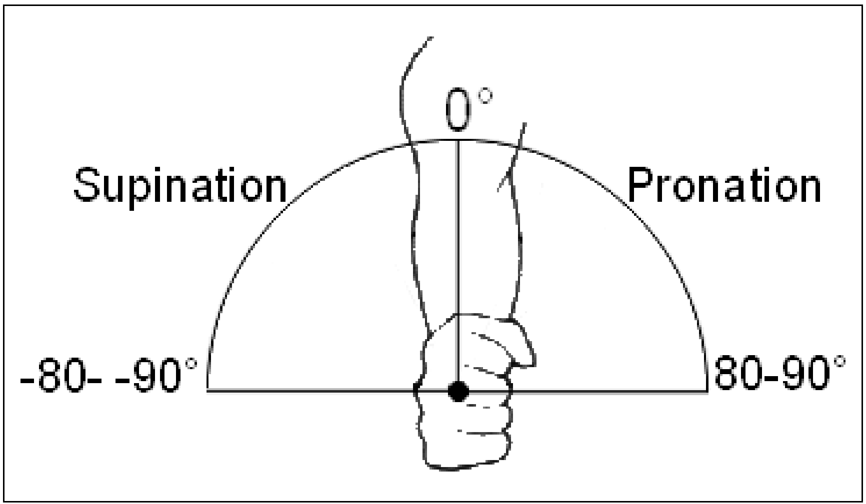



Figure 8:
Hand extension: in the direction of the back of the hand;
hand flexion: in the direction of the palm

### Range of motion of the forearm

Movements of the forearm so that the palm of the hand is facing upwards or downwards are illustrated in Figure 9 (see page 20).

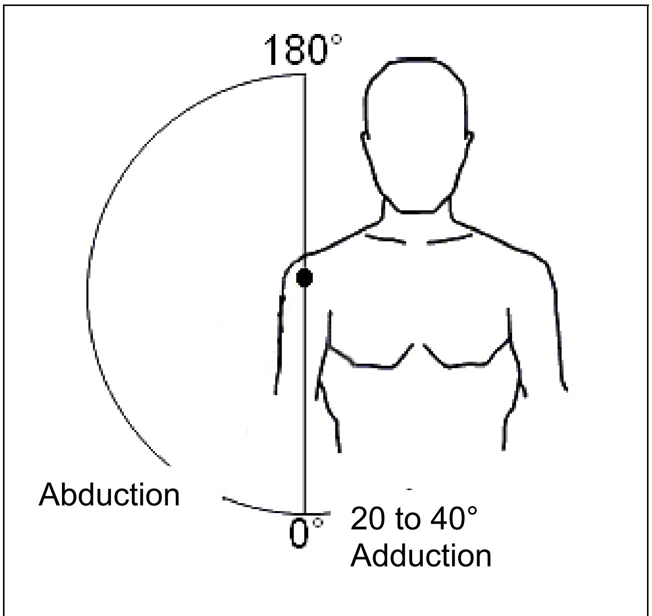
Figure 9:
Supination: turning the palm upwards;
pronation: turning the palm downwards




**Range of motion of the upper arm**

The shoulder can perform movements in all three planes. Figure 10 shows a sideward motion of the arm; Figure 11 shows the arm extended to the rear and to the front; and Figure 12 shows the upper arm rotating on its own axis.

Figure 10:
Abduction: arm extended sidewards away from the torso;
adduction: arm pulled in sidewards towards the torso



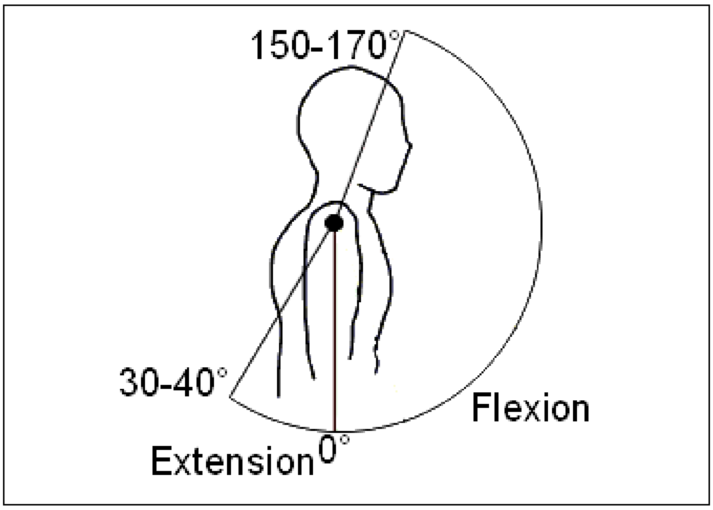



Figure 11:
Arm extension: arm extended towards the rear;
arm flexion: arm pulled 90° to the front (> 90° = elevation)

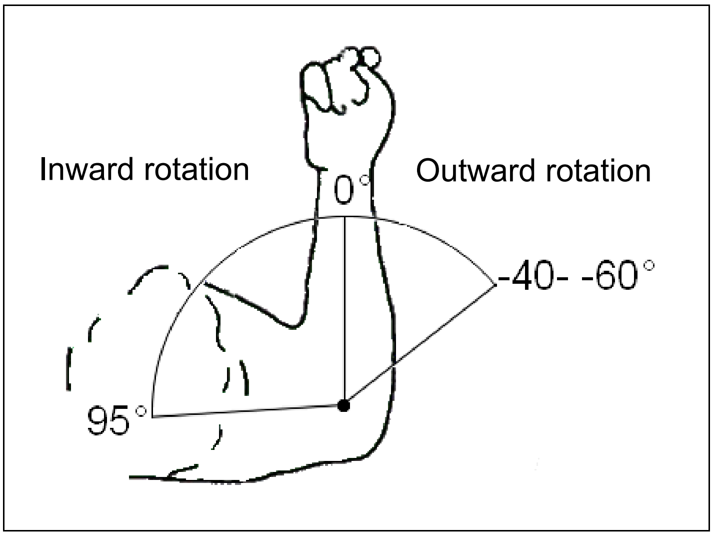



Figure 12:
Inward rotation: upper arm turned inwards, forearm follows;
outward rotation: upper arm turned outward, forearm follows

### 2.3.3 Biomechanical strain and load factors and methods of recording them

This section explains the biomechanical strains and loads relevant to the subject of "computer input devices" and summarizes the measurement methods.

**Poor body posture**

The neutral posture is marked in part by having low level of muscular strain. As posture deviates increasingly from the neutral position, greater muscular strain is to be assumed. The extent of deviation from neutral posture is determined by measuring the angle with a goniometer either manually or electronically.

Another option is to use optoelectrical measurement, in which reflective markers are affixed to two adjacent parts of the body that allow their positions, and hence the angle of the joints, to be established using infra-red cameras.

Several studies also relied on recording and analysing body posture by way of observation. This was done directly or with the aid of video recordings. Yet, these two measuring methods are much less objective and precise than the goniometer readings or optoelectrical measurements.

**Static body postures**

The European standard DIN EN1005-1 [19] defines static postures as body postures that are assumed for longer than four seconds under an unchanging or a slightly changing level of force. The potential for damage from static body postures is primarily recognized as a source of muscle fatigue. This fatigue results in changes to metabolism, to the sensation of pain and to movement patterns that may also lead to the passive structures of the musculoskeletal system becoming over-exerted.

Static postures are determined with the aid of measurement methods described above under “Poor body postures”.

**Repetitive movements**

Repetitive movements describe movements or arrays of movements (cycles) that are repeated uniformly over a particular period of time. If these cycles are very short or if the frequency of the movement's repetitions are high, this may cause the active and passive structures of the musculoskeletal system to become strained.

According to *Kilbom*, high repetitiveness is assumed to exist when the reference rates given in Table 2 for movements or contractions are exceeded in specific joint regions.

Table 2:
Reference rates for repetitive joint movements in the shoulder-arm-hand system, according to *Kilbom* [20]

| **Joint** | **Reference rate for repetitiveness** |
|---|---|
| Shoulder | > 2.5/minute |
| Upper arm, elbow | > 10/minute |
| Forearm, wrist | > 10/minute |
| Finger | Approximately > 200/min |

**Force exerted**

Strain may result not only from exerting a large amount of force, but also from intermittent static postures and repetitive movements over a longer timeframe. It is possible to measure muscle activity and muscle tension using electromyography (EMG). In surface EMG, sensors are applied to the skin in a regular manner as described in the literature. These electrodes send signals that are technically amplified, filtered and rectified. As quantitative measurements, the amplitude and frequency spectrum of the EMG, the significant values derived from them and the temporal change are used to analyse and physiologically interpret the curves. In order to compare these measurement values within a series of measurements and amongst multiple test subjects, the measurement sequences are preceded by mostly maximum voluntary contractions (MVCs) or, less often, reference voluntary contractions (RVCs) and also recorded. The measurements from the measuring series are then expressed as ratios of the maximum voluntary contractions (as an MVC percentage = % MVC) or of the reference voluntary contractions (RVC percentage = % RVC) and thereby standardized in practice [21; 22].

# 3 Results

## 3.1 Standards and checklists

Several specifications on input devices from various sources are listed below (standards and checklists, see Section 2.2, page 14). The focus here is on subjects that are treated as ergonomic criteria by the studies that were reviewed.

### 3.1.1 Keyboards – Evaluating the standards and checklists

The standards and checklists in Table 1 (page 14) list specifications for keyboard slope, height and size, key displacement and key resistance force.

**Keyboard slope**

The English Health and Safety Executive (HSE) recommends that the slope of the keyboard be adjustable in principle [16], thereby following the EU display screen directive [23]. Furthermore, specific target figures are given for keyboard slope in the standards and various checklists (Table 3).

Table 3:
Recommendations for keyboard slope in standards and checklists

| | **DIN EN ISO 9241-4 [9]** | **ISO/FDIS 9241-410 [12]** | **BGI 650 [14]** | **HRM [15]** | **Occupational Safety & Health, Sweden [17]** | **Arbeit mit dem Bildschirm [13]** |
|---|---|---|---|---|---|---|
| ≤ 15° | | | X | X | | |
| 0 to 15° | | | | | X | |
| 0 to 10°, possibly variable | | | | | | X |
| Suggested: 5 to 12°, required: 0 to 15° | X | X | | | | |

### Keyboard height

The standards and checklists provided dimensions for keyboard height as listed in Table 4. In addition to these recommendations for keyboards to be as flat as possible and no higher than 30 mm, DIN EN ISO 9241-4 and ISO/FDIS 9241-410 deviate from the rest of the standards and checklists in permitting a maximum keyboard height of up to 35 mm [9; 12].

Table 4:
Recommendations for keyboard height in standards and checklists

| | DIN EN ISO 9241-4 [9] | ISO/FDIS 9241-410 [12] | BGI 650 [14] | HRM [15] | Occupational Safety & Health, Sweden [17] | Arbeit mit dem Bildschirm [13] |
|---|---|---|---|---|---|---|
| ≤ 30 mm | | | X | X | X | X |
| < 30 mm, maximum 35 mm | X | X | | | | |

### Keyboard size

The only vague descriptions with the nature of an appeal for a preferred keyboard size found were in ISO/FDIS 9241-410 [12]. In this description, the keyboard should be as short as possible on the side where a mouse is meant to be used. For a work surface of short depth – with little space between the keyboard and the display screen – the keyboard should also be of as little physical depth as possible.

### Key displacement

The applicable standards and checklists specify key displacements for keyboard keys of between 1.5 and 6 mm, optimally between 2 and 4 mm, as tolerable values [9; 12; 14].

### Key resistance

Table 5 contrasts the forces considered as acceptable in the literature for overcoming keyboard key resistance. The standards DIN EN ISO 9241-4 and ISO/FDIS 9241-410 define an ideal force range of between 0.5 and 0.8 N within a tolerance range of between 0.25 and 1.5 N.

Table 5:
Key resistance

| | DIN EN ISO 9241-4 [9] | ISO/FDIS 9241-410 [12] | BGI 650 [14] | Arbeit mit dem Bildschirm [13] |
|---|---|---|---|---|
| 0.25 to 1.5 N | | | | X |
| Ideally: 0.5 to 0.8 N | X | X | X | |
| Required: 0.25 to 1.5 N | X | X | | |

The force needed to overcome the initial resistance is generally required to be between 25 and 75% of the force needed to activate the key [9; 12].

### 3.1.2 Mouse – Evaluating the standards and checklists

The information on computer mice specifically mentions the shape, position, function, buttons and exerted force.

#### Shape

Size, design and button location should allow for a relaxed, comfortable hand posture [15] or prevent a cramped hand posture [17]. The fingers should be able to depress the keys without any major deviations from neutral posture [11].

#### Position

The mouse should be at the same height as the keyboard [15] and should allow operation without any abduction of the arm and with neutral wrist posture [18].

#### Function

The mouse needs to be designed for right- or left-handed use [12; 14; 17].

**Buttons**

The force required to operate the mouse buttons should be between 0.5 and 1.5 N [12]; the travel distance between 0.5 and 6 mm [11; 12; 18].

**Force exerted**

It is assumed that the force required to operate the mouse is not more than 1% of the maximum finger force [12]. Reference values for this maximum force were not given.

### 3.1.3 Trackball – Evaluating the standards and checklists

Information on the rolling ball, buttons, maintenance and the advantages and disadvantages in comparison to mice was provided in the key standards on trackballs.

**Ball**

The angle of the opening for the uncovered part of the ball should be between 100 and 140º, and ideally 120º [11; 12] (Figure 13). The minimum diameter of the visible part of the ball was given as 25 mm [11; 12; 18] (Figure 13).

A range of between 0.2 and 1.5 N was considered acceptable for rolling resistance; initial resistance should be between 0.2 and 0.4 N [11; 12; 18].

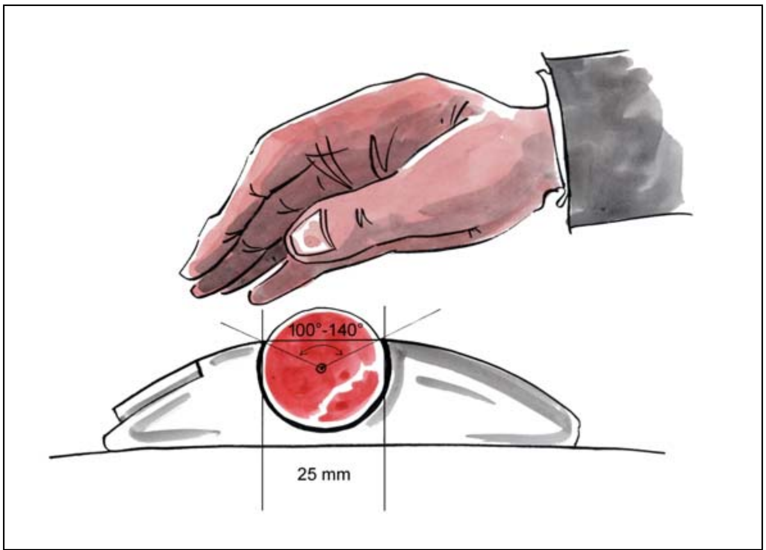



Figure 13:
Diameter and angle of the opening for the uncovered part of the ball in a trackball, excerpted from DIN EN ISO 9241-9 [11]

#### Buttons

The buttons should be arranged in a fashion that will not disturb the hand. Otherwise, the same standards apply that also apply to the buttons of a mouse [12].

#### Advantages and disadvantages of a trackball over a mouse

- The mouse is assessed as better in terms of effectiveness and efficiency. For graphics applications and in surroundings offering little space, the trackball is preferred [12].
- Loss of control occurs more often than with the mouse [12].
- In considering environmental factors such as vibration, instability of the work surface, dirt and dust, the mouse and trackball are comparable to one another [12].

#### Other aspects

It is important to keep the trackball clean for the ball to retain good rolling properties [12].

### 3.1.4 Pen-tablets – Evaluating the standards and checklists

The design, buttons and forces required to use a pen-tablet are described below.

#### Design

A cylindrically shaped stylus, referred to as a pen, should be between 120 and 180 mm in length and between 7 and 20 mm in diameter [11; 12; 18], with a preferred weight of between 10 and 25 g [11; 12; 18].

#### Buttons

The contact surfaces of the buttons should be perpendicular to the direction of pressure and to the movement of the fingers in flexion [12; 18]. Furthermore, buttons should be circular in shape and have a minimum diameter of 5 [12; 18] or 6 mm [11].

**Force exerted**

Table 6 summarizes the requirements for the force needed to operate a pen-tablet as provided in standards and checklists.

Table 6:
Force required to operate a pen-tablet device

| | DIN EN ISO 9241-9 [11] | ISO/FDIS 9241-410 [12] | CSA-Z412 [18] |
|---|---|---|---|
| For continuous input, the force that needs to be exerted on the tablet should not exceed 0.5 N. | | | X |
| For continuous input, the force that needs to be exerted on the tablet should not exceed 1.5 N. | X | X | |
| The force required to operate the selection elements should be between 0.3 and 1.5 N. | X | X | |

### 3.1.5 Hand/arm supports – Evaluating the standards and checklists

Table 7 lists the recommendations for how much space should be available in front of the keyboard for a hand or arm support.

Table 7:
Space in front of the keyboard

| | DIN EN ISO 9241-4 [9] | DIN EN ISO 9241-5 [10] | ISO/FDIS 9241-410 [12] | BGI 650 [14] | HSE [16] | Arbeit mit dem Bildschirm [13] |
|---|---|---|---|---|---|---|
| Enough space for hands and arms | | | | | X | |
| > 50 mm in front of the field of keys | | | | | | X |
| For a hand support: at least 100 mm in front of the keyboard | X | X | X | | | |
| 100 to 150 mm in front of the keyboard | | | | X | | |

### 3.1.6 Summary of the evaluations of standards and checklists

The information given in standards and checklists does not show any basic contradictions. Yet at times, the limits are given in ways that are different in terms of breadth, as was the case for keyboard slope, space in front of the keyboard for hand or arm supports or the force needed to operate a pen with a tablet. Yet the recommendations are often left vague. It is thus difficult to derive specific parameters for checklists.

## 3.2 Literature on keyboards

### 3.2.1 Assessing studies on keyboards

Table 8 shows the number of articles reviewed and their different evaluations. The criteria for the scores are given in Section 2.1 (page 11 ff.). Brief descriptions of the contents of each study are given in Annexe A (page 104 ff.).

Table 8:
Overview of the literature on keyboards

| Score | 1 | 2 | 3 | Sum |
|---|---|---|---|---|
| Number | 2 | 16 | 6 | 27 |

### 3.2.2 Keyboard – Evaluating the literature

Keyboards require the user to assume a certain posture in the shoulder-arm system. The literature provides data that especially describe hand and forearm postures along three axes: in the transversal plane of ulnar or radial deviation, in the sagittal plane of extension or flexion and in the frontal plane of pronation or supination (see Figures 7 to 12 in Section 2.3.2, page 18 ff.). The following hand postures were observed in conjunction with the use of a conventional keyboard [24 to 26]:

- hand extension: 8 to 20°
- hand ulnar deviation: 10 to 20°
- forearm pronation: approxemately 80° (almost complete)

The reported health problems appear to originate from the deviation of the hand posture from the neutral posture, among other factors [27]. The following measures can serve to achieve a nearly neutral hand posture when using a keyboard:

- reducing extension: by way of negative keyboard slope or elevation of the wrist above the level of the elbow
- reducing ulnar deviation: by separating the keyboard in half and rotating the halves outward from each other
- reducing pronation: by laterally sloping the halves of the keyboard.

The advantages and disadvantages of these measures are discussed below.

**Negative slope**

Negative keyboard slope was studied in several papers and determined to be a positive feature [5; 24; 25; 28 to 32]. The degree to which hand posture depends on keyboard slope is evident in Figure 14: The extension of the wrist increases with the degree of positive slope, whereas hand position changes toward flexion the flatter or more negatively the keyboard is angled (Figure 14). By changing the slope from 7.5 to -15º, a reduction in wrist extension from 12 to 3º was observed, which corresponds approximately to a ratio of 2 : 1 [30]. When test subjects were allowed to set the keyboard angle of slope for themselves, *Hedge* and *Powers* [32] reported that an angle of -12 ± 0.4º was chosen; *Marklin* and *Simoneau* [24] reported subjects as finding a slope of -7.5º to be the most comfortable. The wrist was in nearly neutral posture in these positions in terms of extension/flexion. *Gilad* and *Harel* [5] showed in their study that the EMG readings of forearm muscles (for flexors as well as for extensors) were lower for a negative keyboard slope of around -10º. In *Woods* and *Babski-Reeves* [28], however, no differences on this criterion were found for slopes of between 0 and -7º. An epidemiological study by *Cail* and *Aptel* [33] of computer users with complaints due to wrist extension during work found that the angles were much greater than those for users with no complaints (means of 37 to 26º).

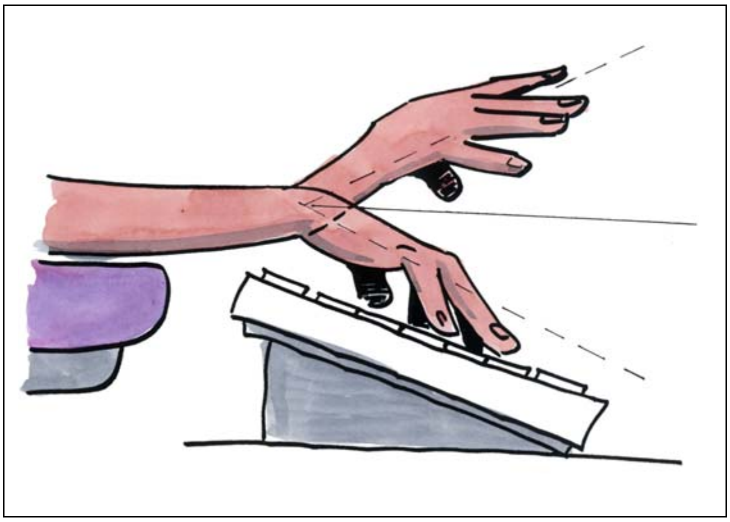


Figure 14:
Effects of keyboard slope on hand posture

Changing the keyboard slope towards the display screen, however, was found to result not only in a reduction of extension, but also an increase in ulnar deviation [24; 25; 28]. This can be compensated for by turning the halves of the keyboard outwards (see below).

**Elevating the wrist**

Raising the wrist above the level of the elbow also helps to achieve a reduction in wrist extension. Yet, as such a posture was observed to give rise to shoulder and neck problems, this measure is not advised [30; 34]. Recommended instead is a working posture in which the wrists are at the level of the elbows.

**Turning the halves of the keyboard outwards**

Turning the halves of the keyboard outwards by a total of around 25º (12.5º per half) resulted in a reading for ulnar deviation of nearly 0º, thereby achieving a neutral posture for this dimension [24; 27]. When test subjects chose the rotation angle of the keyboard halves themselves, 48% chose angles of between 11 and 20º, 35% chose 21 to 28º and only 17% chose angles of 0 to 10º [29]. Forearm muscles responsible for ulnar deviation (*M. flexor carpi ulnaris*) displayed decreased activity of around 10% on ergonomic keyboards with halves turned outwards by 12º (12º right and 12º left) [26].

### Detached split keyboards

Insufficient information was found on the subject of split keyboards and the question of how far apart these should lie. Theoretically, ulnar deviation could be eliminated by positioning the halves a shoulder's breadth apart [24]. In *Swanson* et al. [35], test subjects using keyboard halves this far apart reported difficulties.

### Lateral slope of the keyboard halves

Studies with alternate findings were found that attempted to reduce forearm pronation by placing the halves of the keyboard at an angle to one another. *Zecevic* et al. [27] reported a reduction of only 5º for a lateral angle of 10º. For an angle of 42º, pronation was reduced on average from 57 to 34º, but the steep tent-like shape of the keyboard caused problems for test subjects in usage. Test subjects in another study were allowed to set the lateral angle themselves [24]. The subjects selected a mean angle of 28º on the left and 33º on the right, thereby cutting pronation roughly in half. Yet uniform acceptance was also not achieved here. In the study by *McLoone* and *Jacobsen* [36], in contrast, the test subjects agreed when offered angles of 8, 10 and 12º that they preferred the latter.

The EMG measurements of *Strasser* et al. [26] found that a lateral slope of the keyboard halves reduced the activities of *M. pronator teres* by around one fourth. *Zipp* et al. [37] also identified significant EMG reductions for a lateral slope of as little as 10º.

### Alternative keyboard designs in general

The design recommendations described above have been realised individually or in various combinations (see Figure 15) and variants to produce the alternative keyboard designs in question; these are often referred to as "ergonomic keyboards". Such keyboards were well received in the studies, especially those that did not alter traditional design too extremely [26; 27; 29; 38; 39]. Hardly any user felt the ergonomic keyboards to be worse than the conventional models, and the feedback mostly consisted of more positive acceptance. Observations indicated that the use of ergonomically shaped keys often led to hand postures in the neutral range. Complaints from test subjects with existing difficulties decreased after six months of using the alternative keyboard [38].

Only in the study by *Swanson* et al. [35] a more negative statement made on ergonomic keyboards was found. Here, only minor differences were identified in comparing alternative and conventional keyboards, which raised the question as to whether using an ergonomic keyboard was worth the expense.

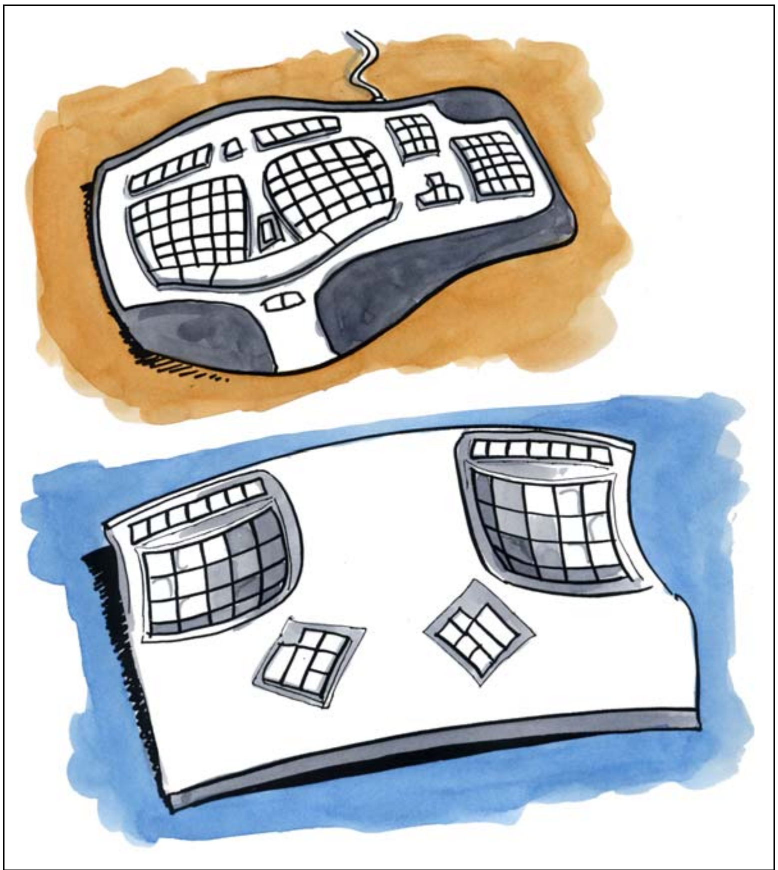


Figure 15:
Examples of keyboards that apply combinations of design recommendations (lateral angle, concave key blocks, outward angle of keys)

**Performance**

A question that is soon posed by the new keyboard shapes is whether they reduce performance (typing speed and accuracy). If performance suffers too much, users are mostly unlikely to accept the designs. A majority of the studies demonstrated that performance was not changed [24; 25; 30] or – at least after a period of adjustment of from eight to ten hours – up to 90% of original performance was achieved again [27; 35; 40]. *Woods* and *Babski-Reeves* [28] reported that test subjects using ergonomic keyboards even for part of the time displayed improved performance. Extreme designs, however, caused performance to suffer, and it may require longer periods of practice to get used to them [27; 40].

#### Problems with alternative keyboard designs

Greater tendon travel[1] is discussed as a source of biomechanical strain or load in the tendons, their sheaths or the neighbouring nerves. Tendon travel was found to be minimal at a positive keyboard slope of 25º and a lateral angle of the keyboard halves of 15º or at 0º sagittal and, with it, a greater lateral angle of 30º [41]. Nonetheless, pronounced individual differences were observed. *Treaster* and *Marras* [42] also pointed out these differences. Significantly more tendon travel was measured for negative keyboard slopes than for positive slopes.

It is unclear what the weighted effect of negative keyboard slope is in comparison to an improved neutral posture. Moreover, this raises the question of what it is that tendon travel actually indicates and how precisely it can be measured. Furthermore, the highly individual differences seriously limit the ability of making a definitive judgment.

Alternative keyboard designs are meant above all to achieve improvements in hand and forearm posture. Yet, attention must also be paid to ensuring that the rest of the body's posture does not suffer from negative effects. One example is the keyboards with a negative slope. It was proven that such a keyboard has positive effects on wrist extension. Yet, if negative slope is achieved simply by elevating the front of the keyboard, the user's wrists still have to be in an elevated position. In order for the elbows and the wrists to be at the same height, either the writing surface must be lowered or the chair must be raised. The first solution, however, places the mouse or other input devices too low, and the height of the surface also becomes uncomfortable for other activities, such as handwriting. If the chair is raised, seating ergonomics is lost unless other measures are taken, such as adding a supportive foot rest.

[1] Distance traveled by the tendons of muscles (e.g. *M. flexor digitorum profundus* and *superficialis*) relative to their sheathes.

The use of an additional computer table is also problematic. If such a table is a separate piece of furniture, the user has to change workplaces for different activities along with changes to the respective chair adjustments; the problems described above still remain when other input devices alongside the keyboard are used at the computer workplace.

The addition of a keyboard tray, for example as a drawer on the desk, often restricts leg movements, increases the distance to the display screen and can limit the option of using hand or arm supports (Figure 16).

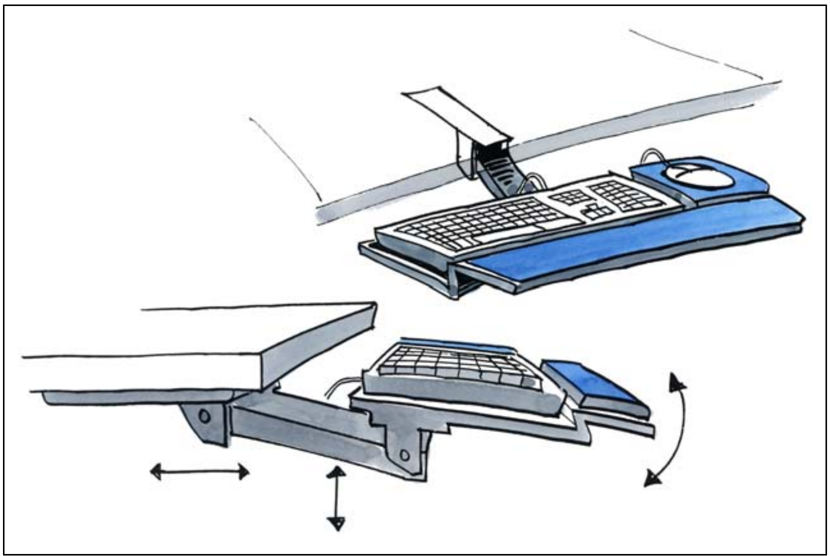


Figure 16:
Keyboard trays in the form of drawers and clamps on a desk

In addition, an ergonomically shaped keyboard requires a perfectly symmetrical position for the user in front of the input device. This can restrict seating variability [13].

Other problems may potentially arise from the combined use with other input devices. Keyboards designed in accordance with the described recommendations for optimization are often wider than conventional keyboards, which means that the mouse has to be used farther off to the side and, hence, with greater arm abduction. This subject is discussed in greater detail in the section on the mouse (Section 3.1.2, page 27). It should be noted at this point that it is apparently helpful to separate the numeric keypad from the rest of the keyboard, thereby reducing keyboard width.

*Krueger* [13] points out that learning to adopt the new posture – that an alternatively designed keyboard requires – may at first result in musculoskeletal complaints, which were actually meant to be avoided or reduced. In such circumstances it is worth considering which keyboard choice promises greater long-term success.

Individual needs should always be taken into account. An alternatively shaped keyboard makes particularly good sense in situations where a lot of data is entered via the keyboard and users type "blind," using all ten fingers. As users who do not type with all ten fingers often press keys on the left side of the keyboard with the right hand and vice-versa, ergonomic keyboards require the fingers to travel greater distances because the keyboards are mostly larger and elevated in the middle in cases of lateral slopes.

Moreover, such users do not orient their typing towards the home keys of the keyboard, and fewer poor hand postures thus occur from excessive muscle tensions. Nearly all studies observed test subjects who had mastered the ten-finger typing system; no conclusions can thus be drawn for other typing habits.

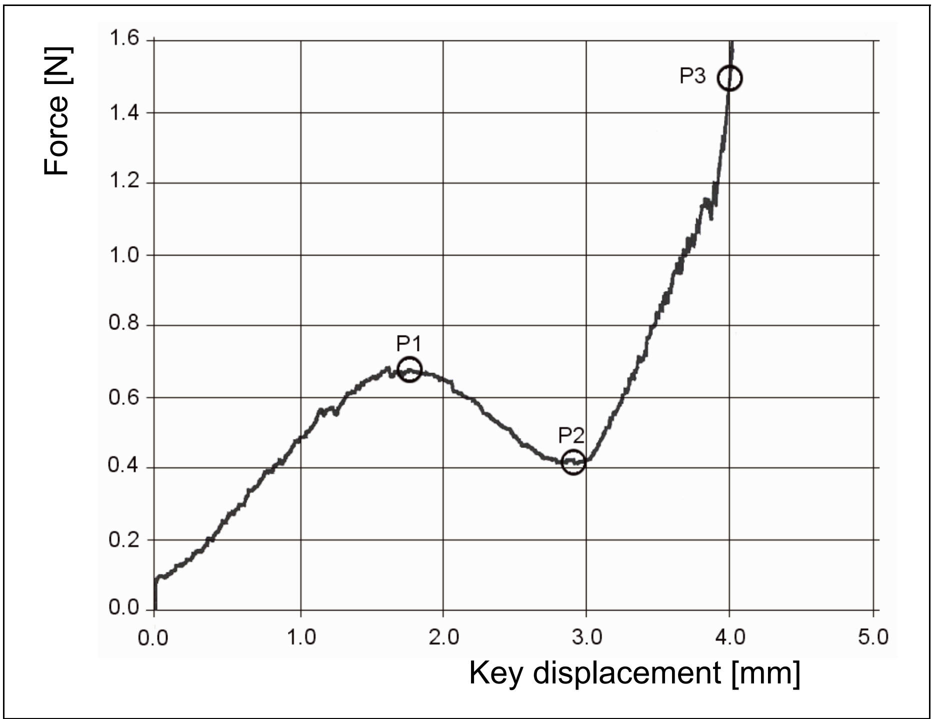
**Force exerted and typing speed**

Several studies investigated the force or effort exerted to type on a keyboard. More force exertion is directly related to greater muscle activity and results in greater strain after longer periods of work. *Cail* and *Aptel* [33] measured 13 to 24% MVC in hand/finger flexors and 18 to 27% MVC in the extensors when operating a keyboard, depending on the type of work. The study's authors determined that the force exerted was much greater than necessary [7; 43]. On modified keyboards with variable triggering forces required (0.28N, 0.56N, 0.72N, 0.83N) (see also Figure 5, Section 2.3.1, page 17), test subjects judged keyboards that required greater effort as uncomfortable.

Yet, it was also found that keyboards requiring little effort for activation took longer for users to get used to [43]. Furthermore, users could not leave their fingers on the keys when resting, as they might have inadvertently operated the keys. Finger extensors thus have to remain tense for the entire time, which, in turn, results in considerably greater strain [31].

A more precise examination of key behaviour includes the characteristics of the force-displacement curve. In this, three points are described within the force-displacement diagram (Figure 17): P1 is the minimum force required to press a key; P2 is the least force over the course of the keystroke after P1; P3 stands for the entire distance of key travel. Test subjects who already had complaints (hand paraesthesia[2]), at least, showed signs of observable improvement when the distance to P1 was long (1.69 mm) and the rise in the above-named curve from P2 to P3 was not too steep at the end of the key movement (stiffness). The demonstrable effects were, however, relatively low [44].

Figure 17:
Exemplary force-distance curve for a key [44]




Increased muscle activity was not only measured on keyboards with high required force exertion, but also during typing with an enforced typing speed, where even higher readings were taken [6]. Moreover, increased tendon travel was measured during rapid typing, corresponding to greater repetitiveness of more movements [41].

[2] An incorrect perception: This actually refers to the sensation in the skin of tingling or broad itchiness.

### 3.2.3 Literature on keyboards – Summary

Poor postures or deviations from neutral position, repetitive movements with corresponding effort exerted and static loads are risk factors for health problems related to using a keyboard [5; 34]. The literature reviewed pointed out that ergonomically designed keyboards offer improvements to users.

Keyboards with a negative slope of around -7º, the halves of the keyboard turned outwards by around 25º and with a lateral angle appear to reduce strain or load. These recommendations apply particularly to individuals who type with all ten fingers and write a lot at the keyboard, for instance in word processing and data entry work.

Keyboard users with existing complaints may possibly benefit from a change in the force-displacement behaviour of the keys, and such users' typing speeds should be reduced if need be.

### 3.2.4 Literature on keyboards – Discussion

The European standards recommend a keyboard slope of 0 to 15º. Yet, based on the literature reviewed here, a keyboard with a moderately negative slope towards the display screen would seem to make more sense. However, a solution must still be found to allow this recommendation to be implemented in a way that prevents negative effects from impacting the rest of the working posture (see Section 4.2.1, page 73).

Other contradictions with the recommendations of the standards were not found, although the recommended key resistance force of 0.25 to 1.5 N seemed to be rather broad. Test subjects themselves rated values within the range of 0.28 and 0.83 N as causing differing comfort or discomfort [43]. The behaviour of the keys in this instance – whether the keyboard uses the snap or ramp function – also appears to play a role in this perception. Yet the literature research on this subject failed to discover any more recent studies that had been carried out during the last twenty years.

## 3.3 Literature on computer mice

### 3.3.1 Assessing studies on the mouse

Table 9 shows the number of articles reviewed and their different assessments. The criteria for the scores are given in Section 2.1 (page 11). Brief descriptions of the contents of each study are given in Annexe B (page 121 ff.).

Table 9:
Overview of the literature on computer mice

| Score | 1 | 2 | 3 | Sum |
|---|---|---|---|---|
| Number | 4 | 21 | 7 | 35 |

### 3.3.2 The mouse – Evaluating the literature

According to *Woods* et al. [3], 97% of computer users use a mouse at their jobs during periods of around 25% [45] to over 33% [46; 47] of their time at work. Information on deviations in postures of the hand and the arm from neutral posture varied widely in the different studies, and individual differences were repeatedly featured prominently [48 to 55]:

- hand extension: 15 to 30°
- hand ulnar deviation: 5 to 18°
- upper arm flexion: up to 30° in the shoulder joint
- upper arm abduction: up to 30°, sometimes over 40° in the shoulder joint
- upper arm outward rotation: 5 to 45°

In comparison to using the keyboard, using a mouse requires greater upper arm abduction and outward rotation. This is true in particular when the mouse is used in combination with a keyboard. The alphanumeric portion of a conventional keyboard is 283 mm wide. Adding the numeric keypad of 150 mm, which is most often combined with the keyboard, increases this width to 433 mm. If the mouse is placed to the right of the keyboard, this results automatically in a forced posture with an upper arm abduction in conjunction with upper arm outward rotation for the average shoulder width of men of nearly 400 mm and women of 350 mm [56].

Various measures are available and have been investigated in the researched studies that would improve hand and arm posture during mouse usage:

- alternative mouse design
- improved mouse position
- alternate use of the mouse with the right and left hand
- changing working techniques

These points are described first below, followed by a discussion of additional topics that deserve to be explored in the attempt to alleviate stress and strain in the upper extremities.

**Alternative mouse design**

The general aim of alternative mouse designs is to enable a nearly neutral hand and arm posture and to facilitate comfortable mouse operation thanks to the mouse's size and shape, all while promoting relaxed periods of rest for the hand and fingers in between periods of mouse use. During rest periods, the forearm and the heels of the hands should be able to rest on the surface of the desk (Figure 18).

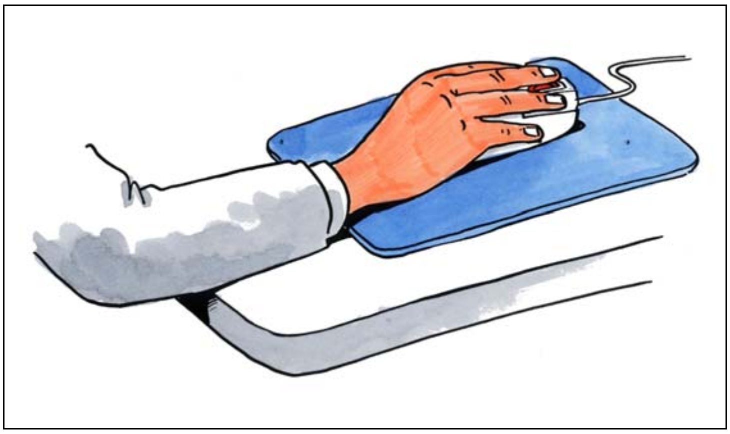


Figure 18:
Relaxed rest phase for the fingers, hand and forearm

To allow for anthropometric adaptation to hand size, computer mice are manufactured in various sizes in order to achieve a comfortable position for the palm of the hand to rest on the mouse as facilitated by its shape. It would seem useful to offer mice in different sizes or of adjustable sizes and lengths to accommodate larger or smaller hands and longer or shorter hands and fingers so as to allow the fingers to press the mouse buttons from a relaxed posture. Examples of mice designed in this fashion are illustrated in Figure 19.

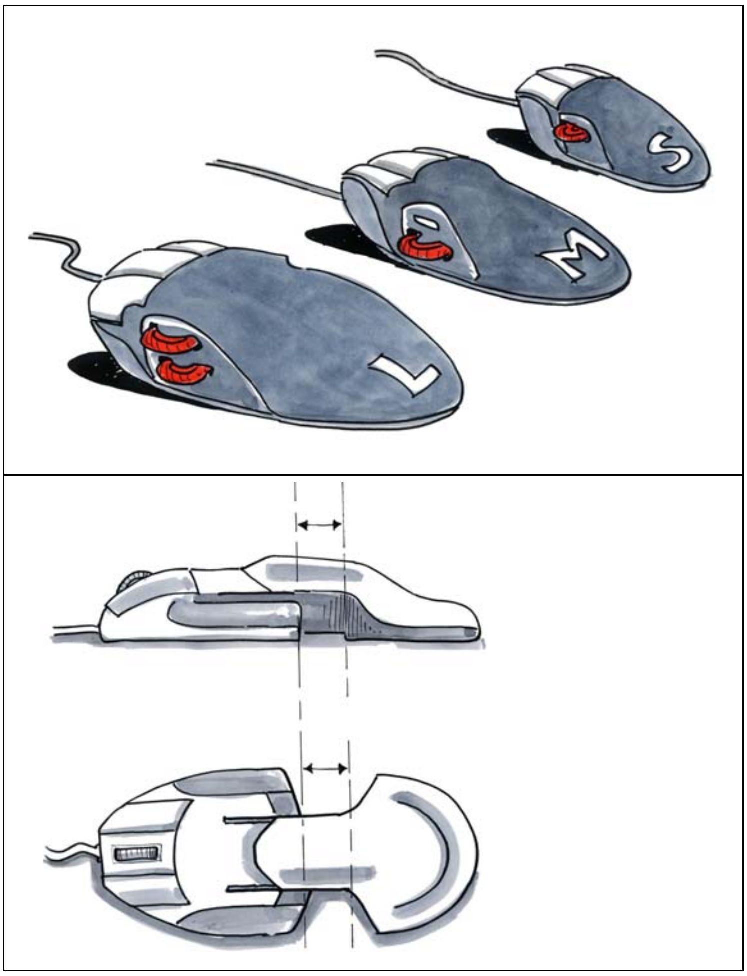



Figure 19:
Top: mice of different sizes;
bottom: adjustable mouse

Studies on a mouse with a design resembling a joystick (Figure 20, page 44) found improvements in cases of complaints in the neck, shoulder, forearm and hand regions [57; 58]. Even in healthy test subjects, this design resulted in lower muscle activity, a more neutral posture and more frequent micro-breaks (thanks to relaxed resting) in comparison to traditional mouse designs [59; 60].

Another alternative mouse design comes in the form of a hand-grip, or vertical, mouse (figure 21, page 44). Operating this input device and holding the hand posture that comes with it is comparable to using a conventional pen or pencil. The utilisation of fine-motor muscle movements in the hand enabled precision work, and the EMG readings showed lower muscular exertion in comparison to conventional mouse designs [61].

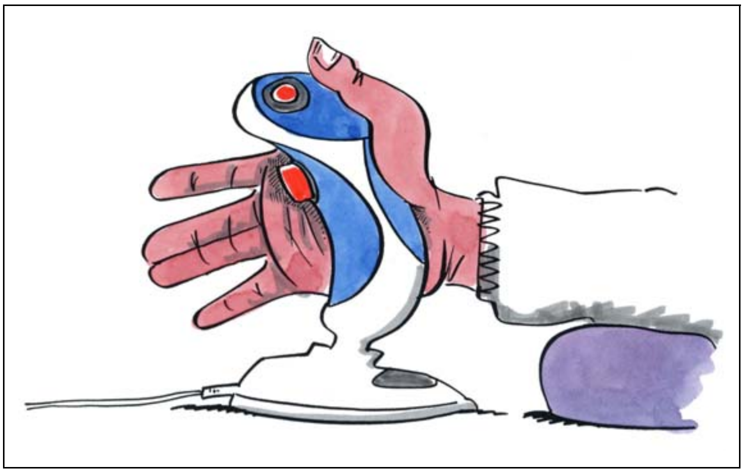
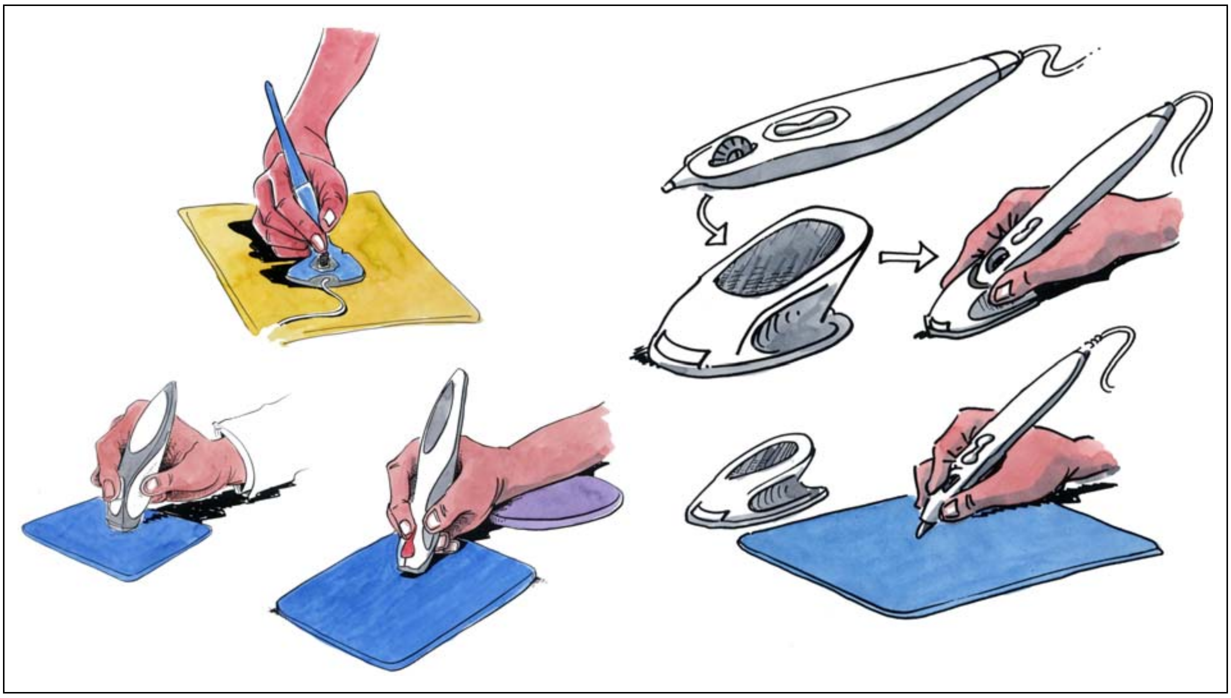


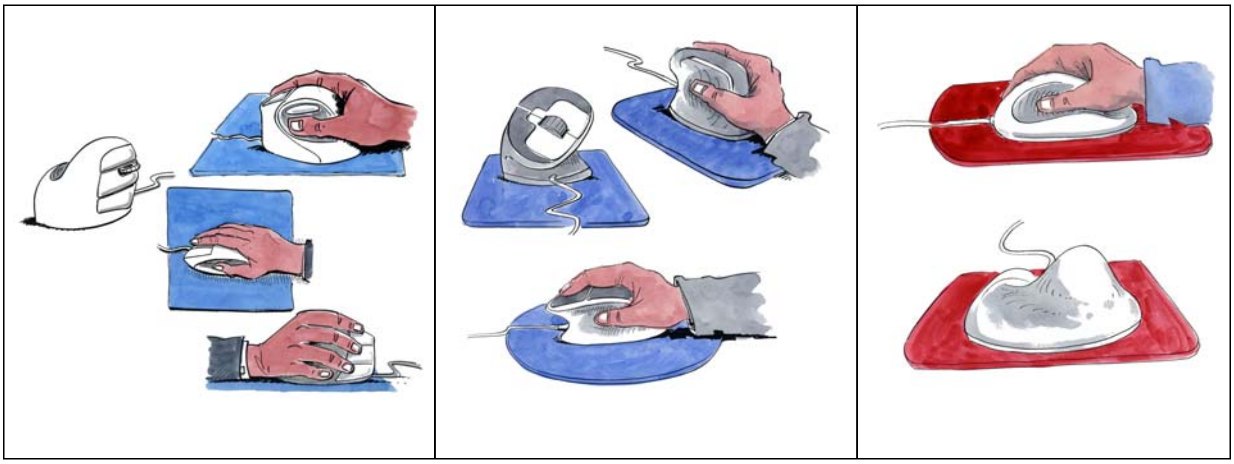
Figure 20:
Joystick-shaped mouse

Figure 21:
Various forms of vertical mice



Other mouse shapes that displayed positive effects on posture and muscle activity in comparison to conventional mouse designs tended to be larger, adapted to the contours of the hand – in part individually by way of gripping the device – and swept outward (towards the ulna) in order to reduce forearm pronation [51; 62]. Figure 22 shows examples of such mouse designs.

Figure 22:
Three examples of alternative mouse designs



Obvious here are the contours and indentations for the fingers to ensure that the hand has a better grasp. From the present studies on different mouse designs, however, it is not possible to derive a recommendation for a preferable mouse shape. More predominantly, the discussions of the variants of ergonomic mouse designs indicate specific advantages and disadvantages that should be weighed against each other on a case-by-case basis.

Aside from the shape of the mouse, the arrangement of its buttons and the direction of button operation all influence finger posture and movement along with the related muscle activity [63; 64]. Yet, the studies reviewed did not permit for clear suggestions on button design to be derived.

The disadvantage shared by all "ergonomically shaped" mice is that they can only be used on one side, thereby eliminating the possibility of using each device with the right and left hands in alternation.

**Performance**

The more unusual an alternative mouse design was, the more it was found to reduce speed and accuracy. *Hedge* et al. [65] registered a reduction in speed of 19% when performing the actions of selecting, clicking and scrolling with the mouse in Figure 23 (page 46). Yet, the tests in that study lasted only a few minutes. It is safe to assume that the performance could be greatly improved after a suitable period of getting used to the alternative design.

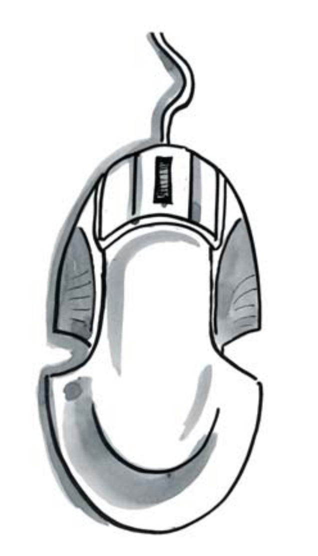


Figure 23:
Mouse tested in *Hedge* et al. [65]

According to *Gustafsson* and *Hagberg* [60], the joystick-like mouse was not very well received because productivity was reduced by nearly a quarter after using this device for a half a day (text editing). Better results in terms of performance on the tasks of pointing, clicking and dragging were found by *Aaras* et al [58]. Here, after using the joystick mouse for six months, test subjects only experienced slightly more errors (2.5%) than with a conventional mouse, and their speed was only marginally slower.

Test subjects showed a similar or improved performance as early as the second day after using the hand-grip mouse for selecting and clicking in comparison to traditional mice thanks to the alternative's similarity and familiarity of operation with that of holding and using a conventional pencil [61].

**Improved mouse position**

With regard to biomechanical load factors, the position of the mouse or its location in the workspace appears to be more significant than the mouse's design. In a study of 1,000 test subjects, *Dennerlein* and *Johnson* [66] found that 92% used the mouse on the right, and 4% used it on the left. The mouse was up to 22 cm to the right of the keyboard for 78% of subjects, and farther than 22 cm away for another 14%. Seventy-nine% of all test subjects used the mouse in the area between the edge of the desk and the display screen in line with the keyboard; 13% used the mouse above the line (closer to the screen) and 8% below the line (towards the edge of the desk).

Strains to the shoulder and arm can be reduced by positioning the mouse as close as possible to shoulder breadth. Ergonomically designed keyboards, which are often wider than those of conventional design (see Section 3.2.2, page 31), may especially prohibit the placement of the mouse within shoulder breadth. Depending on other external conditions and job tasks, keyboards without numeric keypads or with separate numeric keypads may provide a solution. This commendable measure not only makes the distribution of letter keys on the keyboard more symmetrical, it also reduces the width of the keyboard, permitting the mouse to be placed in a more convenient location within reach and with room for movement [48]. As an alternative to this measure, the mouse may also simply be operated by the left hand (see "Alternate use of the mouse with the right and left hand", page 49).

Figure 24 provides an illustration of a workplace that applies both of the options described above, wherein a mouse designed for right- or left-hand use could of course be moved from one side to the other.

Figure 24:
Workplace with a flat keyboard turned outwards,
dual-side mouse use and a separate numeric keypad

For tasks primarily requiring work with the computer mouse, it is useful to consider removing the keyboard from the convenient working location in front of the display screen and placing it to the side, for instance, or closer to the screen so as to place the mouse in shoulder breadth for using it without causing considerable flexion and/or abduction and outward rotation in the shoulder joint. Such an arrangement actually did result in lower measurements for muscle activity [67]. Furthermore, the mouse should be placed far enough from the edge of the desk to allow the forearm to rest on the desk's surface [68] (see Section 3.6, page 65).

Another option for a tested location for the mouse is the use of a mouse tray, which can be affixed to the edge of the desk, for example, and adjusted to individual needs (Figure 25).

Figure 25:
Example of a mouse tray

*Mierdel* [69] studied a mouse tray similar to that in Figure 25, except that the studied device could also be adjusted to be lower than the surface of the desk. Test subjects were permitted to adjust the tray's height and inclination to their own preferences without any instruction from the researchers. The subjects on average preferred a height of 7.5 ± 3 cm below the level of the working surface, resulting in an angle between the upper arm and forearm of 95 to 155°, a sideward tilt of 3 ± 5° in the ulnar direction and a negative inclination of 4 ± 6° (towards the display screen). This individually adjusted operating platform for the mouse was felt to be very comfortable by all test subjects. Problems arose at times due to the spatial restrictions at the workplace caused by the additional mouse tray. Such problems may include the tray/ stand blocking the worker from standing up and leaving the workplace or bumping the arm rest of the chair against the mouse stand. The mouse stand was recommended in combination with a chair arm (support) rest providing support for the forearm.

**Alternate use of the mouse with the right and left hand**

Most mouse users work with the mouse on the right side of the keyboard [3; 66] although right-handedness is only prevalent amongst around two-thirds of the population [49]. Moving the mouse to the left side offers several advantages. For a keyboard with an integrated numeric keypad located on the right-hand side, it makes sense to move the keyboard to the right so as to centre the letter keys that are primarily used in front of the body.

Using the mouse with the left hand means that the mouse is closer to the body centre, resulting in lower upper arm abduction and outward rotation when using the mouse. Alternate use of the mouse with the left and right hand effects a distribution of strains to both sides of the body's hand-arm-shoulder systems.

*Delisle* et al. [53] studied test subjects who had shifted their mouse usage from the right to the left hand and demonstrated that this shift reduced arm abduction and flexion. Performance was initially worsened, however, but it recovered again after the subjects got used to the arrangement. According to the results from *Delisle* et al. [53], test subjects were only 8% slower after using the left hand for one month than they originally were when using the right hand.

*Ackland* and *Hendrie* [70] observed that test subjects were 61% faster and 51% more accurate using the dominant right hand than with the left hand; after 15 x 30 minutes of practice, performance improved over a period of three weeks to an acceptable level. Mouse users who were left-hand dominant but still used the mouse with their right hands managed the change with less negative impacts on performance [71; 72]. These subjects performed broad motor movements – such as scrolling or clicking on large fields – with the left hand practically without problems right from the beginning [73].

### Work techniques

Effective work techniques are marked by a high proportion of time spent with a nearly neutral body posture and by proportionate and changing muscle effort as expressed in predominantly low muscle activity and an even distribution of rest for individual muscles. A difference between different work techniques is illustrated by the types of mouse movements [52]. If the mouse was moved by the whole arm, increased wrist extensions and trapezius muscle activity were measured. Fatigue was identified in particular proximities.

Another work technique was to move the mouse only by using the wrist with a supported forearm. This technique resulted in less activity in the *M. trapezius* muscle, but the forces pressing against the sides of the mouse were greater. Fatigue here was registered in particular in the distal area. The technique proved to be somewhat slower. Nevertheless, a work technique with support for the forearm tended to be recommended [52]. Furthermore, attention should be paid that the mouse is not raised often during use, for instance for repositioning the device [52].

It is not possible to postulate a generally applicable, good work technique for all mouse users. In this context, *Woods* et al. [3] expressly point out the individually different working styles that also depend on the respective activity. Discussion is needed to determine whether a change in work techniques – such as alternating mouse operation by way of the forearm or of the wrist and/or alternating the mouse between the left and right hands – may be a sensible preventive measure.

### Force exerted

Another stress factor in using a mouse is the amount of effort that has to be exerted: First, force is exerted against the side of the mouse to move the device; second, force is exerted to operate the mouse buttons. Pressing the buttons requires only around 0.5 N – nearly 1% of the maximum force exerted intentionally on the mouse [45] – yet this is often a monotonously repetitive action, and both the arrangement of the buttons and the direction in which they are depressed influence muscle loads [63; 64]. A predominantly positive solution here, however, was not found; the results of different studies appeared to be generally heterogeneous.

The muscle activity that has to be exerted sideways on the mouse can be reduced if the mouse only requires light force to move it, in other words, when the mouse glides well. One study reported that lower muscle activity on average was measured on a mouse with a low activation force [62]. Other positive factors for reducing muscle activity included the surface form of the mouse and its shape (including side indentations) [63]. Yet *Cail* and *Aptel* [33] stress that the exerted effort varies widely from person to person independent of the influences described above.

The present literature reviewed did not yield uniform recommendations for reference values on activating forces, button layout and orientation or detailed descriptions of mouse contours.

**Software**

Strain resulting from mouse use can be reduced if the mouse is programmed optimally. It is often possible to replace double-clicking with a single click of the right mouse button or similar alterations, for instance. For tasks that require more frequent double clicking, such functional changes may make very good sense. There are also computer mice on the market that allow the particularly onerous action of "dragging" – holding the mouse button while dragging the mouse – to be replaced by an additional button [63].

*Dennerlein* and *Yang* [74] studied a software program that exerted electromagnetic force on the mouse. The cursor was first accelerated on the way to the target before being decelerated and manipulated once near the destination field so as to make it easier for users to hit the targets. The use of this software resulted in less discomfort and less fatigue in comparison to the use of a normal mouse. It also reduced the error rate by 43%, and tasks were completed in up to 25% less time. Yet the question as to whether such a program could be usefully integrated into everyday work remained unanswered.

Newer keyboards have extra keys with additional functions that can partly obviate the need to reach for the mouse [36]. Software is also available that makes it possible to eliminate the mouse almost completely [75].

### 3.3.3 Literature on the mouse – Summary

Intensive use of the mouse and a mouse shape that poorly matches the shape of the hand along with the common necessity to assume a pronation posture and increased arm abduction and outward rotation can all result in complaints. The use of an alternative mouse design that permits a more neutral hand and arm posture can counteract some of these problems. Arm abduction and outward rotation can be offset by placing the mouse within shoulder breadth in the work area.

Using a keyboard without a numeric keypad or alternating the mouse from the right to the left hand makes it easier to implement this measure. Also worth investigation are optimisations to work techniques under consideration of the occupational task as described above, and potentially even using suitable software to reduce mouse use.

### 3.3.4 Literature on the mouse – Discussion

The results of the studies in part offer suggestions for uniform and specific solutions that might be applied to the very generally stated recommendations in European standards. This aspect is best demonstrated using arm abduction as an example. The standard only says that arm abduction should be kept as low as possible. Yet, specific solutions as were given in the previous sections are lacking. While the standards do point out that a keyboard should be as short as possible when used simultaneously with a mouse, and it points out that a mouse needs to be capable of use with the right or the left hand, no clear link is established between these suggestions and the desired avoidance of major arm abduction.

There is a discrepancy between the assumption in the standards that the force applied by the fingers does not exceed 1% MVC and the measured values reported in the respective studies. The studies reported values for finger flexors of between 2 and 19% MVC and for finger extensors of between 3 and 17% MVC. These in part high exertion forces were larger than the effort actually necessary for operating the mouse.

One should note, however, how the MVC was determined. Most studies relied on measurements of each muscle to be studied as it exerted the maximum voluntary force to perform a movement. Another reference value similar to the MVC was obtained by deriving the EMG while maximum force is applied to the mouse (to its buttons or to its sides). These two different measurement procedures produced different MVC values, and they may explain the discrepancies and ranges of the measurements. It would thus seem reasonable to specify the MVC and how it should be determined.

## 3.4 Literature on trackballs

### 3.4.1 Assessing studies on trackballs

The number of articles reviewed and their different assessments are given below. The criteria for the scores are explained in Section 2.1 (page 11). Brief descriptions of the contents of each study are given in Annexe C (page 139 ff.).

Table 10:
Overview of the literature on trackballs

| Score | 1 | 2 | 3 | Sum |
|---|---|---|---|---|
| Number | 4 | 7 | 2 | 16 |

### 3.4.2 Trackballs – Evaluating the literature

Most studies compare trackballs to computer mice or other input devices. Few studies focused exclusively on trackballs. The focus of the presentation of the results of these studies thus refers to the comparison of mice and trackballs. Comparisons between trackballs and pen-tablets are found in Section 3.5 (page 60).

Generally, trackballs offer the advantage of permitting the user to operate them without moving them, thereby requiring less space than is needed to operate a mouse [76 to 78]. Trackballs also do not necessarily have to be placed on a smooth surface, but can even be held in and operated from the user's lap [78].

One similarity that trackballs have with mice is that trackballs may succumb to dirt. This can seriously impair the rolling performance of the ball. Another disadvantage of the trackball is that it cannot be removed to the side as easily as the mouse can because the trackball's friction at its base is greater [76]. Yet users may wish to move the trackball out of the way if they frequently change their activities between using the keyboard, using the trackball, writing manually on paper, and so on – situations in which the workplace has to be rearranged frequently.

**Hand and arm posture**

An approximately 5º greater wrist extension was identified in connection with the use of the trackball in comparison to the use of the mouse [55; 79; 80]. This angle was as great as 25º, in particular for large trackballs. This extension can be reduced in a manner similar to that used with keyboards, by sloping the trackball negatively or reducing the base on which it is situated [81].

In contrast, shoulder lifting and ulnar deviation were lower for trackballs [4; 55; 80]. *Burgess-Limerick* and *Schemmell* [55], for instance, measured ulnar deviation of 6º for the trackball and 10º for the mouse. It should be noted that the design of the trackball and individual properties influence hand and arm postures [55; 79]. The question of where the individual differences in hand and arm posture originate and whether these can be changed by way of training remains unanswered.

**Design**

A very wide variety of trackball shapes is available on the market (Figure 26). The following criteria are offered as criteria for helping buyers select a design [76; 78]:

- Trackball size
  The size should be adapted to the anthropometrics of the hand.

- Size of the ball or of the exposed portion of the ball
  Larger balls or balls that protrude more from the housing were generally preferred by one author [78].

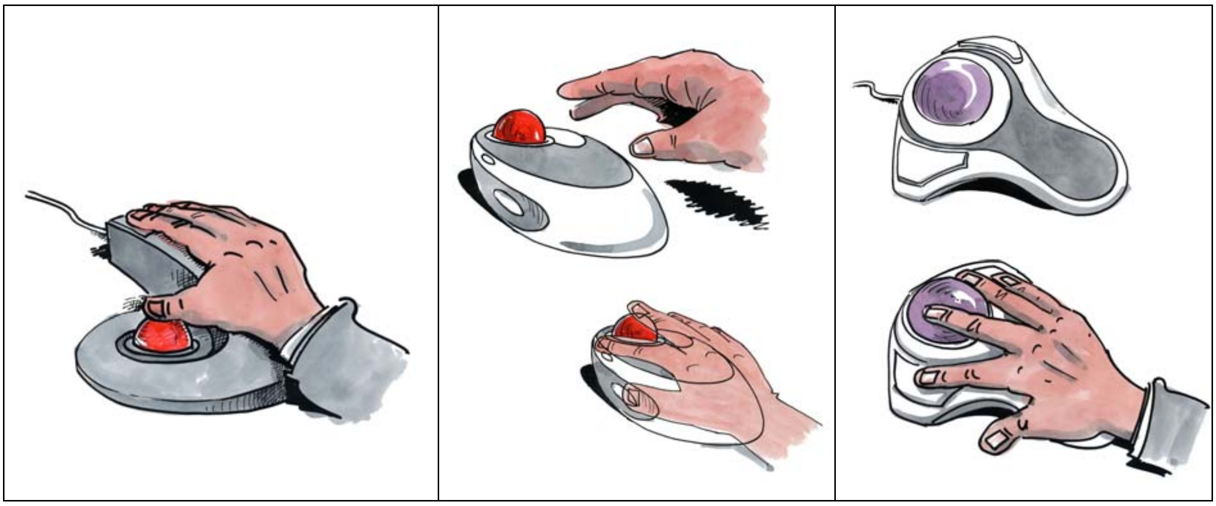
- Ball movement (ease of roll, precision, control, acceleration curve)
  A balance between ease of ball roll and sufficient ball control is important for operating the trackball. The acceleration curve of a trackball is often individually adjustable.

- Number and arrangement of buttons
  The buttons should be designed such that they can be depressed with the fingers in a posture as neutral as possible.

- Button functions
  The functions of the buttons on several trackballs can be assigned individually, making the devices adaptable to work requirements.

- Cleaning possibilities
  Because the rolling behaviour of the ball is sensitive to dirt and impurities, it is useful for the ball to allow easy removal from its housing so as to facilitate regular cleaning.

Figure 26:
Examples of trackballs operated by the thumb, pointer finger and middle finger



*Hsu* and *Wang* [82] compared three trackballs that used different fingers to move the ball:

- Thumb operated (TO)
- Pointer-finger operated (PO)
- Middle-finger operated (MO)

Based on the parameters of posture, muscle activity, performance and subjective impression, an evaluation system was produced in which higher evaluation scores represent better results. The authors arrived at the results shown in Table 11 after calculating the evaluation scores across all the tasks performed.

Based on these results, *Hsu* and *Wang* [82] recommended a trackball in which the ball was operated with the middle-finger for slow tasks requiring great precision, with the caveat that this activity not last for a very long time (the duration was not specified). Trackballs with middle-finger operation should only be operated for brief work periods. Trackballs operated by the thumb were considered particularly well-suited for longer periods of time spent working with this device, even if the tasks in question required precision in moving the cursor to exact points and took more time at the same level of performance. The physiological loads involved with this model appeared to be the lowest.

Table 11:
Comparison of three trackballs
Ball handling: middle-finger operation = MO, thumb operation = TO, pointer-finger operation = PO

| | Posture | Muscle activity | Performance | Total | Subjective impression |
|---|---|---|---|---|---|
| MO | -2 | 2 | -1[1] | -1 | poor |
| TO | 4 | 3 | -1[2] | 6 | good |
| PO | -2 | -2 | -2 | -6 | good[3] |

1 Performance was good for slow, precise cursor movement. Fast, precise movements caused problems in comparison.
2 Tasks that required precision were somewhat slower to perform with this trackball.
3 Although this trackball was worst in terms of posture, muscle activity and performance, test subjects rated it highly for subjective performance. This may be because they felt that they had the most control in the pointer finger.

### Muscle activity

Four studies were found [4; 80; 82; 83] that compared the use of mice and trackballs on the basis of muscle activity as measured using EMG. It is difficult to arrive at a simple conclusion from the studies because, on the one hand, they relied on measurements of different muscles and, on the other, different trackball designs were used. At the very least, a tendency is apparent that the shoulder muscles are under less load when the trackball is used [4; 80]. Depending on the design, less electrical activity was recorded in the EMG for the forearm muscles [4; 82]; the thumb-operated trackballs proved to be more ergonomic in comparison with the pointer-finger and middle-finger-operated designs [82] (see the Design section on page 54 ff.).

### Right- or left-hand use

There appear to be many fewer performance differences between using the right or left hand to operate the trackball than were found in using the mouse [72]. This means that it is easier to change hands, and the change requires less time for the user to adjust. The impact on the musculoskeletal system by operating this input device can hence be spread across both arms without any problems. Yet in alternating the use of the trackball between the right and left hand, it should be kept in mind that not every design is equally suited for both hands [77]. The shapes and button arrangements may be designed specifically for left- or right-hand use.

Aside from the dual-sided use of the trackball on the right and left, another possibility is to use a mouse on the dominant side and a trackball on the non-dominant side.

### Performance

Table 12 (see page 58) provides an overview of the performance differences between trackballs and mice. It is obvious that manipulating a trackball is somewhat slower than manipulating a mouse. A look at the error rates indicates that the two input devices are roughly equal in terms of that criterion.

Table 12:
Comparing trackball and mouse performance

| Study | Speed | Error rate |
|---|---|---|
| *Chaparro* et al. [83] | – | |
| *Chase* and *Casali* [84] | = | = |
| *Hancock* [85] | | – |
| *Hsu* and *Wang* [82] | – | |
| *Kabbash* et al. [72] | – | = |
| *Karlqvist* et al. [80] | = | = |
| *MacKenzie* et al. [86] | – | + |
| *Zöller* and *Konheisner* [87] | – | = |

-: Trackball is slower or has a lower error rate
=: Trackball and mouse are equal
+: Trackball is faster or has a higher error rate

The tests in the studies, however, were almost always of only a few minutes in duration, and the test subjects who were used to working with computer mice but not with trackballs were given insufficient time to adjust (several days would have been better, for example). It is thus possible that the test subjects would have worked at comparable speeds with the mouse and the trackball as they became more used to the latter device.

**Subjective perception**

Five studies chose subjective perception as a criterion for evaluation, and the test subjects were allowed to decide whether they preferred to work with a mouse or with a trackball. Two studies concluded that subjective perception for using a mouse were more positive than for using a trackball [80; 88], test subjects in three of the studies preferred using trackballs [82; 83; 85].

Test subjects in all of the studies were used to working with a mouse. Trackballs, in contrast, were new as input devices for the test subjects, and were used only during the testing period, although one of the studies that reported positive perception of working with trackballs had the longest testing regimen, with a total of 3.5 hours [82].

So there is still a possibility that subjective perception might have changed after a longer adjustment period of using the trackball for regular work on a daily basis, potentially leading subjects to prefer using trackballs to a greater degree.

**Force feedback**

As with computer mice, there is also software for trackballs that affects the behaviour of the cursor and the sensation of operating the ball in a manner meant to enhance user control. Such software, for instance, can make the ball feel to the user as though the ball is about to roll into a hole when the user moves the cursor ever closer to a target area. In a study by *Keuning* et al. [89], such force feedback helped to improve performance. The shape of the field of the force and the strength of the feedback influenced the degree of improvement found in the study (see the brief summary of the report's contents in Annexe C, page 139 ff., for more detailed information). Yet no conclusions could be drawn as to implementation and application to everyday use at work.

### 3.4.3 Literature on trackballs – Summary

Comparisons between trackballs and mice have not resulted in clear statements that one of the two input devices should definitely be preferred over the other. There are some studies in which the trackball performed better, and others in which the reverse was true. Trackballs require more finger movement, and computer mice are operated more by the wrist and forearm [87]. Ulnar deviation appears to be lower with the trackball, but wrist extension appears to be greater. This posture may also depend primarily on trackball design. Vast individual differences were identified in part, which makes interpreting the results of the studies all the more difficult.

If a trackball is to be used as an alternative to a mouse, for instance to avoid posture problems, a sufficient period for workers to adjust needs to be provided to find out if the new input device truly results in improvements.

A major advantage of trackballs is the ease of switching between right- and left-hand use with apparently few adjustment problems and performance losses. This advantage offers the simple potential of easing the burden on the dominant side of the body. Trackballs with thumb operation are suggested in particular for longer periods of pointing device work.

### 3.4.4 Literature on trackballs – Discussion

The results of the studies are in agreement with the recommendations and reference values of the standards. There is a potential for deriving recommendations and decision-making aids for resolving problems that arise and questions about working with input devices from the studies that compare mice and trackballs.

## 3.5 Literature on pen-tablets

### 3.5.1 Assessing studies on pen-tablets

Only seven articles provided useable information on pen-tablets (Figure 27) in office workplace settings. The results of these studies are mentioned in the present report because these input devices may offer a major alternative to the use of computer mice.

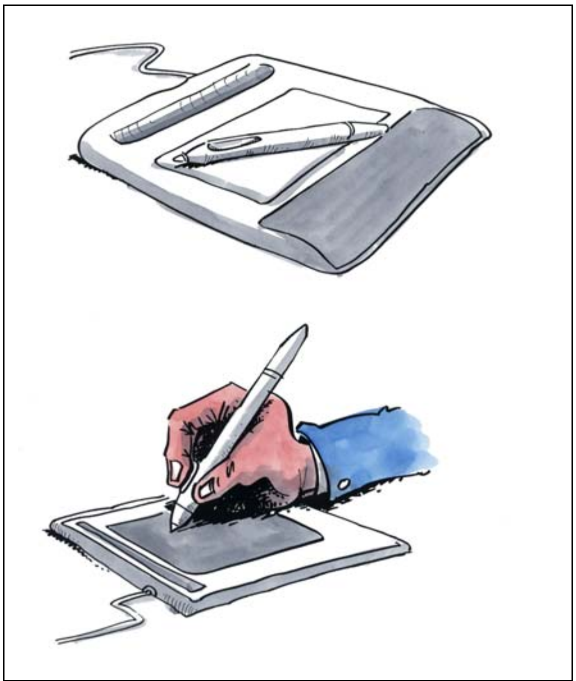


Figure 27:
Example of a pen-and-tablet device

The assessment criteria for Table 13 were described in Section 2.1 (page 11).
A short summary of the contents of the individual studies is provided in Annexe D (page 149 ff.).

Table 13:
Overview of the literature on pen-tablets

| Score | 1 | 2 | 3 | Sum |
|---|---|---|---|---|
| Number | 2 | 5 | 0 | 7 |

### 3.5.2 Pen-tablets – Evaluating the literature

The selected studies pertain exclusively to pen-tablets meant as an alternative to using a computer mouse; in other words, only the tasks of selecting, clicking, dragging, tracing figures and similar actions were studied. The use of the pen-tablet as an alternative to the use of a keyboard by interpreting handwriting was not investigated. No useable studies on the latter topic were found.

**Hand and arm posture**

One technical report [90] compared hand and arm postures in data entry activities by way of a mouse with the postures for the same activities by way of a pen-tablet (Table 14).

Table 14:
Comparison of postures when using a pen-tablet and when using a mouse

| | Pen-tablet | Mouse |
|---|---|---|
| Forearm pronation | none | maximum |
| Wrist extension | none | 8 to 12° |
| Wrist flexion | minor | none |
| Ulnar deviation | < 4°, most of the time even < 1.5° | up to 12° |
| Radial deviation | < 2.5°, most of the time even < 1° | 2 to 3° |
| Finger extension | none | depends on button angle |
| Finger flexion | permanent | during operating the buttons or when using too small mice |
| Finger abduction | none | depends on button arrangement |

Overall, it seems that the pen-tablet permits a more neutral hand posture than is permitted by using a conventional mouse. However, arm abduction was not studied here, which depends on the location of the tablet. The same recommendations for its location obtain as for workplace layout designed for using the mouse (Section 3.3.2, page 41). Moreover, for the same reason, the workspace reserved for the tablet should not be too large.

**Design**

The designs of pen-and-tablet systems is not as widely varied as those for keyboards, computer mice or trackballs. No studies were found on the shapes of the tablets. The tablet itself should certainly be as flat as possible and the edges should be rounded so as to avoid pressure points against the forearm.

Diameter and length are important for the ergonomics of the pen. The length should not be longer than the width of the hand. A length of 100 mm was recommended [91]. The optimum diameter of the pen depends on the tasks to be performed with it. Studies that explored the use of pens in diameters of 5.5 mm, 8 mm, 11 mm and 15 mm for pointing and clicking fields on the computer display showed that the thinner pens did better in terms of performance and test subject preference. For tasks requiring greater precision, such as tracing figures, the thicker pens were best. If the device is meant for several different tasks, *Wu* and *Luo* recommended a pen diameter of 8 mm [91].

**Muscle activity**

A study that compared the use of a conventional mouse with two buttons and the use of a pen-tablet concluded that the use of the pen required less muscle activity in the forearm that did the mouse. Stress on fingers was reduced by around 5 to 10% [92].

To avoid muscular loads resulting from poor posture, the forearm holding the pen should rest on the tablet as it would when writing normally on paper [93].

## Performance

The pen-and-tablet systems were compared in various studies in terms of comparative performance with mice, with mouse-and-keyboard combinations and with keyboards.

- *Kotani* and *Horii* [92] – Comparison between a pen-and-tablet system and a mouse
  In the beginning, subjects using a mouse performed better in terms of speed and accuracy than those using the pen-tablet, but by the second day, the performance evened out, and those using the pen-tablets actually performed better. The pen-tablet performed better from the beginning on tasks requiring a great degree of precision.

- *Coll* et al. [94] – Comparison of a keyboard (with cursor keys), a mouse and a pen-and-tablet system
  The mouse proved to be the fastest input device in this study, followed by the pen-tablet system. Using the cursor keys on a keyboard proved to be the slowest. Yet the test subjects using only the keyboard made the fewest mistakes. The error rate on the pen-and-tablet system was the worst. The tests in the study lasted for 2 x 45 minutes.

- *Kabbash* et al. [72], *MacKenzie* et al. [86] – Comparison between a pen-tablet system and a trackball
  It was faster to use the pen-tablet system than the trackball in these two studies. The accuracy results of the two studies differed: While the test subjects in *MacKenzie* et al. [86] performed the selection (pointing) tasks equally well with both input devices, they did better in the task of dragging (moving while holding a button) when using the pen, which was the opposite of the results found by *Kabbash* et al. [72]. Moreover, the latter study also investigated the performance after switching the use of the input device from the dominant hand to the non-dominant one. The performance differences were substantially greater with the pen-and-tablet system than with the trackball. The test periods in both studies were short.

In summary, after a brief period of practice and adjustment, subjects using the pen on a tablet worked at least as fast as those using a mouse and faster than those using a trackball or cursor keys on a keyboard. Yet the results for the accuracy rates varied and were in part contradictory. But here, too, performance in using the pen-and-tablet combination appears to have matched the performance in using a mouse after a suitable period of adjustment.

**Subjective perception**

In a comparison of a pen-and-tablet system, a keyboard (cursor keys) and a mouse, significantly more test subjects preferred to use the other two input devices over using the pen-tablet [94]. The tests were, however, only 45 minutes long for each input device. Additional studies would be helpful in answering the question as to whether attitudes towards pen-and-tablet devices might change if users are given a longer period to adjust.

### 3.5.3 Literature on pen-tablets – Summary

The few studies suggest that, from a biomechanical point of view (muscle activity, postures), the use of a pen with a tablet may offer certain advantages. This device might be an alternative for users having difficulties using a mouse. Performance received differing evaluations, but it was in part as good as or better than that of a mouse from the beginning. Yet due to the possible poor acceptance of using a pen-tablet device, choosing to adopt the device calls for careful consideration on a case-by-case basis.

### 3.5.4 Literature on pen-tablets – Discussion

A comparison of the results of the studies with the standards indicates minor differences in the design of the pen. The standard defines a length of between 120 and 180 mm; *Wu* and *Luo* [91] recommended for the pen length to correspond to the width of the hand and stated a figure of 100 mm. The same study recommended a diameter of the pen of 8 mm, which places the suggestion within the realm of the standard, which sets the pen diameter as from 7 to 20 mm. Yet if the pen is only meant for use primarily in selecting and clicking screen elements, *Wu* and *Luo* [91] recommended a (thin) diameter of 5.5 mm. The discrepancies discussed here may potentially reflect the different typical anthropomorphic dimensions found in Europe and Asia.

No information on the arrangement and operation of the buttons on the pen was found in the studies.

## 3.6 Literature on hand and arm supports

### 3.6.1 Assessing studies on hand and arm supports

Table 15 shows the number of articles reviewed and their different scores. The evaluation criteria were discussed in Section 2.1 (page 11). Brief summaries of the contents of the individual studies are found in Annexe E (page 155 ff.).

Table 15:
Overview of the literature on hand and arm supports

| Score | 1 | 2 | 3 | Sum |
|---|---|---|---|---|
| Number | 0 | 14 | 6 | 21 |

### 3.6.2 Hand and arm supports – Evaluating the literature

Aside from the form of input device, individual working techniques have an influence on the user's body posture and muscle activity. In this context, the question of whether the arms should be supported for typing or for using other input devices needs to be addressed. The support may be in the distinct forms of forearm supports or supports for the heels of the hands or the wrists (wrist supports). Table 16 (page 66) lists the studies that examined the effects of hand and arm supports. The list indicates whether the results were positive, negative or disputed; the type of supports in question; and what input devices were used in the test.

The table makes it clear that forearm supports were almost all assessed as being positive. Their main advantage is in the extent to which they reduce muscle activity above all in *M. trapezius* [3; 68; 80; 95; 97; 99; 101 to 103; 106; 107]. A reduction in wrist extensions [97; 103; 105] and in ulnar deviation [3; 97; 106] was measured in part. An improved sense of comfort [68; 96; 97; 102; 105] and a decline in the number complaints [96; 98; 104] were also registered.

Table 16:
Results of studies on hand and arm supports

| **Study** | **Results** | | | **Input device/type of support** |
|---|---|---|---|---|
| | **positive** | **negative** | **disputed** | |
| *Aaras* et al. [95] | X | | | • Keyboard and mouse<br>• Forearm support<br>forearm on desk |
| *Cook* and *Burgess-Limerick* [96] | X | | | • Keyboard and mouse<br>• Forearm support<br>with keyboard whole forearm without elbow; at least half of the forearm with the mouse |
| *Cook* et al. [97] | X | | | • Keyboard<br>• Forearm and wrist support<br>Wrist support: 65 mm deep, 17 mm high, 100 mm space before the support<br>• Forearm support: keyboard pushed back as far as possible to allow the whole forearm to rest on the desk |
| *Delisle* et al. [98] | X | | | • Keyboard and mouse<br>• Forearm support<br>Forearm on the desk or the arm rests of the chair |
| *Erderlyi* et al. [99] | X<br>with complaints | | X<br>without complaints | • Keyboard<br>• Forearm support<br>Two different designs, 150 mm |
| *Feng* et al. [100] | | | X | • Keyboard<br>• Forearm support<br>Three designs: 280 mm, 200 mm, whole forearm with elbow |
| *Fernström* and *Ericson* [101] | | | X<br>shoulder positive, forearm and hand negative | • Mouse<br>• Forearm support<br>Adjustable forearm rest on chair |
| *Hasegawa* and *Kumashiro* [102] | X | | | • Keyboard<br>• Forearm support<br>Arm rests of the chair, 310 mm long and/or wrist support 80 mm on the desk |
| *Hedge* and *Powers* [32] | | X | | • Keyboard<br>• Forearm support<br>Adjustable design attached to the desk |
| *Karlqvist* et al. [68] | X | | | • Mouse<br>• Forearm support<br>20 cm on desk |
| *Karlqvist* et al. [80] | X | | | • Mouse and trackball<br>• Forearm support<br>Around 20 cm on desk, no exact details given |

Table 16: continued

| Study | Results | | | Input device/type of support |
|---|---|---|---|---|
| | positive | negative | disputed | |
| *Lintula* et al. [103] | X | | | • Keyboard and mouse<br>• Forearm support<br>Attached to edge of desk, part of forearms resting on it |
| *Marcus* et al. [34] | X<br>Support on desk > 12 cm | X<br>Wrist support | | • Keyboard<br>• Forearm and wrist support<br>Wrist support not otherwise specified |
| *Rempel* et al. [104] | X | | | • Keyboard, mouse, trackball<br>• Forearm support<br>Attached to keyboard, 30 cm deep |
| *Smith* et al. [105] | X | | | • Keyboard<br>• Wrist support<br>Not otherwise specified |
| *Sillanpää* et al. [106] | | | X | • Mouse<br>• Forearm support, desk, whole forearm<br>• Wrist support<br>Cushion 20 mm thick |
| *Stack* [31] | X | | | • Keyboard<br>• Wrist support, at least 70 mm, adapted to keyboard slope and height |
| *Visser* et al. [107] | X<br>Forearm support | X<br>Wrist support | | • Keyboard and mouse<br>• Wrist and forearm supports of different design:<br>Forearm supports of 204 mm and 131 mm<br>Wrist supports of 130 mm and 75 mm |
| *Woods* et al. [3] | | | X | • Mouse<br>• Forearm support<br>Whole forearm on desk<br>• Wrist support<br>Desk |

Studies whose results documented disputed or negative assessments of the forearm supports often used more or less complicated support designs [32; 99 to 101]. Particularly in situations where working posture is changed more frequently, complex support designs can be a hindrance [103]. Resting the forearms on the desk – at least partly – by moving the keyboard back away from the edge of the desk appears to suffice, and this method should be taken into consideration when considering the ergonomic design of the workplace.

Despite the many positive aspects of arm supports, negative side effects were also identified. Whereas many studies reported a reduction in muscle activity in the shoulder region, in part muscle activity in the forearm and hand region was elevated [3; 101; 106]. A forearm support placed on the surface of the desk – thus by moving the keyboard farther back from the edge of the desk – corresponded to greater upper arm flexion [98].

The studies on wrist supports indicated generally more negative effects on muscular activity [107] and hand or arm complaints [34] than did the use of forearm supports in comparison. Yet positive results were found by *Stack* [31]. Wrist support was essential in particular for use with a keyboard with a very light keyswitch (force) because users cannot rest their fingers on the keys, as this could result in unintentional keystrokes. Yet the study also emphasized that correct design was of major importance for a wrist support: It has to be specifically matched to the keyboard in question; the support's angle has to correspond to the slope of the keyboard; the support's height has to be even with that of the keyboard; and the support should be at least 70 mm deep (better still: 80 mm, or even longer for individuals with long forearms and hands). The forearm and hand should form a straight line. Preferable is a flat shape for the support, and it should preferably be made of wood or plastic (non-heat-conducting and no major friction [31].

The studies were not always clear as to exactly what was referred to as a hand support or as an arm support, or how much of the forearm was supported by an arm support. Table 17 lists the studies that provide specific dimensions and that in part arrived at positive conclusions on arm supports.

Table 17:
Depth and length of forearm supports

| **Depth and length of arm supports** | **Number of studies** |
|---|---|
| Whole forearm | 5 [3; 96; 97; 100; 106] |
| 300 mm | 2 [102; 104] |
| 200 mm | 3, of which 2 with only a mouse [68; 80; 107] |
| 150 mm | 1 [99] |
| At least half of forearm | 1 (mouse) [96] |
| 130 mm | 1 [107] |
| > 120 mm | 1 [34] |

The anthropometric forearm length is 286 mm in the fiftieth percentile of males and 253 mm in females. An arm support of 300 mm can thus be considered as a support for the entire forearm. Seven studies thus reported positive results in using a full forearm support.

### 3.6.3 Literature on hand and arm supports – Summary

It would appear to be sensible to offer the option of using a type of rest as support for using computer input devices. This is to be recommended in particular for individuals with neck complaints. In applying the recommendation, attention needs to be paid to ensure that the height of the arm support is matched to the ergonomic seating posture and workplace design because a forearm support that is too high may result in increased muscle activity in the shoulder region [68; 99; 108]. A support placed on the desk by moving the keyboard and other input devices back away from the front edge of the desk appears sufficient. If there is not enough space to do this, the arm rests on the chair (Figure 28) or other special designs may be selected (Figure 29 and 30). Attention here needs to be paid that the overall ergonomics of the workplace in question is not forfeited with these modifications. Wrist supports should be selected with caution.

Figure 28:
Chair arm rests as forearm supports

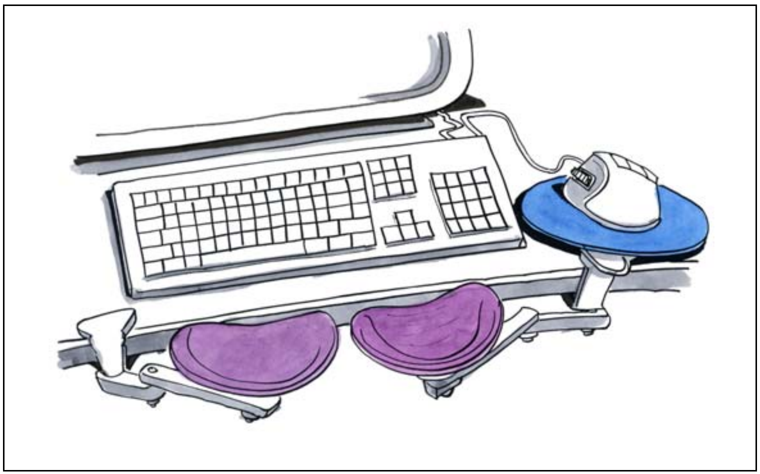


Figure 29:
Movable arm supports for using a keyboard and a mouse

Figure 30:
Arm support for using a keyboard

### 3.6.4 Literature on hand and arm supports – Discussion

The standards recommend space in front of the keyboard of at least 100 mm. The checklist of the VBG recommends 100 to 150 mm. Most studies with positive results used larger arm supports. Whether or not a selection of smaller arm supports would have yielded the same results cannot be definitively stated. No studies were found that tested arm supports of different sizes and otherwise identical designs used under the same conditions. Additional, more targeted studies would be necessary before any definitive statements on the style and size of arm supports could be made.

# 4 Implementation/use in practice

## 4.1 General ergonomic criteria

The following criteria should be met when computer input devices are used:

- The input device should be suited to the job tasks. One aid in decision-making may be the brochure published by the Netherlands' occupational safety institute, TNO Arbeid [109].
- The input device should permit use with the body in a posture that is as neutral as possible. Neutral posture is influenced by the design and position of the input device and by individual work techniques.
- The aim should be to minimize the level of muscle activity by enabling a small amount of effort to suffice and by producing the least static and least poor posture. This is influenced by the design and position of the input device and by working technique.
- Individual differences in body posture, anthropometric measurements, working techniques and individual preferences must be taken into account.

The ergonomic use of computer input devices should receive initial attention before physical complaints are reported. Sensible preventive measures can protect against health problems and the corresponding losses in productivity. It is a key importance in this for the measures under consideration to be viewed with regard to their effects on the overall workplace. The BGI publication 650, "Bildschirm- und Büroarbeitsplätze – Leitfaden für die Gestaltung", contains all the data, information and examples of implementation to serve as a practical guide in making computer work as ergonomic as possible [14]. In following the guide's suggestions, it is safe to assume that all of the requirements and protective targets given by the German Labour Protection Law, the Ordinance on Display workstations and the Ordinanace on Industrial Safety and Health will be maintained and achieved, and that accidents and occupation-related health risks are avoided.

Should health problems nonetheless arise in association with a computer workplace and with the use of input devices, it is suggested that employers seek the advice of a specialist for occupational medicine early on.

## 4.2 Check lists

Computer work and the use of input devices may result in complaints of the musculoskeletal system of the hand, the arm, the shoulder and the neck. Especially in cases of developing acute or chronic diseases of the locomotion system, including rheumatic diseases, "tennis elbow" or "golfer's elbow", complaints may arise or symptoms may be worsened.

The following checklists (Tables 18 and 19, pages 73 and 81) should serve as an aid for occupational health experts in identifying occupation-related sources of complaints or their exacerbation on a case-by-case basis and in finding adapted solutions potentially in co-operation with specialists for workplace health and safety or others who work on designing ergonomic workplaces. The aim should be to make it possible to perform all of the data entry tasks described here in a neutral body posture, while not restricting body posture for other activities that may arise.

The following procedure is recommended for using these checklists: If and when the described complaints (see above) arise, it is a good idea to consult the company physician in order to determine whether or not the complaints can be traced back to the workplace. As this is done, the workplace itself needs to be inspected along with the normal procedure of taking the patient's medical history. The type of activity and the type of use of the input devices as well as the body posture and work method need to be reviewed.

The pattern of the complaints and the workplace analysis serve to identify the problem as it is listed in the first column of the checklist. The second column with the heading "Measure" lists the suggested solutions, and the section "Comments" in this column provides notes on the individual and workplace-related peculiarities that need to be taken into consideration. The effectiveness of the measures applied should be reviewed after a suitable period of adjustment and acclimatisation.

### 4.2.1 Keyboard

Table 18:
Keyboard checklist

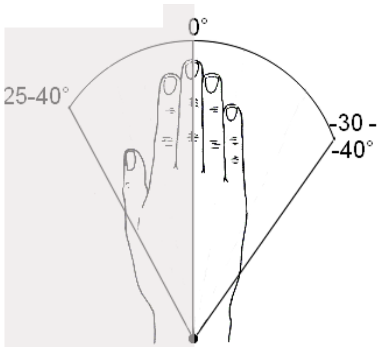
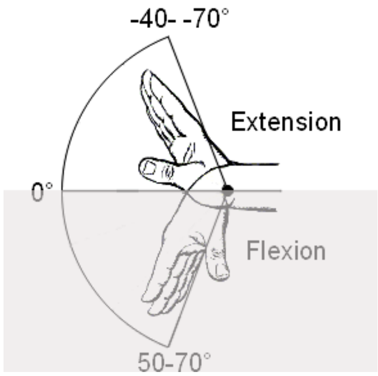
| A Deviation from neutral posture | | |
|---|---|---|
| | **Measure** | |
| **A I**<br><br>Wrist ulnar deviation<br><br><br><br>Radial deviation/<br>Ulnar deviation | • Turn the halves of the keyboards outward by up to 25º.<br>• Separate the halves of the keyboard to shoulder breadth.<br>*Comment:*<br>• The two measures only make sense for users who type using the ten-finger method without looking at the keyboard.<br>• Having the two halves of the keyboard at shoulder breadth cause some users problems with typing performance and the subjective perception of fatigue. |  |

Table 18: Continued

<table>
<tr><th colspan="3">A Deviation from neutral posture</th></tr>
<tr><th></th><th>Measure</th><th></th></tr>
<tr>
<td>

**A II**

Wrist extension




</td>
<td>

- Avoid a positive keyboard slope (collapse the keyboard's feet).
- Position the wrist at the height of the elbow.

*Comment:*

- Negative keyboard slope increases ulnar deviation. This can be compensated by applying measure A I.
- An elevated wrist position relative to the elbow does reduce extension, yet health problems may arise in the neck and shoulder regions.
- It is difficult respectively costly to implement negative keyboard slope as a universal workplace concept without restricting the rest of the working posture.

</td>
<td>

Keyboard laid flat (collapsed feet), wrist and elbow roughly at the same level

</td>
</tr>
</table>

Table 18: Continued

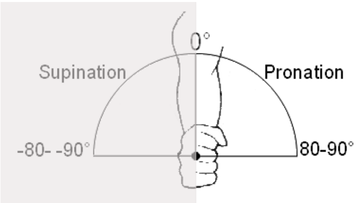
| A Deviation from neutral posture | | |
|---|---|---|
| | **Measure** | |
| **A III**<br><br>Forearm pronation<br><br> | • Keyboard halves sloped in a tent-like fashion.<br><br>*Comment:*<br><br>• Keyboard halves sloped in a tent-like fashion upwards to the middle only make sense for users who type using the ten-finger method without looking at the keyboard.<br>• Users vary widely in how they accept keyboards sloped in a tent-like fashion. The degree of slope should thus be adjustable by the individual user. |  |

Table 18: Continued

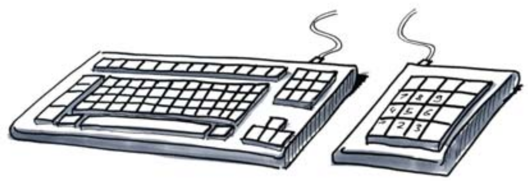
| A Deviation from neutral posture | | |
|---|---|---|
| | **Measure** | |
| **A IV**<br><br>For keyboards with numeric keypads*:<br>• The torso is turned to the left<br>• Increased ulnar deviation on right relative to the left<br>*See also Mouse checklist **A III** (page 83) | • Move the keyboard so that the alphabetic keys are in a centred position in front of the user.<br>• Use a keyboard without a numeric keypad or with a separate one that is only placed beside the keyboard when needed.<br>*Comment:*<br>• The measures described should be selected depending on the proportion of time spent in entering text and numbers relative to total work time.<br>• The numeric keypad is rarely used during text entry. It is thus recommended that the alphabetic portion of the keyboard be placed in the centre in front of the display screen. | <br> |

Table 18: Continued

| B Force exerted | | |
|---|---|---|
| | **Measure** | |
| **B I**<br><br>Disproportionate effort exerted and a lack of key feedback | • Choose keyboards requiring a force of between 0.5 and 0.8 N for keyswitching.<br>• Test key behaviour.<br>*Comment:*<br>• If the force necessary for activating the keys is too low, users cannot rest their fingers on the keys when not typing for fear of inadvertently depressing the keys (see B II).<br>• There are keyboards with different keyswitch behaviour. The manufacturer should be consulted for this information. Previous research indicates that kinaesthetic feedback is helpful (a point at which the fingers feel the key has been depressed). | |

Table 18: Continued

| B Force exerted | | |
|---|---|---|
| | **Measure** | |
| **B II**<br><br>Holding the fingers in a static posture | • Select a keyboard with a balanced key behaviour between the force necessary for activating the keys and the possibility of resting the fingers on the keys.<br><br>*Comment:*<br><br>• If the force needed to activate the keys is too low, users cannot rest their fingers on the keys when not typing for fear of inadvertently depressing the keys. This means that users have to hold their fingers above the keys constantly, which can result in severe local muscle fatigue and strain. | |

Table 18: Continued

| B Force exerted | | |
|---|---|---|
| | **Measure** | |
| **B III**<br><br>Holding the arms in a static posture | • Use hand-heel and forearm supports.<br><br>*Comment:*<br><br>• As a support for the hand-heels, space on the desk surface in front of the keyboard of 100 to 150 mm in depth normally suffices. A padded support (as flat as possible) may also make sense for individual sensitivities and anatomical peculiarities.<br><br>• The arm rests on an office chair serve as forearm supports. Fixed arm supports should be sloped forward to accommodate the different body dimensions of different users. The design of the arm supports should not inhibit the act of carrying out the user's job. Chair arm rests that are height- and width-adjustable allow for a better fit. | <br> |

Table 18: Continued

| **C Repetitive movements** | | |
|---|---|---|
| | **Measure** | |
| **C I**<br><br>Fatigue and strain from long-lasting and rapid repetitive movements | • Design the activity so that it is varied.<br>• Offer micro-breaks*.<br>*Comment:*<br>• The repetitive nature of an action can hardly be influenced by proportionate prevention – in other words, the choice of an ergonomic input device – but instead by measures of behavioural prevention.<br><br>*A micro-break is a short break of only a few seconds during which a static posture is interrupted and the muscles can relax. | |

## 4.2.2 Mouse

Table 19:
Mouse checklist

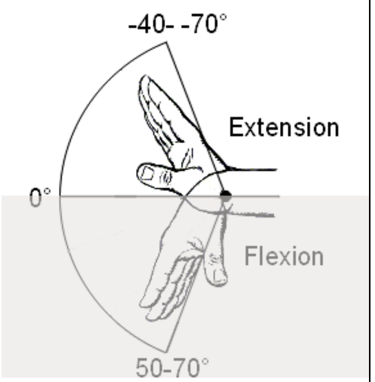
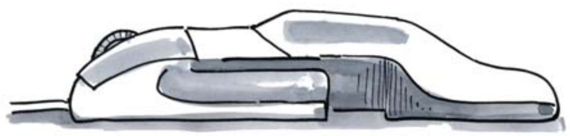
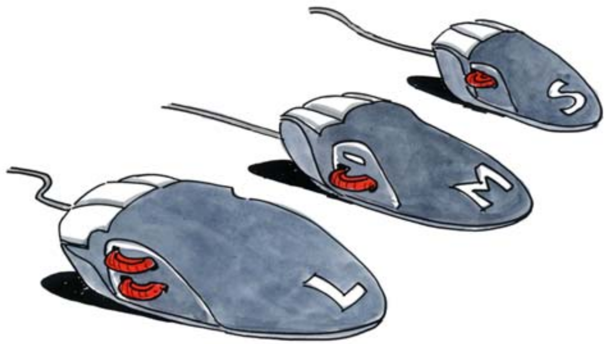
| A Deviation from neutral posture | | |
|---|---|---|
| | **Measure** | |
| **A I**<br><br>Wrist extension<br><br><br> | • Select a mouse with a low angle of rise in curvature (not too tall in height) and of suitable size.<br><br>*Comment:*<br><br>• Place the mouse at the correct working height and in a manner that the desk serves as a forearm support. | <br><br> |

Table 19: Continued

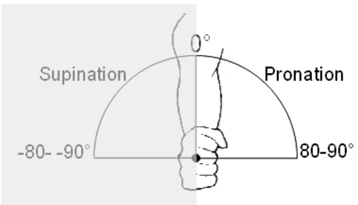
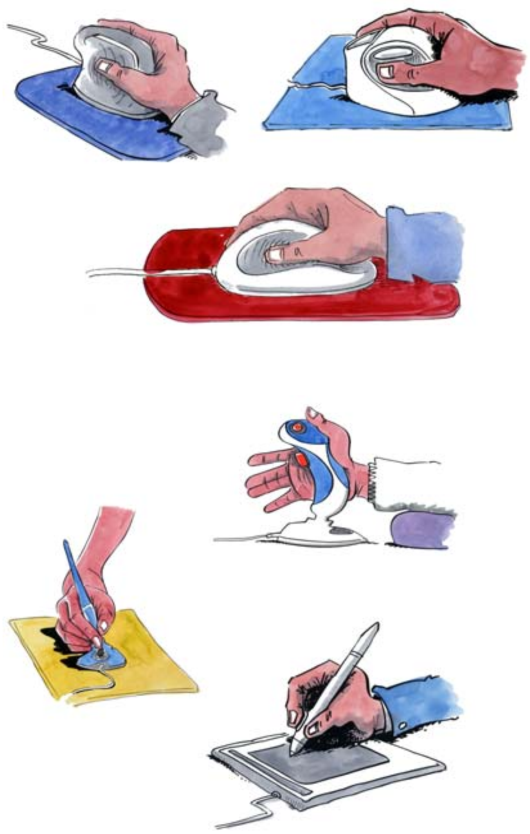
| **A Deviation from neutral posture** | | |
|---|---|---|
| | **Measure** | |
| **A II**<br><br>Forearm pronation<br><br> | • Choose a mouse with an optimized design or choose an alternative pointing device.<br><br>*Comment:*<br><br>• Pointing devices that reduce pronation include e.g. joystick mice, stylus-type mice, alternative mice with a shape that sinks to the outside (toward the elbow) or pen-tablet designs.<br>• Alternative pointing devices may require a period for the user to adjust. User preferences should be taken into consideration.<br>• Alternative pointing devices usually have to be chosen specifically for right- or left-hand use. |  |

Table 19: Continued

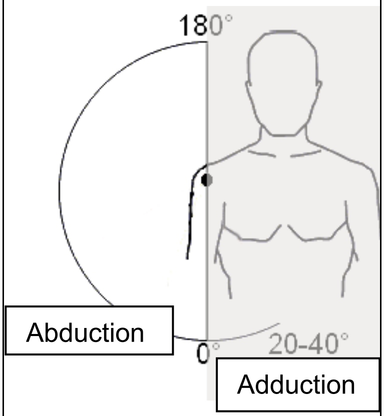
| A Deviation from neutral posture | | |
|---|---|---|
| | **Measure** | |
| **A III**<br><br>Arm abduction<br><br> | • Improve mouse position (shoulder breadth) by:<br>o Using a compact keyboard without a numeric keypad<br>o Using the mouse with the left hand (if a numeric keypad is on the keyboard).<br>• Use a mouse pad to define the workspace.<br>• Use a trackball as a fixed-location pointing device, see also Section 3.4.3, page 59.<br><br>*Comment:*<br><br>• Separate numeric keypads are available, if necessary.<br>• It takes practice to use the mouse with the left hand.<br>• While working with a mouse, the hand operating it often "wanders" unconsciously outside the ergonomically pre-ferable working area. The use of a mouse pad helps to keep the mouse positioned consciously at a better location.<br>• If an activity requires only mouse work, the keyboard can be moved aside to allow the work to be performed at shoulder breadth. | <br> |

Table 19: Continued

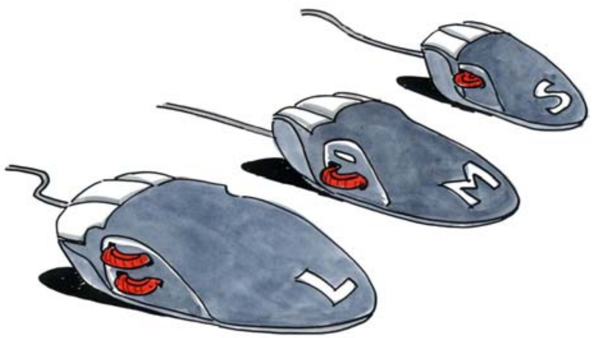
| A Deviation from neutral posture | | |
|---|---|---|
| | **Measure** | |
| **A IV**<br><br>Finger abduction | • Choose a mouse designed with a button arrangement suited to the individual or individual job.<br><br>*Comment:*<br><br>• In particular for mouse designs with additional buttons, attention needs to be paid that these can be depressed with a finger posture that is as neutral as possible. | |
| **A V**<br><br>Cramped finger posture | • Choose a mouse that matches the size of the hand.<br><br>*Comment:*<br><br>• If the mouse is too small, there is a risk that users will hold their fingers in a bent, cramped posture ("claws"). |  |

Table 19: Continued

| B Force exerted | | |
|---|---|---|
| | **Measure** | |
| **B I**<br><br>Disproportionate effort exerted | • Choose a mouse whose buttons are operated by a force of 0.5 to 0.8 N.<br>• Check button behaviour.<br>• Select a mouse that slides or moves easily.<br>• Avoid raising the mouse frequently to adjust its position.<br><br>*Comment:*<br><br>• The amount of force necessary to depress the buttons should not be too high, but nor should it be too low, because the latter situation would make it impossible for users to rest their fingers on the buttons for fear of inadvertently activating them (see B II). There are mouse buttons with different behaviours, and the manufacturer should be contacted for more information. Current research suggests that kinaesthetic feedback (a perceptible pressure point) is an advantage.<br>• Generally, an optical mouse is easier to move than a mouse with a rolling ball inside. Dirt on the underside of the mouse or on the working area (desk surface) can restrict mouse movability. | |

Table 19: Continued

| B Force exerted | | |
|---|---|---|
| | **Measure** | |
| | • Frequent adjustments in the mouse position are made necessary by unconscious "wandering" beyond the preferred work area (see A III) or by a work area that is too small. Correcting these problems helps to avoid the need for picking up and moving the mouse. | |
| **B II**<br><br>Static finger posture | • Choose a mouse that balances the properties of effort required to depress the buttons and buttons that serve as a place to rest the fingers.<br>• Choose a more suitable mouse design.<br>*Comment:*<br>• If the force necessary to depress the buttons is too low, users cannot rest their fingers on the buttons for fear of inadvertently depressing them. This means that users have to hold their fingers above the buttons the whole time, which may cause severe local muscle fatigue and strain.<br>• If the mouse is too small, for instance, users cannot rest their fingers on the mouse when the fingers are idle. | |

Table 19: Continued

| B Force exerted | | |
|---|---|---|
| | **Measure** | |
| **B III**<br><br>Static arm postures | • Use the mouse with the forearm supported.<br>*Comment:*<br>• Match the size of the mouse to the size of the hand so as to allow the heel of the hand to rest on the desk surface.<br>• The arm rests of the chair serve as forearm supports for this purpose. Fixed arm rests should be sloped forward for the different body dimensions of different users. The design of these supports should not hinder users in carrying out their job tasks. Height- and width-adjustable arm rests permit better fit.<br>• The area for moving the mouse (the mouse pad) should be at the same height as the keyboard. | |

Table 19: Continued

| C Repetitive movements | | |
|---|---|---|
| | **Measure** | |
| **C I**<br><br>Long periods of mouse use | • Design activities to be diverse and varied.<br>• Alternate mouse use between the right and left hands.<br>• Use different input devices, such as the keyboard (shortcut cursor keys), alternative pointing devices, including joystick mice, stylus-type mice, trackballs, pen-tablets, etc.<br>• Use suitable software.<br>*Comment:*<br>• It takes a certain amount of practice to learn to use the mouse with the non-dominant hand. Experience shows that gross motor movements, such as scrolling or clicking on large fields, can be performed practically from the beginning by using the non-dominant hand.<br>• There are keyboards available that have function keys that can in part replace mouse action. Suitable software is available that replaces mouse double-clicking with single clicks, or that supports the assignment of shortcut key combinations to the keyboard. | |

# 5 Conclusions and outlook

A literature survey was performed on the initiative of the VBG (Institution for Statutory Accident Insurance and Prevention in the administrative sector); the survey aimed to review the current state of the research on the ergonomics of computer input devices and input device testing on the basis of biomechanical and physiological criteria. The survey first compiled information from studies on keyboards, computer mice, pen-tablet devices and hand or arm supports.

Generally, work-related health risks and the appearance of occupationally related complaints in the musculoskeletal system of the hand, arm, shoulder and neck can be avoided by following all the recommendations of the publication BGI 650 “Bildschirm- und Büroarbeitsplätze – Leitfaden für die Gestaltung", which offers guidelines for designing display screen and office workplaces. Yet complaints and limitations on the use of input devices caused by repetitive movements or long periods of muscle tension in unfavourable postures are reported in individual cases, especially by employees suffering from acute or chronic disease resulting from non-occupational sources.

In order to keep the stresses and strains in such individual cases to a minimum, it is important to facilitate the use of computer input devices in a nearly neutral body posture with the lowest possible muscle activity. This can only be achieved with the aid of a suitable design and good position of the devices as well as with good working techniques:

- Keyboard: an ergonomic split design with the keyboard halves turned outwards and with a slightly elevated tent-like rise between them results in a more neutral hand and forearm posture. In contrast to the information provided in the standards, studies showed that a negative keyboard slope away from the user should be recommended. All of these studies were limited to test subjects who were proficient in typing by using the "blind", ten-finger method.

- Mouse: It is suggested that the mouse be positioned as close as possible to shoulder breadth, and closely adjacent to the keyboard. Using a mouse in combination with a keyboard that lacks a numeric keypad facilitates a more neutral body posture. It is also recommended that the mouse be used by the left hand.

- Trackballs and pen-and-tablet devices are sensible alternatives to computer mice.

- Hand and arm supports: It is suggested that the forearm be supported when using input devices. No uniform suggestions were found to specify the size of such forearm supports. Studies that documented contradictory or negative assessments of forearm supports often used more or less complicated designs [32; 99 to 101]. Elaborate designs could be a hindrance, especially if different working postures are needed for frequently changing job tasks [103]. It is apparently sufficient for the forearms (or, at least, portions of the forearms) to be allowed to rest on the desk by moving the keyboard away from the edge of the desk, and this recommendation should thus be taken into consideration for ergonomic workplace design (see also Keyboard checklist, B III, page 79).

In any intervention aimed at the use of input devices, the overall ergonomics of the workplace should be kept in mind. It should also be taken into consideration that one solution will not necessarily be good for all users. Individual work techniques, anthropometrics, different preferences and the variety of job tasks all influence posture and the use of input devices.

As a result of the literature study, a checklist of biomechanical and physiological criteria was compiled for choosing and using keyboards and mice, and the checklist also offers suggestions for the direction of discussions on the existing standards. The results of the literature survey suggest that it would be helpful for further projects to investigate the correct implementation of negative keyboard slope and to study the ideal dimensions of arm supports.

# 6 Directory of key terminology and abbreviations

**Explanation for** **Page**

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# Annexe

The following contains brief summaries of the literature reviewed on keyboards, computer mice, trackballs, pen-and-tablet devices and hand/arm supports. Most of the summaries refer to the sections of the literature discussed to in this report. Additional information is provided for a few articles that were not cited – even if they were not explicitly mentioned to in this report – because these contributed to the general review. These sections of the literature are marked in the "No." column by their lack of numeration.

## Annexe A: Contents of the literature – Keyboard

| Literature section | No. | Content | Score |
|---|---|---|---|
| Anonymus: Der Trick mit dem Knick – Ergonomische PC-Tastaturen. Test (1996) No. 7, pp. 40-44 | 39 | Eight ergonomic keyboards were tested by 50 test subjects.<br><br>Three basic settings were considered to be important for relaxed work:<br>lateral angle, positive slope and having the halves of the keyboard turned outward.<br><br>The simplest solution is an ergonomically shaped, but non-adjustable keyboards.<br><br>Summary:<br>The majority of test subjects would prefer to use an ergonomic keyboard. Nearly half experienced less strain in the joints of the shoulder, arm and hand when using the ergonomic keyboards than when using traditional models. At least one third reported that they could not tell any difference. | A non-scientific study |
| *Cail, F.; Aptel, M.:* Biomechanical stresses in computer-aided design and in data entry. Int. J. Occup. Saf. Ergon. 9 (2003), pp. 235-255 | 33 | The following tests were performed with 56 test subjects:<br>Surveys on complaints and work organisation, ergonomic trials (e.g., workplace design), EMG (flexors of the hand and fingers, extensors of the wrist, *M. trapezius*), electrogoniometry (wrist postures with regard to extension/flexion and ulnar/radial deviation), video recordings (abduction of the right arm from behind), number of repetitive movements in the wrist. The measurements were taken at the workplace, performed two to three times and lasted 10 minutes each. The trials studied data entry (only women) and other computer-based work (CAD) (men only). On average, the subjects worked for around 6.5 hours per day on the computer: data entry mostly using a keyboard (62% keyboard, 12% mouse), CAD mostly using a mouse (81%, 10% keyboard).<br><br>Data entry:<br>A total of 42% of subjects used a wrist support at the keyboard, and when using the mouse, the forearm of 93% of subjects rested on the desk.<br><br>CAD:<br>When using the mouse, the forearm of 80% of subjects rested on the desk. 20% of subjects used a wrist support at the keyboard.<br><br>Mouse position:<br>Distance between the user and the mouse was on average 40 cm. Around half of test subjects were of the opinion that the mouse was too far away from their upper bodies as they worked.<br><br>Complaints:<br>50% of female subjects (data entry) and 33% of male subjects (CAD) reported | 2 |

| Literature section | No. | Content | Score |
|---|---|---|---|
| | | discomfort in the cervical spine area; 62% and 43%, respectively, in the area of the right upper extremities, 35% and 10% in the area of the left upper extremities.<br><br>Postures:<br>• Wrist extension:<br>Keyboard: data entry 33 ± 8°, CAD 28 ± 6°<br>Mouse: data entry 26 ± 10°, CAD 33 ± 8°<br>• Ulnar deviation:<br>Mouse: data entry -5 ± 6°, CAD -6 ± 11°<br>Keyboard: data entry 0 ± 5°, CAD: 10 ± 9°<br>• Shoulder abduction:<br>Mouse: data entry 30 ± 1°, CAD 34 ± 4°<br>Keyboard: data entry 25 ± 8°, CAD: 24 ± 5°<br>(In comparison to other studies, the values here were so high and widely varied because the office furniture did not allow individual adjustments.)<br><br>EMG:<br>In the flexors, there were significant differences between data entry (mouse 6% MVC, keyboard 13% MVC) and CAD (mouse 19% MVC, keyboard 24% MVC). (This difference may be due to the fact that only women were measured for data entry and only men for CAD work.)<br><br>Repetitive movement:<br>Data entry required significantly more repetitive movement.<br><br>Individual variability:<br>Major individual differences were observed both in the exerted force and in the postures.<br><br>Relationship between complaints and biomechanical measurements:<br>During date entry a significantly larger extension (37º) was found amongst test subjects with pain in the wrist than amongst those without such complaints (26º).<br><br>Summary:<br>Stress associated with mouse use is above all caused by shoulder posture, for keyboard use it is due to repetitive movement and muscular strain in the shoulders. This study established a relationship between complaints in the wrist and the size of wrist extension. Major individual differences were found.<br><br>Problematic in this study was that CAD trials were only done with men and data entry trials only with women as test subjects. | |

| Literature section | No. | Content | Score |
|---|---|---|---|
| *Fagarasanu, M.; Kumar, S.; Narayan, Y.*: The training effect on typing on two alternative keyboards. Int. J. Ind. Ergon. 35 (2005), pp. 509-516 | 40 | The influence of training of eight hours in text entry was studied on 30 test subjects. Three different keyboards were used in the study:<br>• A: Standard<br>• B: Keyboard with an outward turn (12º), lateral angle (10º), central numeric keypad<br>• C: Keyboard with variable outward turn angle and lateral angle (measured at 25º outward turn, 0º lateral angle).<br>Measured were body postures (electrogoniometer), muscle activities (EMG), force and performance.<br><br>Performance:<br>The training had a significant influence on typing performance.<br>After eight hours of training, typing speed on keyboard B improved from 30 to 44%, on keyboard C from 60 to 89%. This corresponded to an increase of 48%. The error rate was reduced by 27%.<br><br>Posture:<br>No significant differences were identified in hand and arm postures along all three planes after the training period.<br><br>Force:<br>The training reduced the force exerted on two keyboards: on C by 58% from 2.27 to 0.97 N; on B by 42% from 9.92 to 5.84 N.<br><br>EMG:<br>The training showed no significant effects here.<br><br>Results:<br>Keyboard B generally performed slightly worse than keyboard C. | 3 |
| *Gerard, M.; Armstrong, T.; Foulke, J.; Martin, B.:* Effects of key stiffness on force and the development of fatigue while typing. Am. Ind. Hyg. Assoc. J. 57 (1996), pp. 849-854 | 7 | This study is less conclusive, and its analysis is questionable.<br><br>The difference between two altered keyboards with different amounts of necessary force to operate the keys (0.28 and 0.83 N) was studied.<br><br>Study design:<br>Six healthy students, using the ten-finger typing method.<br>The test subjects were asked to type at the same rate the whole time. The force, muscle activity in the finger flexors and extensors and performance were measured.<br><br>Summary:<br>Under all conditions, the force exerted was greater than needed. On the 0.83 N keyboard, 54% greater force peaks were measured than on the 0.28 N keyboard. | 2 |

| Literature section | No. | Content | Score |
|---|---|---|---|
| | | The EMG recorded 34% greater peaks for finger flexors and 2% greater peaks for finger extensors. The highest values (peaks) and 90 percentile values showed similar trends. | |
| *Gerard, M.; Armstrong, T.; Franzblau, A.; Martin, B.; Rempel, D.:* The effect of keyswitch stiffness on typing force, finger electromyography, and subjective discomfort. Am. Ind. Hyg. Assoc. J. 60 (1999), pp. 762-769 | 43 | Twenty-four practiced keyboard users were measured when using keyboards requiring different amounts of force (0.28 N, 0.56 N, 0.83 N).<br>Study design:<br>The control keyboard (used at the workplace) required a force of 0.72 N. Each keyboard was used by the test subjects for seven days at their workplaces. The force, EMG and subjective comfort were determined before and after.<br>Long-term test:<br>Seventeen test subjects preferred the old keyboard (0.72 N) afterwards; four chose the 0.28 N keyboard; three the 0.56 N keyboard. Those who preferred the 0.28 N and 0.56 N keyboards continued to use these at their workplaces and were tested again after four months.<br>Summary:<br>The increase in the necessary force from 0.28 to 0.83 N resulted in a 32% increase in exerted effort. The EMG values measured each rose in the 90 percentile group by 20% for finger flexors and 9% for finger extensors. The relationship between exerted force and necessary force was thus approximately 3.8 : 1. The perceived general discomfort for the 0.83N keyboard was greater than for all the others. No major differrences were found between the 0.28 and 0.72N keyboards. Yet, it must be taken into consideration that the 0.72N keyboard differed from the former also in the other key behaviours (the existence of a snap function and acoustic feedback for key actuation). Values in the EMG of the extensors were recorded as between 6.3 and 6.8% MVC during continuous typing. The adjustment to keyboards with keys requiring a lower force for operation took several weeks of use.<br>Problems:<br>The keyboards also were not uniform with regard to their key switching behaviours (different feedback and force curves); long-term effects were not measured in a scientifically appropriate fashion (no control group). | 2 |

| Literature section | No. | Content | Score |
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| *Gilad, I.; Harel, S.*: Muscular effort in four keyboard designs. Int. J. Ind. Ergon. 26 (2000), pp. 1-7 | 5 | Four keyboards with different properties were tested: "flat" (conventional), "negatively sloped", "Tony" (turned outward with lateral angle, positive slope in the sagittal plane) and "apart" design (splitted keyboard with space between the two halves, with lateral angle and negative slope in the sagittal plane).<br><br>Study design:<br>Seven test subjects were asked to type for around ten minutes. Muscle activity (EMG), performance and subjective comfort were measured.<br><br>Summary:<br>The keyboard design with a negative slope of around -10º did very well in the objective measurements and in the subjective impressions of comfort: The muscle activity of flexors measured in the EMG were 36% below those during the use of "Tony" and 58% below those during the use of the splitted keyboard halves. Furthermore, 28% lower muscle activity was reported in the extensors than with "Tony". Performance was best when using the design with a negative slope of around -10º (27% better than with a conventional keyboard, 64% better than with "Tony" and 60% better than with a splitted keyboard). The negatively sloped keyboard was well received, as the design was similar to that of a conventional keyboard. For *M. trapezius*, higher muscle activity was measured in the EMG on all three alternative designs than on the traditional keyboard. Possible explanations for this may be that the hand position required for the three alternative designs did not allow the forearms to rest on any surface, or that the height adjustments of the workplace were not ideal. The imprecise slope angle information for the individual settings were a problem with the study. | 2 |
| *Hedge, A.; Powers, J.*: Wrist postures while keyboarding: effects of a negative slope keyboard system and full motion forearm supports. Ergonomics 38 (1995), pp. 508-517 | 32 | Study design:<br>The study worked with 12 test subjects under three sets of conditions: typing on a conventional keyboard without arm supports (CK); typing with adjustable forearm supports that supported the full range of motion (FMFS: free-moving forearm supports – movable on the horizontal plane); typing on an adjustable, negatively sloped keyboard (NSKS with integrated support for the heels of the hands). The test subjects were allowed to set the adjustments themselves (self-adjusted slope angle of -12 ± 0.4º). The posture, performance and subjective perception were recorded.<br><br>NSKS:<br>Wrist extension was significantly reduced (CK +13º stretch, NSKS -1.2º bend). Significant differences were identified in the elbow angle and ulnar deviation as well as in typing accuracy and speed. There were no negative reactions in the reported subjective perception. | 2 |

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| *Marcus, M.; Gerr, F.; Monteilh, C.; Ortiz, D. J.; Gentry, E.; Cohen, S.; Edwards, A.; Ensor, C.; Kleinbaum, D.*: A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. Am. J. Ind. Med. 41 (2002), pp. 236-249 | 34 | An epidemiological study with 632 newly hired workers at eight companies spent three years investigating the relationship between different conditions at the work-place and musculoskeletal complaints. Data on the workplace and on working methods were recorded at the beginning of the study and any time changes in work or workplace format. A checklist and a goniometer were used as aids. The test subjects filled out a questionnaire on a weekly basis on the work they had performed and their symptoms. Any time subjects reported symptoms in the neck, shoulder and hand/arm regions, they were checked by a physician for specific complaints.<br>Neck/shoulder symptoms:<br><br>Identified as risk factors for symptoms were: Keyboard placed higher than the elbow, elbow angle for the mouse arm < 137 to 148°, head angle > 3° (when facing forward horizontally to view the screen, the angle of the head is 10°, i.e., a 3° head angle means the individual is viewing a display screen below the horizontal plane), the presence of a shoulder telephone holder. Fewer symptoms were reported when the observed elbow angle during keyboard use was > 121°, but the risk increased again with increasing weekly working hours (e.g., at 20 hours/week).<br>Hand/arm symptoms:<br><br>A greater risk was found amongst test subjects who used a wrist support. In contrast, the risk was decreased when the keyboard was placed at least 12 cm back from the edge of the desk, so that at least part of the forearms could rest on the desk. At the same time, a lower correlation was identified between increased risk of symptoms and keyboard height: If the "J" key was elevated more than 3.5 cm above the desk surface, the test subject registered more complaints. It was also found that a radial deviation > 5° came with greater risks than a neutral wrist posture between -5 and 5°. | 3 |
| *Marklin, R.; Simoneau, G.:* Effect of setup configu-rations of split computer keyboards on wrist angle. Phys. Ther. 81 (2001), pp. 1038-1048 | -- | Studied were four different keyboard adjustments with regard to the outward turn of the keyboard halves and the distance between them measured as the distance between the keys E and P.<br>• CV = Conventional keyboard (0° outward turn, distance 15.25 cm).<br>• S-20 = Distance between the keys E and P on the two keyboard halves at 20 cm. The outward turn was selected so that a neutral position for radio-ulnar deviation was theoretically possible, whereby the 20 cm distance was reduced. | 2 |

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| | | • S-MID = The keyboard halves were placed at half the distance between the conventional keyboard and shoulder breadth. Outward turn was set so that a neutral position on the radio-ulnar plane was theoretically possible.<br>• S-SW = The distance between the keyboard halves was set at shoulder breadth. The halves were in line with one another.<br><br>Study design:<br>Eleven test subjects performed tasks that lasted 30 seconds. The median, maximum and minimum ulnar deviation of the right and left wrists, the typing speed and accuracy as well as perceived discomfort were measured.<br><br>Wrist ulnar deviation:<br>No difference was discerned between the three alternative keyboard arrangements (left 7.7 to 8.5º, right 2.7 to 5.0º). The median angle of ulnar deviation was smaller on the three alternative arrangements than on the conventional design (CV: left 18.9º, right 14.2º).<br><br>Typing speed and accuracy remained unaffected by the four keyboard designs.<br><br>Subjective perception of comfort and/or reports of pain or discomfort differed only with regard to neck complaints. The CV arrangement gave rise to more complaints (0.92) than was the case with the alternative arrangements (0.31 to 0.62). These findings may possibly be explained in that the test subjects maintained an inward rotation of their shoulders when working with the alternative keyboard arrangements.<br><br>Problems:<br>The sample size, duration of the task and the measured differences were all too small to make a distinction amongst the three alternative keyboard arrangements. | |
| *Marklin, R. W. Simoneau, G. G.*: Design features of alternative computer keyboards: A review of experimental data. J. Orthop. Sports Phys. Ther. 34 (2004), pp. 638-649 | 24 | The review article deals with different alternative keyboard designs: keyboards with an outward turn, slope, separate halves and lateral angle.<br><br>The following postures were measured on the conventional design:<br>wrist extension 20º, ulnar deviation 10 to 15º, pronation: almost total.<br><br>Outward turn:<br>At around 12.5º (total 25º for both halves), wrist ulnar deviation of nearly 0º was achieved; the increase in the outward turn of the keyboard halves corresponded approximately 1 : 1 with the decrease in ulnar deviation. The influence on typing performance was minimal. The test subjects got used to the new conditions in six minutes. | Review article |

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| | | Separate keyboard halves:<br>The halves could be separated from one another at shoulder's breadth, thereby theoretically eliminating ulnar deviation. Yet data on this were provided in only limited form.<br>Keyboard slope:<br>A slope of -7.5º gave rise to a nearly neutral hand posture in terms of extension in the wrist, which test subjects perceived as the most comfortable posture. Typing performance was almost unchanged. Greater negative slope resulted in a lower increase in ulnar deviation accompanying the decrease in wrist extension.<br>Lateral angle:<br>Test subjects were allowed to set the angle themselves, and they chose an angle on average of 27.8º left, 32.8º right. This gave rise to a forearm pronation of around 40º, around 22º less than on conventional keyboards. A slight loss in typing speed, however, was also reported. Acceptance varied very widely amongst individuals. Aside from the reduction in forearm pronation, lower ulnar deviation was also reported. The article also mentions that CT (carpal tunnel) pressure is the lowest at 45º pronation.<br>The long-term effects remain unclear. | |
| *McLoone, H.; Jacobsen, M.:* Innovation and design process for a fixed-split ergonomic keyboard. Ed.: Microsoft Corporation USA | 36 | Different combinations of lateral and sagittal angles (and outward turn angles) were tested for a fixed-split ergonomic keyboard in the framework of a design process.<br>Study 1 was performed with 13 test subjects. Different arrangements for the keyboard halves were tested under the following conditions: lateral angles of 8, 10 and 12º; sagittal angles: positive, 0º and negative.<br>Furthermore, several keys were arranged differently, and the shape was modified in part ("gull wings") so as to achieve a moulded, concave profile. A wide support for the heels of the hands was tested in the following heights: 0, 7, 14, 21, and 28 mm. Test subjects were asked to report their subjective preferences.<br>Results of Study 1:<br>Test subjects preferred a steeper lateral angle. They liked the new key shapes. As for sagittal angle, one third each preferred the positive, negative and flat versions. Only the 7 and 14 mm high versions of the supports for the heels of the hands were accepted; the 21 and 28 mm high versions were perceived to be too high, as they made it difficult to depress the space bar. | 1 |

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| | | Study 2 was also performed with 13 test subjects, but these were different than in the first study. Even larger angles were tested this time: lateral angles of 8 to 16º in 2º increments. The heights of the hand-shaped supports were set at 0, 7, 10 and 14 mm. The keyboards had the "gull wing" key shapes.<br><br>Results of study 2:<br>The slope angle of 14º performed best in the judgments of the test subjects, followed by 16 and 12º; 8 and 10º were also accepted, in contrast to 18º. Test subjects liked the key shapes and accepted a hand heel support that was 7 and 10 mm in height. In contrast, 14 mm was perceived as too high.<br><br>Summary:<br>The following parameters were selected for the design of a keyboard with halves that were not adjustable relative to one another: The lateral angle should be between 12 and 14º (also for individuals with smaller hands). A height of 7 mm was set for the hand heel support rests. 22 of 23 test subjects preferred the "gull wing" keys. Sagittal slope can be set positively, negatively, or at zero. | |
| *Nelson, J.; Treaster, D.; Marras, W.:* Finger motion, wrist motion and tendon travel as a function of keyboard angles. Clin. Biomech. 15 (2000), pp. 489-498 | 41 | The keyboards were turned outwards at different degrees (0º, 15º, 30º), sloped (0º, 12.5º, 25º), laterally tilted (0º, 15º, 30º) and the keyboard halves were separated at different distances (0 cm, 9.2 cm, 18.4 cm).<br><br>Thirty different combinations were studied. Fifteen test subjects were available; each was given a standardized text to enter for a maximum of three minutes. Measure-ments were taken using optoelectric finger goniometers, wrist and finger monitors, from which tendon travel was derived. Participants were also given a questionnaire to fill out.<br><br>The results in general: Minimal tendon travel was identified in conjunction with the greatest positive slope and moderate lateral angle. Significantly more tendon travel was found for 0º slope and outward turn. Furthermore, tendon travel was low when the keyboard slope was 0º and the lateral tent-shape was simultaneously high. Greater positive slope resulted in greater dorsal extension of the wrist and the associated corresponding greater flexion in the fingers. This combination could reduce the contribution of movement in the flexor tendons. There were major individual differences, and different designs of keyboards were thus suggested (e.g., for finger segments of varying lengths).<br><br>Faster typing causes more movement and, hence, also greater tendon travel.<br><br>Problem: How significant is the relevance of tendon travel? What does the tendon travel actually indicate? | 2 |

<table>
<tr><th>Literature section</th><th>No.</th><th>Content</th><th>Score</th></tr>
<tr><td>Rempel, D.; Tittiranonda, P.; Burastero, S.; Hudes, M.; So, Y.: Effect of keyboard keyswitch design on hand pain. J. Occup. Environm. Med. 41 (1999), pp. 111-119</td><td>44</td><td>This study investigated the difference in the force-distance behaviour of the keys. Twenty patients with paresthesia of the hand (potentially CTS – carpal tunnel syndrome) worked for 12 weeks using two different keyboards (A and B) with different force-displacement characteristics in the keys: The keys of A had greater key displacements to reach the point P1 (the point requiring minimum force to be exerted) than B. On keyboard A, this contributed to a feeling of more relaxation when the fingers were able to rest on the keys because there was less risk that the keys would be inadvertently depressed. At the end of the curve (i.e., after P2, the deepest force point after P1), keyboard A also showed a lower increase in stiffness than B (i.e., the keys on A had more cushioning when they struck the base of the keyboard, which influenced the sensation of strike force).<br><br>After 12 weeks, keyboard A was rated higher amongst test subjects with complaints than keyboard B (decrease in pain on A, increase in pain on B).<br><br>A keyboard with a long distance to P1 and a less steep increase in stiffness at the end of the key travel is recommended for users with hand paresthesia.<br><br>Problem:<br>The effects were only very minor.</td><td>3</td></tr>
<tr><td>Simoneau, G. G.; Marklin, R. W.: Effect of computer keyboard slope and height on wrist extension angle. Hum. Factors 43 (2001), pp. 287-298</td><td>30</td><td>The variations in the slope of the keyboard (+15, +7,5, 0, -7,5 and -15°) were tested on 30 test subjects, and the positions of their wrists relative to the elbow (wrist at even height with the elbow, 5 cm above it and 4 cm below it) were studied. The wrist supports were not sloped along with the keyboards. The test subjects were asked to enter text for 13 minutes per keyboard (with a break in between).<br><br>Typing speed and accuracy:<br>No significant differences were measured. Test subjects got used to the new situation after five minutes.<br><br>Conclusion:<br>The wrists should be at an even height with the elbows to support a neutral hand posture. When the wrists are higher, wrist extension is reduced, but problems may arise in the neck in return. The recommended slope for the keyboard is -7.5 or -15º. Yet this negative position causes a slight increase in ulnar deviation.</td><td>2</td></tr>
<tr><td>Simoneau, G. G.; Marklin, R. W.; Berman, J. E.: Effect of computer keyboard slope on wrist position and forearm electromyography of typists without musculoskeletal disorders. Phys. Ther. 83 (2003), pp. 816-830</td><td>25</td><td>Fifteen test subjects were asked to type on different keyboards for nine minutes each. A conventional keyboard was used that was set at different slope angles (7,5°, 0°, -7,5°, -15º). The keyboard was fitted with an integrated wrist support (it tilted along with the keyboard, but it was conceived more for the control of the wrist height relative to the elbow, and it was not meant for use during typing). Measured</td><td>2</td></tr>
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| | | here were muscle activity (EMG), wrist posture (electrogoniometer), performance and personal discomfort.<br><br>Wrist extension decreased with negative keyboard slope at a ratio of 1 : 2.<br><br>No decreases were found in typing speed and accuracy. A keyboard slope of -15° was judged to be less comfortable in comparison to other angles. | |
| *Smith, M.; Karsh, B.; Conway, F.; Cohen, W.; James, C.; Morgan, J.; Sanders, K.; Zehel, D.:* Effects of a split keyboard design and wrist rest on performance, posture, and comfort. Hum. Factors 40 (1998), pp. 324-336 | -- | Eighteen test subjects tried out two keyboards over five days: a conventional one and an alternative design (separate numeric keypad, separate halves: inside front corners 9 cm apart, inside back corners 4.5 cm apart, inside front corners elevated by 8 cm, inside back corners raised 12.5 cm, outside front corners raised 1.5 cm). Half of the test subjects worked with wrist supports, the other half without. Wrist positions were measured using video, performance and subjective comfort were also recorded.<br><br>With just a little bit of practice (two hours), performance on both keyboards was the same. Somewhat fewer complaints were registered in the evenings from those using the alternative keyboards. Moreover, slightly larger angles for hand stretching (right and left) and radial deviation were observed, yet with smaller angles for ulnar deviation and pronation. All differences, except for pronation, were very slight.<br><br>Problem:<br>Measurements proved to be imprecise. | 2 |
| *Sommerich, C.; Marras, W.; Parnianpour, M.:* Observations on the relationship between key strike force and typing speed. Am. Ind. Hyg. Ass. J. 57 (1996), pp. 1109-1114 | -- | According to a variously stated hypothesis, human tendons are not capable of tolerating more than 1,500 to 2,000 movements (contractions and expansions) per hour (23 to 33 per minute). This study aimed to investigate the relationship between force exerted and typing speed.<br><br>Two trials were performed to do this:<br>The first was conducted at a workplace with 25 test subjects who were asked to work at their own preferred pace for 60 to 90 minutes, partly with one hand, partly with two. The other trial was conducted in a laboratory with five test subjects. These five subjects were asked to type at different predetermined speeds on keyboards with different arrangements. The typing speed and the force exerted were measured.<br><br>No general relationship was found between force and typing speed at the users' preferred pace. Changes were only identified when specific tasks were given as described for the second trial above. | 2 - 1 |

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| *Stack, B.*: Keyboard RSI: the practical solution. Muden Publishing Company, Tasmania 1987 | 31 | The book is about the risk factors for RSI (repetitive strain injury) and presents measures against RSI. The point is made that there are no generally applicable instructions. The individuality of different workers is too large, and the individual traits are marked by height and weight, age, gender, sensitivity (different critical points), working environment, work technique, job, etc. For ergonomic improvements to succeed in the fields of workplace equipment, furnishings, lighting, posture and work performance, three additional components are needed: manufacturers, employers and employees.<br><br>Recommendations:<br><br>Keyboard shape:<br>Keyboards should be concave in profile so that all the rows of keys can be easily reached. The shape of the individual keys should also be slightly concave; the size should match the size of the fingertips. The "home row" of keys – the keys where the fingers rest as a starting point – should feel different than the other keys so that users can feel their way to the right starting points after a break without the user having to look at the keyboard. This is the only way that users will tend to take their fingers off of the keyboard after a break. The front edge of the keyboard should be as flat as possible.<br><br>Keystroke force:<br>A keyboard that is operated with a light touch has the advantage that users can type very quickly without great effort, but the problem is that users tend not to rest their fingers on the keyboard during short breaks for fear of inadvertently typing. This makes the effort of holding up the forearms greater. A wrist support (see below) and a negative keyboard slope can provide relief. Users do not rest their fingers vertically on the keys on such a slope, i.e., the direction of force is not the direction that force needs to be exerted to strike the keys.<br><br>Keyboard position:<br>The user should sit in the middle in front of the portion of the keyboard used most often (letter keys). Ideally (most important for the author), the keyboard should be negatively sloped. The degree of slope is different for different users (depending on his or her size, the relative distance from forearm to upper arm, the typing method, etc.). On average, the slope would be from 5 to 10º.<br><br>Keyboard add-ons:<br>In particular for an ultra-sensitive keyboard that requires only a very low amount of force for typing, the author recommends using a wrist rest or support so that the heels of the hands can rest in a good position during short typing breaks. This hand support add-on should, however, be correctly placed and shaped; it should be | Not a scientific study: book version of an individual's personal experiences |

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| | | specifically matched to the keyboard: its slope should match the slope of the key-board, the height should be the same, it should be at least 70 mm deep (80 mm is better, or even larger for individuals with long forearms and large hands). The fore-arm and hand should form a straight line. A flat form should be preferred for the support, and it should preferably be made of wood or plastic (non-heat-conducting and without major friction). The add-on can also be integrated into the keyboard.<br>The desk should have adjustments for height and slope.<br>Chairs without arm rests are recommended for ten-finger typists.<br>Even the best equipment and ideal settings do not make breaks unnecessary! | |
| *Strasser, H.; Fleischer, R.; Keller, E.*: Muscle strain of the hand-arm-shoulder system during typing at conventional and ergonomic keyboards. Occup. Ergon. 4 (2004), pp. 105-119 | 26 | The study was conducted with ten test subjects. Compared were a conventional key-board (slope 5.5º) and a so-called ergonomic keyboard (Microsoft, turned outward by 24º, the halves slightly separate, slight lateral angle). The test subjects were asked to type text in six sittings of ten minutes each. The activity of several muscles was measured using EMG. The subjective assessments of the subjects were provided in a questionnaire.<br>The ergonomic keyboard produced a slight reduction in the activity of most muscles; the outward-turned keyboard provided benefits above all in the forearm and hand. The test subjects preferred the ergonomic keyboard after a short period of practice.<br>One problem may lie in the larger width of the so-called ergonomic keyboard because the arm must perform greater abduction in order to operate the computer mouse. | 2 |
| *Swanson, N.; Galinsky, T.; Cole, L.; Pan, C.; Sauter, S.:* The impact of keyboard design on comfort and productivity in a test-entry task. Appl. Ergon. 28 (1997), pp. 9-16 | 35 | Fifty test subjects typed for 300 minutes on three days using different keyboards:<br>One alternative keyboard was tested by ten test subjects each. If the keyboard did not have an integrated hand support, a separate one was provided.<br>Key:<br>Angle of outward turn = A, lateral angle = LA, distance between the letter keys G and H = G-H<br>• Keyboard A (standard): A = 0°, LA = 0°, G-H = 1.9 cm<br>• Keyboard B: like keyboard A, but with adjustable wrist supports<br>• Keyboard C:<br>A = 0°, LA = 9°, G-H = 19 cm, concave keyboard profile, approximately 7 cm hand support | 2 |

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| | | • Keyboard D:<br>flexible (A and LA adjustable, but not independent of one another and only adjustable with right and left together), A = 0°, LA = 12°, G-H = 3.8 cm<br>• Keyboard E: flexible (right and left, A, LA and distance adjustable independently of one another), A = 25°, LA = 45°, G-H = 10.8 cm.<br>At the beginning of the study, there was a loss of typing speed that had disappeared nearly entirely by on the second day. Test subjects had the most difficulties with keyboard C, which had a free-split design with the halves positioned far apart – around shoulder breadth – and a concave profile; this was followed by keyboard E, with keyboard halves placed far apart and LA set high. In terms of fatigue and discomfort, no great differences could be discerned.<br>In summary, no very great differences were identified during the two latter days. Are there advantages to alternative keyboards? Are the measuring methods sufficient? | |
| *Szeto, G.; Straker, L.; O'Sullivan, P.*: The effects of speed and force of keyboard operation on neck-shoulder muscle activities in symptomatic and asymptomatic office workers. Int. J. Ind. Ergon. 35 (2005), pp. 429-444 | 6 | Healthy test subjects and several with existing complaints – 41 in total – were asked to type for 20 minutes as they usually would and then quickly for 20 minutes, followed by 20 minutes using greater typing force. Muscle activity (EMG), speed, force and subjective discomfort were all determined.<br>Elevated muscle activity was identified during fast typing, above all in the neck-shoulder muscles on the dominant side. Test subjects with pre-existing complaints were found to have greater left-right differences, which indicated that the group of healthy test subjects had better control strategies. Forceful typing resulted in less increase in the measured muscle activity than was the case during faster typing.<br>The relevance of the given tasks is questionable. The externally imposed conditions may give rise to psychological stress that may have had an impact on the results of an unknown dimension. | 2 |
| *Tittiranonda, P.; Rempel, D.; Armstrong, T.; Burastero, S.*: Workplace use of an adjustable keyboard: adjustment preferences and effect on wrist posture. Am. Ind. Hyg. Assoc. J. 60 (1999), pp. 340-348 | 29 | Objectives of the study:<br>• To discover the preferences of computer users with regard to the arrangement of the keyboard<br>• To measure which changes in posture result from the preferred keyboard arrangement in comparison to conventional keyboard arrangements<br>The study was performed on 35 test subjects. The flexible-split keyboard was an "Apple Adjustable Keyboard": the halves could be turned outward up to 28º, the slope adjusted by 7º on feet. Wrist supports were affixed to the keyboard but could be removed. The numeric keypad was separate from the rest of the keyboard. Test subjects had seven to 14 days to try out the adjustments of the keyboard. | 3 |

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| | | 17% of computer users preferred an outward turn of 0 to 10°, 48% preferred 11 to 20° and 35 preferred 21 to 28°. No one used the feet under the keyboard to increase its positive slope. The group that turned the halves outward by 11 to 20° rated the keyboard significantly higher than those who turned it outward by 0 to 10°.<br>Summary for the keyboard with adjustable halves:<br>Causes less fatigue, more comfortable posture, fewer complaints.<br>No one found the adjustable keyboard to be worse than the conventional keyboard.<br>Positions closer to neutral zero with regard to wrist extension and ulnar deviation were observed more often on the alternative keyboard. | |
| *Tittiranonda, P.; Rempel, D.; Armstrong, T., Burastero, S.*: Effect of four computer keyboards in computer users with upper extremity musculoskeletal disorders. Am. J. Ind. Med. 35 (1999), pp. 647-661 | 38 | Eighty test subjects with CTS (carpal tunnel syndrome) and/or tendonitis participated in the study. Each subject used one keyboard for six months. Studied here were four different keyboards: Apple Adjustable Keyboard (Kb1) (slope of 3.8° or 7°, outward turn between the two halves of 0 to 28°, distance between the keys B and N of 2 cm), Komfort Keyboard System (Kb2) (slope of 44 to 38.5°, lateral angle of 0 to 90°, outward turn between the two halves of 0 to 360°, distance between the keys B and N of 2 to 36 cm), Microsoft Natural Keyboard (Kb3) (slope of 5.5 or 2.6°, lateral turn of 8.5 or 10°, outward turn between the halves of 12°, distance between the keys B and N of 8.2 cm), a placebo (slope of 8°).<br>The complaints with regard to general pain, tendonitis and CTS decreased on all of the alternative keyboards (CTS was slightly elevated on the placebo keyboard); Kb3 achieved a 50% improvement with regard to general pain, followed by Kb2 (40%) and Kb1 (35%).<br>Viewed from a clinical perspective, the use of alternative keyboards results in a tendency towards greater improvements, above all in tendonitis, but the tendency is not very significant. The changes were very different for different individuals. | 3 |
| *Treaster, D.; Marras, W.*: An assessment of alternate keyboards using finger motion, wrist motion and tendon travel. Clin. Biomech. 15 (2000), pp. 499-503 | 42 | Fifteen test subjects tested different keyboards: Microsoft Natural (slope 5°/-3°), Kinesis Keyboard (concave-curved keyboard sections – test subjects were allowed to practice for an hour on this one), standard keyboard (slope 5°/11°), Lexmark Keyboard (like a standard keyboard, but the halves of this fixed-split keyboard were turned outward from one another and slightly separated). The measurements took a maximum of three minutes each and consisted of standardized text entry tasks.<br>Tendon travel is expressed differently in different individuals, and the influence that keyboard formats could have on tendon travel is thus difficult to prove. Men appear to respond differently to keyboard slope settings than women do (not only because of their different anthropometrics). Tendon travel responded above all to changes in the | 2 |

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| | | slope of the keyboard. Negative keyboard slope resulted in significantly greater tendon travel than positive slope did.<br>It is difficult to derive clear statements based on this study because too many different comparisons were made. There were also different conditions for the trials: some were with wrist supports, others without. | |
| *Woods, M.; Babski-Reeves, K.*: Effects of negatively sloped keyboard wedges on risk factors for upper extremity work-related musculoskeletal disorders and user performance. Ergonomics 48 (2005), pp. 1793-1808 | 28 | Ten test subjects tested a standard keyboard with different slope angles: 7°, 0°, -10°, -20°, -30°. No wrist supports were used. The test subjects were asked to type for 15 minutes at each keyboard slope setting. The tests were repeated again a week later.<br>Wrist posture: The more negative the keyboard's slope, the less wrist extension was measured, but with all the more ulnar deviation. No significant differences were identified between 7 and 0º.<br>Gender-specific differences could not be identified: At -30º keyboard slope, the men had a 7.7º wrist extension, whereas the women had 0.3º wrist extension.<br>There were no great differences in the EMG.<br>No single optimal keyboard slope could be identified because the results were in part contradictory. Nevertheless, a negative slope appears to be advantageous with regard to hand posture and muscle activity, while performance was equal or better. | 2 |
| *Zecevic, A.; Miller, D.; Harburn, K.*: An evaluation of the ergonomics of three computer keyboards. Ergonomics 43 (2000), pp. 55-72 | 27 | Sixteen test subjects completed ten hours of training on different keyboards before participating in tests of 30 to 60 minutes in duration.<br>Keyboards:<br>• Standard (S)<br>• Fixed (F): 10° lateral and 0° sagittal slope, wrist supports present<br>• Open (O): each half turned outward by 15°, lateral angle approximately 42°<br>Body posture:<br>• Pronation: on S 57°, on F 52°, on O 34°<br>• Ulnar/radial deviation: on S 6° ulnar deviation, on F 3° ulnar deviation, on O 4° radial deviation<br>• Extension: on S 11°, on F 0°, on O 7° (significant differences)<br>Test subjects who showed extreme wrist extensions using keyboard S also assumed similar postures on the other keyboards. This indicates differences in individual patterns of movement and posture. On keyboard F, subjects' hands were primarily in the neutral range (extension/flexion ±10º, ulnar deviation -15º, radial deviation 5º). | 3 |

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| | | Test subjects on keyboards S and O tended to hold moderate or extreme postures, more on keyboard S than on keyboard O.<br><br>Typing productivity:<br>Speed was 56 wpm (words per minute) on S, 50 wpm on F, 45 wpm on O: F was thus 89% of S and O was 80% of S. This was after ten hours of training.<br><br>Half of the test subjects found one of the alternative designs better than S. Keyboard F appeared to have a problematic acceptance amongst test subjects with smaller hands, as this design was rather large in its manifestation. The problem with O was its instability, the keys were hard to see, wrist supports were not fixed, and the keys were in part arranged in an inconvenient way. | |
| *Zipp, P.; Haider, E.; Halpern, N.; Rohmert, W.:* Keyboard design through physiological strain measurements. Appl. Ergon. 14 (1983), pp. 117-122 | 37 | This article described postures found with the use of conventional keyboards: Ulnar deviation of 20 to 26°, in part up to 40°; pronation nearly total (ca. 90°). The experiments were performed with only three test subjects, with EMG measurements taken of their shoulder and arm regions. The studies were performed in three stages:<br>• EMG taken during continuous typing on a conventional keyboard<br>Muscle activity increased with the amount of typing time, which indicates fatigue. Strain and stress on the shoulder-arm muscles should be reduced in terms of static tension.<br>• Determining tolerable posture ranges for ulnar deviation and pronation<br>Tolerable postures with regard to pronation and ulnar deviation were determined to be as follows on the basis of lower muscle activity levels recorded in the EMG: 0 to 60° pronation and 0 to 15° ulnar deviation.<br>• EMG taken during continuous typing on an alternative keyboard<br>The halves of the keyboard were laterally angled (10°, 20°, 30°) and turned outwards (half angles of 13° and 26°). Significant reductions in EMG values were already registered at a lateral angle of 10°, with the exception of the EMG on the biceps, which increased with lateral slope. In observations of the angle of outward turn, the greater the angle was, the lower the muscle activity that was recorded in the EMG, except for *M. pronator*. At an outward turn angle of 13°, static muscle effort of the upper extremities was reduced.<br>In the summary, the suggestion was made to turn the halves of the keyboard 10 to 20° (or a total of 20 to 40°) outwards from each other and to try to achieve a lateral angle of 10 to 20°. Problems were reported at a large lateral angle with seeing the keys and for the small fingers in achieving the necessary stretch to reach the keys. A different positioning of the corresponding keys was recommended as a potential solution. | 1 |

## Annexe B: Contents of the literature – Mouse

| Literature section | No. | Content | Score |
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| *Aaras, A.; Dainoff, M.; Ro, O.; Thoresen, M.:* Can a more neutral position of the forearm when operating a computer mouse reduce the pain level for visual display unit operators? A prospective epidemiological intervention study: part II. Int. J. Hum.-Comp. Interaction 13 (2001), pp. 13-40 | 58 | A total of 67 test subjects experiencing pain were asked to use the Anir mouse, which has a form similar to a joystick. The intervention lasted for six months, with an early study conducted within the six-month period in which a subset of the test subjects was used as a control group. Medical tests were performed, surveys were analysed and performance was tested.<br>Neck, shoulder, forearm, hand and wrist pain were significantly reduced in frequency and intensity with the use of the Anir mouse. Fewer days were lost to sick leave due to muscle problems (from 3.1 to 0 days). In the clinical studies, practically all of the tests found improvements in their diagnostics.<br>In terms of performance, the subjects could work a bit faster with the conventional mouse. Around 2.5% more errors were reported in conjunction with use of the alternative mouse.<br>In summary, it is safe to conclude that, while performance with the ergonomic mouse was a bit poorer, the improvements with regard to pain can counterbalance this weakness. | 3 |
| *Aaras, A.; Ro, O.:* Position of the forearm and VDU work. In: Proceedings of the Human Factors and Ergonomics Society. 44th Annual Meeting, 29 July to 4 August 2000, San Diego, USA. pp. 648-649 | 57 | A study was conducted to compare a conventional mouse with an alternative mouse that enables a more neutral posture by reducing forearm pronation (Anir mouse, shaped similar to a joystick). EMG measurements in the forearm musculature of eleven test subjects were performed in a laboratory. In the field study portion of the research, 67 test subjects with existing pain complaints were asked to use the alternative mouse while a control group used a conventional mouse over the period of six months.<br>Lower muscle activity was measured in the area of the forearm when subjects used the alternative mouse. The intensity of pain was significantly reduced by using the alternative mouse.<br>The conclusion drawn from this was that a mouse that supports a more neutral forearm posture should be preferred.<br>Yet the procedures used in the study were insufficiently described. | 1 |
| *Aaras, A.; Ro, O.:* Workload when using a mouse as an input device. Int. J. Hum.-Comput. Interactions 9 (1997), pp. 105-118 | 59 | Thirteen test subjects trained on an alternative mouse (with a shape similar to a joystick) for two days. Next, EMG measurements were taken while subjects worked for 30 minutes using an alternative and a conventional mouse. | 2 |

| Literature section | No. | Content | Score |
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| | | The alternative mouse performed better than the conventional design. The measured muscle activity in the forearm area and the activity of *M. trapezius* in supporting the forearm indicated longer and more frequent periods of relaxation in the EMG measurements when using the alternative mouse. | |
| *Ackland, T.; Hendrie, G.*: Training the non-preferred hand for fine motor control using a computer mouse. Int. J. Ind. Ergon. 35 (2005), pp. 149-155 | 70 | The alternating use of the mouse with the right and the left hand was meant to reduce monotonous, repetitive movements for the self-same structure.<br>The improvements in performance in using the non-dominant hand after 15 x 30 minutes of training were measured over a period of three weeks on 30 test subjects.<br>Differences between the dominant and non-dominant hand could still be found after three weeks of training. The readiness of the left hand, however, achieved performance nearly equal to that of the right. The willingness of test subjects to work using their non-dominant hands increased after the training. | 2 |
| *Blatter, B.; Bongers, P.*: Duration of computer use and mouse use in relation to musculoskeletal disorders of neck or upper limb. Int. J. Ind. Ergon. 30 (2002), pp. 295-306 | 46 | This study recorded the duration of computer and mouse use as well as the complaints of discomfort in the upper extremities of different workers. The results of the studies on men and women were compared, and the connection between complaints and physical and psychological risk factors were explored. A total of 5,403 individuals filled out a questionnaire.<br>Of the test subjects, 44% used a computer for four to eight hours per day, and in part even more than 60%. A computer mouse was used for four to eight hours per day by 30% of test subjects. 19.3% of test subjects reported problems in the upper extremities, 10.3% in the neck-shoulder region, 2.6% in the elbow, arm, wrist and hand regions. In this, computer use of more than six hours per day was associated with intense complaints in the upper extremities among women and with moderate complaints among men. Among women, as little as four to six hours of computer use per day were found to be moderately associated with complaints. The connection between long-lasting static postures and long periods of computer use was the strongest. Of the test subjects who used a computer for six to eight hours per day, 60% reported working for the same amount of time with a mouse, and 11% did not use the mouse at all. No differences were discerned between intensive mouse use and low to non-existent mouse use in the reports of complaints.<br>In evaluating the data, it is important to bear in mind that it originated from self-reporting by the test subjects. | 2 |
| *Burgess-Limerick, R.; Shemmell, J. S.*: Wrist posture during computer pointing device use. Clin. Biomech. 14 (1999), pp. 280-286 | 55 | *See Annexe C* | 2 |

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| *Byström, J. U.; Hansson, G.; Rylander, L.; Ohlsson, K.; Kallrot, G.; Skerfving, S.*: Physical workload on neck and upper limb using two CAD applications. Appl. Ergon. 33 (2002), pp. 63-74 | -- | Fifteen test subjects were studied. The study compared a conventional mouse and a conventional keyboard as well as working in the seated and standing positions. The forearms were supported in each variant. Measured were productivity (typing speed), muscle activity by way of EMG measurements (*M. trapezius* and extensors in the forearm), movements of the head, the upper back and upper arms by way of inclino-meter and the wrist postures and movements by way of an electrogoniometer.<br><br>Productivity:<br>Speed in working with the keyboard tended to be somewhat greater than with the mouse, but the differences were not significant. Work was significantly faster in the standing than in the seated position (13 to 23 minutes).<br><br>Comparing the mouse and the keyboard:<br>Major individual differences were registered in the muscle activity of *M. trapezius*. No systematic distinctions were identified. No different values were found in the extensors of the right forearm. Higher activity in the extensors of the left forearm was measured on the keyboard than on the mouse (which makes logical sense, because only the right hand is active in the right-handed use of the mouse). No significant differences were observed in body posture. The head was moved more frequently when working with the keyboard (shifting gazes between the computer screen and the keyboard).<br><br>Comparing seated and standing positions:<br>No significant different EMG measurements were recorded on *M. trapezius*. In the standing position, the extensors showed higher activity (above all on the right), the head was tilted more forward, the upper back was leaned forward less, and the upper arms were held closer to the torso. Movements were also made at a higher speed in the standing position. Wrist postures showed no differences. | 2 |
| *Cail, F.; Aptel, M.:* Biomechanical stresses in computer-aided design and in data entry. Int. J. Occup. Saf. Ergon. 9 (2003), pp. 235-255 | 33 | *See Annexe A* | 2 |
| *Çakir, A.*: RSI oder Mausarm – ein Standard macht krank! Computer-Fachwissen (2004) No. 9, pp. 4-8 | 56 | Pursuant to ISO 9995, the width of a standard keyboard was:<br>283 mm + 150 mm = 433 mm. The median shoulder breadth is nearly 400 mm for men and approximately 250 mm for women. It can be concluded from these measurements that the use of a mouse along with a keyboard may affect a forced posture that results in abduction in the shoulder joints.<br><br>Solutions and recommendations:<br>• Obtain a keyboard without a numeric keypad<br>If a numeric keypad is necessary, it is still possible to use a separate one.<br>• Choose an alternative to a mouse that takes up less space, e.g., a trackpad | Not a scientific article |

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| | | (= touchpad), pen-shaped mouse (improved arm posture, less strained surface), perhaps even a trackball or pen-and-pad system.<br>• Use software that can be used without a mouse.<br>• Change work techniques and postures, take small breaks. | |
| *Cook, C. K.:* Influence of mouse position on muscular activity in the neck, shoulder and arm in computer users. Appl. Ergon. 29 (1998), pp. 439-443 | 48 | Different mouse positions were tested and assessed on the basis of muscle activities measured with EMG and on the basis of observed arm and hand postures. For the study, ten test subjects were asked to perform text editing tasks for 3 x 20 minutes.<br>The observed mouse positions can be described as follows: standard position (keyboard with an integrated numeric keypad, 405 mm wide, mouse positioned right at the side), extreme position (keyboard with integrated numeric keypad, 405 mm wide, mouse positioned farther to the right and farther away than in the normal position), compact position (keyboard without a numeric keypad, 281 mm wide). Forearm and wrist rested on the desk surface.<br>Results:<br>The activity in the *M. trapezius* muscle showed no significant differences with the different mouse positions. The muscle *M. deltoideus* showed more activity with the standard position than with the compact position. The front *M. deltoideus* was more active in the standard position than in the compact position. The upper arm postures were best for 80% of test subjects with the compact position, for 20% with the standard position. The forearm postures were best for everyone with the compact position. The wrist postures were poor with all mouse positions (either wrist extensions over 15º or ulnar/radial deviation).<br>Summary:<br>For right-hand mouse users, the keyboard without the numeric keypad was better. The mouse can be used on the left side as an alternative. | 2 |
| *Cooper, A.; Straker, L.:* Mouse versus keyboard use: a comparison of shoulder muscle load. Int. J. Ind. Ergon. 22 (1998), pp. 351-357 | -- | Eight test subjects compared a conventional keyboard with a mouse. Subjects were asked to play for ten minutes as the muscle activities were measured using EMG, the postures were documented by observation and subjective discomfort was determined by survey questionnaires.<br>Higher activity levels in the frontal *M. deltoideus* along with lower activity levels in the upper *M. trapezius* were registered during mouse use in comparison to keyboard use. There were very large individual differences. The test subjects who reported elevated discomfort showed higher activity in the *M. trapezius* and *M. deltoideus* when using the mouse than when using the keyboard. Seven test subjects only had their wrists supported when using the keyboard, six test subjects had their entire forearms resting | 1 |

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| | | on the surface and one had only the foremost section of the forearm resting on the surface.<br><br>The differences were not very pronounced in general. | |
| *Delisle, A.; Imbeau, D.; Santos, B.; Plamondon, A.; Montpetit, Y.*: Left-handed versus right-handed computer mouse use: effect on upper-extremity posture. Appl. Ergon. 35 (2004), pp. 21-28 | 53 | Shoulder flexion and abduction are risk factors in musculoskeletal diseases of the neck and shoulder region. The numeric keypad on a keyboard leads to greater abduction when the mouse is used on the right-hand side of the keyboard (RM) than on the left-hand side (LM).<br><br>The advantages and disadvantages of LM in comparison to RM were studied on 27 test subjects. The study proceeded over the course of a month, with the first measurement at the beginning of the month, and the second after a practice period for adjustment. Test parameters included optoelectrically recorded arm and hand postures, surveyed subjective impressions registered on a Borg scale and performance measurements. Different tasks were assigned to be performed for 45 minutes while the measurements were taken.<br><br>Results for LM and RM comparing the first and second measurements:<br>LM reduced shoulder abduction by 16% and the shoulder flexion by 29%, whereas these fell by 9% each for RM. For wrist extension, LM resulted in a reduction by 21% and RM by 10%. The performance time for LM was 8% longer than for RM, yet comparable to the performance time in the first measurement of RM.<br><br>Conclusions:<br>Using the mouse on the left-hand side appears to bring the upper extremities into a more neutral posture. Whether or not LM leads to fewer health complications could not be explored in this study. Performance time for LM after a month corresponded roughly to that for RM at the beginning of the measurements. It is recommended to use a keyboard without an integrated numeric keypad whenever possible. If this is not possible, switching the mouse to the other side is a good alternative. | 2 |
| *Dennerlein, J.; Johnson, P.*: Positions of the computer mouse within a thousand workstations. In: Proceedings of the Human Factors and Ergonomics Society. 47th Annual Meeting, 13 to 17 October 2003, Denver, USA. pp. 1279-1282 | 66 | The use of pointing devices was studied at 1,000 workplaces with the guidance of checklists. The following device types were found: mouse, mouse with scroll wheel, wireless mouse, trackball (5%) and touchpad (3%).<br><br>Positions of the mouse: 92% had the mouse positioned to the right of the keyboard, 4% to the left; 54% had the mouse positioned up to 22 cm away to the right at the distance of the keyboard, 78% at a distance of up to 22 cm to the right of the keyboard, 14% to the right of the keyboard farther away than 22 cm. The input device was at the distance of the keyboard (same distance from the front edge of the desk), 13% farther back and 8% farther forward than the keyboard. | 2 |

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| *Dennerlein, J.; Yang, M.:* Perceived musculoskeletal loading during use of a force-feedback computer mouse. In: Proceedings of the Human Factors and Ergonomics Society. 43rd Annual Meeting, 1999, Houston, USA | 74 | The study explored mouse software, in particular software that offered force-feedback and/or the support for targeted mouse movement using electromagnetic force. The cursor forces in this were oriented in the direction of points to be selected (the movement in the direction of the target: first, acceleration in the direction of the target; second, deceleration of the mouse when the cursor nears the target; third, fine manipulation to hit the target). The force support is meant to ease the third phase so that the user can relax in this phase. The software was tested in use by 14 test subjects and compared to the use of a normal mouse.<br><br>The time in movement was reduced by 25% by using the special mouse software, and the error rate fell by 43%. The subjective assessments in the questionnaires were more positive in all categories. Performance was thus improved by force-feedback and/or the support for targeted mouse movements using electromagnetic force; discomfort and fatigue were reduced.<br><br>Problem:<br>The software was only used for an artificial task. Further study would be required to explore transferability to everyday mouse use. | 1 |
| *Dowell, W.; Fei, Y.; Green, B.:* Office seating behaviours: an investigation of posture, task, and job type. In: Proceedings of the Human Factors and Ergonomics Society. 45th Annual Meeting, 8 to 12 October 2001, Minneapolis, USA. pp. 1245-1248 | 47 | This study investigated the work techniques of four different professional and occupational categories:<br>• Administration (a lot of data entry and secretarial work)<br>• Customer service (telephone work with the most time spent working on the computer)<br>• Technicians/experts<br>• Leadership/supervisory positions<br>Fourty workers were observed at their workplaces using video over 31 hours.<br><br>Mouse use:<br><br>Technicians/experts spent significantly more time (at 43%, nearly twice as much) with a mouse in hand than all other occupational categories. The values across all professional and occupational categories were between 4.8 and 43.4% of working hours.<br><br>Keyboard use:<br><br>From 13.8 to 32.5% of the time was spent using the keyboard. Test subjects in customer service spent nearly twice as much time typing on the keyboard than the other professionnal and occupational categories.<br><br>Reading from the computer screen (without using the keyboard or mouse):<br>From 2.6 to 13.9% of working hours were spent with this activity. The workers in customer service also had the highest rates here at nearly 14%. | 3 |

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| | | Working postures:<br>Test subjects in customer service spent more time than the other groups with neutral arm postures (50% in comparison to from 15 to 20% for the other occupations).<br><br>The different demands of the individual professional and occupational categories should be taken into account when arranging the workplace. | |
| *Gustafsson, E.; Hagberg, M.:* Computer mouse use in two different hand positions: exposure, comfort, exertion and productivity. Appl. Ergon. 34 (2003), pp.107-113 | 60 | Fifteen test subjects compared two mice with one another: a standard mouse (Microsoft 2.1 A) and a prototype (neutral mouse – the ulnar side of the hand and the wrist rested on the mouse, the input device was moved by the entire forearm). The test subjects were given half a day's opportunity to practice working with the alternative mouse. Afterwards, they were asked to edit text for 15 minutes while measurements were taken using EMG and an electrogoniometer as performance and subjective discomfort were recorded.<br><br>Results:<br>A more neutral posture and less muscle activity was found during the use of the prototype, but productivity losses were also registered, and the prototype mouse was not well accepted by the test subjects. | 3 |
| *Harvey, R.; Peper, E.*: Surface electromyography and mouse use position. Ergonomics 40 (1997), pp. 781-789 | 67 | Seventeen test subjects compared a mouse and a laptop keyboard with an integrated trackball. The keyboard was placed in a central position in front of the test subjects, and the mouse was to the direct right of a standard keyboard (with a mouse pad, approximately 42 cm away from the middle of the keyboard). The trackball on the laptop was placed in the centre in front of the test subjects. Muscle activity was recorded via EMG during each of the one-minute tests. Test subjects also reported their subjective impressions of comfort.<br><br>Positioning the mouse to the side of the keyboard forced abduction in the arm, which came in combination with greater muscle activity. Newer, ergonomically designed keyboards are more often wider than conventional keyboards, thus requiring even greater arm abduction. A trackball integrated into the keyboard would thus be advantageous.<br><br>Problem:<br>The tests were very short and irrelevant. | 2 |
| *Hedge, A.; Muss, T.; Barrero, M.:* Comparative study of two computer mouse designs. Ed.: Cornell University, Ithaca, 1999 | 65 | Twenty-four test subjects tested two different mice: Microsoft Corporation Mouse (mouse A) and a Humanscale Whale Mouse (mouse B).<br><br>During the tests of around two to three minutes in duration, electrogoniometers were used to measure hand postures; performance was measured and subjective comfort was surveyed.<br><br>Differences were found in hand postures, whereby higher degrees of wrist extension | 2 |

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| | | were recorded for mouse A than for mouse B. Speed was reduced by approximately 19% on mouse B. Mouse A performed better in assessments of subjective comfort. Yet, as the design of mouse B was very unconventional, this result would potentially be different after a longer period for users to practice with it. Different hand dimensions had an influence on the results. | |
| *Hoffmann, E.; Chang, W.; Yim, K.:* Computer mouse operation: is the left-handed user disadvantaged? Appl. Ergon. 28 (1997), pp. 245-248 | 73 | This study investigated the question of whether left-handed individuals (LH) are at a disadvantage because most computer workplaces are designed for right-handed individuals (RH); i.e., the mouse is used on the right-hand side. Twenty test subjects, ten of whom were LH who mostly used the mouse on the left side but also had practice in using it on the right and ten RH individuals were briefly tested. The subjects were observed to determine whether there were any differences during the time given to complete a task.<br>There was no difference between the two groups in terms of performance when each was permitted to use the preferred hand (LH left, RH right). The LH group had an advantage in working with the non-preferred hand, and their performance showed no significant worsening in comparison to the RH group. | 1 |
| *Jensen, C.; Borg, V.; Finsen, L.; Hansen, K.; Juul-Kristensen, B.; Christensen, H.:* Job demands, muscle activity and musculoskeletal symptoms in relation to work with the computer mouse. Scand. J. Work Environm. Health 24 (1998), pp. 418-424 | 49 | A total of 149 workers at a Danish company were interviewed using a questionnaire to determine their habits and working conditions. Furthermore, observations and measurements were taken on 20 test subjects using electrogoniometer and EMG.<br>A total of 66% used the dominant hand to operate the mouse, 25% used the non-dominant hand, and 9% alternated use between right and left hands.<br>Complaints arising over 12 months:<br>• Mouse hand: Hand/wrist 49%, elbow 35%, shoulder 52%<br>• Other hand: Hand/wrist 13%, elbow 15%, shoulder 19%<br>Women reported more complaints in the hand/wrist and elbow than men.<br>Postures: The upper arm was bent the most when using the mouse and abducted from 0 to 30°. The wrist was stretched and the ulna ducted for more than 90% of the time while working. | 3 |
| *Johnson, P.; Hagberg, M.; Hjelm, E.; Rempel, D.:* Measuring and characterizing force exposures during computer mouse use. Scand. J. Work Environm. Health 26 (2000), pp. 398-405 | 45 | The forces exerted on the mouse, both on the mouse buttons and on the sides of its housing, were measured on 16 test subjects at their workplaces. The force measure-ments were taken on the mouse itself. Along with everyday work, subjects were also asked to perform standardised tasks at various points.<br>The mouse was used during 23.7% of working hours.<br>The measured exerted force was on average 0.5% MVC (MVC approximately 80 N) on | 3 |

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| | | the sides of the mouse housing, 0.7% MVC (MVC of 50 N) on the buttons. Men and women applied the same amount of absolute force, yet women applied slightly more force relative to MVC, which is lower for women than men. No differences were identified with regard to the day of the week or the hour of the day. | |
| *Kabbash, P., MacKenzie, I. S.; Buxton, W.*: Human performance using computer input devices in the preferred and non-preferred hands. In: Proceedings of the ACM Conference on Human Factors in Computing Systems – INTERCHI, New York (1993) | 72 | A total of 24 test subjects were asked to complete standardized point-and-select and drag-and-select tasks in order to compare the performance in using a mouse, trackball and pen-pad device alternately between the dominant and non-dominant hand.<br><br>At short distances and with small target objects, working with the dominant hand was superior. In the opposite case – where more broad motor movements are called for – the non-dominant hand proved to be a good alternative, for instance for scrolling with the mouse. The trackball resulted in the smallest differences between right- and left-hand use, but it was also the slowest pointing device. "Pointing" with a pen-pad system seemed to produce fewer regular errors than with a trackball and mouse. The latter two input devices, in contrast, were better for "dragging" than was the pen-tablet combination. | 2 |
| *Karlqvist, L.; Bernmark, E.; Ekenvall, L.; Hagberg, M.; Isaksson, A.; Rosto, T.*: Computer mouse position as a determinant of posture, muscular load and perceived exertion. Scand. J. Work Environm. Health 24 (1998), pp. 62-73 | 68 | Twenty test subjects completed tests each of two minutes in duration with the mouse in six different positions:<br>Mouse to the immediate right of the keyboard (B and A), 40 cm (C and D) and 60 cm (E and F) away, set back from the front edge of the desk by 10 cm (A, C and E) or 20 cm (B, D and F).<br>Keyboard B D F<br>A C E<br><br>Optoelectric posture measurements and EMGs were performed, and questionnaires on comfort/discomfort were analysed.<br><br>Posture measurements:<br>In the E and F positions, large angles were measured for outward rotation and abduction in the shoulders, in particular amongst shorter individuals. In the A position, in contrast, shoulder inward rotation was observed.<br><br>Subjective impressions:<br>Seven tall and five short test subjects found the D position the most comfortable (many also rested their forearms on the desk or chair arm rests in this position), followed by C, B and F; no one liked position E.<br><br>In practice:<br>Most subjects worked with the mouse in the C and D positions, and many also in E and F. The B position is to be preferred from an ergonomic standpoint. The B position makes it easy for individuals to rest their arms on a surface, which was reflected in the lower | 2 |

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| | | *trapezius* activity and lower perceived strain or load amongst tall test subjects. Postures of the shoulder-arm region are near the neutral position. The authors are convinced that many would be able to work well in this position if given the information and training.<br><br>Problem:<br>The test subjects assumed various body postures during the tests; i.e., the practice of resting their forearms on a desk or arm support and the height setting of the chairs were all different. | |
| *Karlqvist, L.; Hagberg, M.; Selin, K.*: Variation in upper limb posture and movement during word processing with and without mouse use. Ergonomics 37 (1994), pp. 1261-1267 | 50 | To study work using a keyboard with and without a mouse, 24 test subjects were asked to correct texts for 30 minutes each. Video recordings were taken of their work and the hand and arm postures were determined from the video. The performance and subject-tive discomfort were also recorded.<br><br>Joint postures:<br>The median ulnar deviation was 17.6° with the mouse and 1.8° without. Wrists were in ulnar deviation of from 15 to 30° for 34% of the time with the mouse, and 30% of the time in ulnar deviation of < 30°, whereas there was a medium degree of ulnar deviation without the mouse during 2% of the time and no final degree was measured at any time. Without the mouse, ulnar deviation was from 0 to 15° during 62% of the time, and the remaining 34% of the time, the wrist was observed in radial deviation.<br><br>With the mouse, the shoulder was at an outward rotation angle of between 5 and 45°, and without the mouse between 65° inward rotation and 10° outward rotation. The neck was bent under the two conditions by approximately 38.5°.<br><br>Subjective discomfort:<br>Test subjects reported less discomfort when working with the mouse than without.<br><br>Performance:<br>Test subjects worked faster and had fewer errors when working with the mouse.<br><br>Summary:<br>Working with the mouse placed beside the keyboard resulted in greater strain, but this arrangement made the text corrections faster and better – with fewer errors.<br><br>Problems:<br>The measurements were not validated. The measured values for ulnar deviation while working with the keyboard were extremely divergent from those of other studies. | 2 |

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| *Keir, P.; Bach, J.; Rempel, D.:* Effects of computer mouse design and task on carpal tunnel pressure. Ergonomics 42 (1999), pp. 1350-1360 | 51 | Fourteen test subjects tried out three different mouse designs:<br>• Mouse A – Contour Mouse<br>• Mouse B – Apple II ADB Mouse<br>• Mouse C – Microsoft Serial Mouse.<br><br>The measurement parameters here were carpal tunnel pressure (CPT) as measured with a catheter and the wrist postures as recorded with an electrogoniometer. Standardized drag-and-drop tasks, and additional point-and-click tasks on mouse C, were performed for the study. Each posture of the hand resting on the mouse was recorded before the tasks were performed.<br><br>CTP:<br>The median CTP was 5.3 mmHg; 18.7 mmHg when resting on mouse A, 16.8 mmHg on mouse B and 18.4 mmHg on mouse C. CTP increased in dragging tasks on mouse A to 28.8 mmHg, on mouse B to 31.1mmHg and on mouse C to 33.1 mmHg, and subsequently decreased slightly over the course of the drag-and-drop task. These differences were not significant.<br><br>Postures:<br>Wrist extension during the tasks were between 25 and 30° and at rest between 23 and 28°. On all of the mice, the ulnar deviation was observed to deviate by no more than 5.2° from the neutral posture.<br><br>Summary:<br>Similar CTP values and wrist postures were found for all three mice. | 2 |
| *Lee, D.; Fleisher, J.; McLoone, H.; Kotani, K.; Dennerlein, J.:* Alternative computer mouse design to reduce static finger extensor muscle activity. Hum. Factors 49 (2007) No. 4, pp. 573-584 | 64 | Four newly designed mice were developed with the aim of reducing static muscle activity in the finger extensors and compared with a reference mouse (RM) in this study.<br>• NR: The right mouse button was replaced with a fixed surface in this mouse to allow the middle finger to rest on the mouse without the risk that the user might inadvertently depress the button.<br>• HI: The mouse was identical to the reference mouse except in the amount of force required to depress the buttons (HI 1.29 N, reference mouse 0.64 N).<br>• PF: On the push-forward mouse, the left mouse button was arranged and shaped in a way in which the finger has to be pressed forward to click it; the direction of movement was thus nearly perpendicular to the direction in which fingers exert force at rest. The required force of effort was as high as that of the reference mouse (0.64 N). The right-hand button was fixed as on the NR mouse.<br>• SF: On the slide-forward mouse, the button had to be pressed forward to click it as in the PF, but the design of the mouse housing barely diverged from that of the | 2 |

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| | | conventional mouse. Pressing the button forward was made possible by a rough surface texture. The necessary force and right button were designed as on the PF mouse.<br>Twenty test subjects tested the mice in the framework of three tasks (point and click, steering and moving objects). Each task lasted from two to five minutes. The EMGs were derived from those of *M. extensor digitorum communis* (EDC), *M. flexor digitorum superficialis* (FDS) and *Mm. interossei* (dorsal).<br>A reduction in static muscle activity in the finger extensors for PF and SF of up to 22% was found in comparison to the reference mouse and NR. The values for the middle finger followed the same trend, but the differences were not significant. In return, muscle activity in the flexors increased due to static load. This effect was also measurable in HI, but without muscle activity in the extensors changing in comparison to the reference mouse and NR. With regard to dynamically induced muscle activity, the EMG values for the pointer finger's extensors on HI were higher by up to 12% in comparison to all the other designs, and those of the flexors were elevated on HI, PF and SF.<br>Summary:<br>Although the results for PF and SF speak in favour of a decreased strain on the extensors, these two designs influenced the muscle activity in the flexors more negatively than positively. | |
| *Marcus, M.; Gerr, F.; Monteilh, C.; Ortiz, D. J.; Gentry, E.; Cohen, S.; Edwards, A.; Ensor, C.; Kleinbaum, D.:* A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. Am. J. Ind. Med. 41 (2002), pp. 236-249 | 34 | *See Annexe A* | 3 |
| *Mierdel, B.*: Belastung des Hand-Arm-Systems durch Benutzung der Computermaus – Gestaltung einer alternativen Bedienfläche. Wiss. Z. TU Dresden 42 (1993), p. 42 | 69 | Twelve test subjects worked with an adjustable mouse stand/pad from Practical Posture Limited (Oxford) which was attached to the desk and was adjustable for height (60 to 90 cm) as well as for lateral and sagittal orientation, each of between -90º and +90º. The test subjects were allowed to use the mouse stand for one to four days and adjust the device to match their own comfort preferences.<br>Preferred adjustments for the mouse stand and subjective assessments:<br>Height of 7.5 ± 3 cm below the level of the desk surface, with an angle between the upper arm and forearm of 95 to 155º, sideward slope of the mouse stand of 3 ± 5º, sagittal slope of 4 ± 6º. Eight test subjects chose the anticipated adjustment with a sideward slope in the direction of the ulna. The individually adjustable operating surface was regarded as very comfortable by all subjects. | 2 |

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| | | What proved to be a problem was that the additional mouse stand inhibited standing up and sitting down, and it sometimes collided with the back of the chair when the worker stood.<br><br>No EMG or similar measurements were taken. | |
| *Paul, R.; Nair, C.:* Ergonomic evaluation of keyboard and mouse tray designs. In: Proceedings of the Human Factors and Ergonomics Society. 40th Annual Meeting, 2 to 6 September 1996, Philadelphia, USA. pp. 632-636 | -- | This study investigated four workplace arrangements of keyboard and mouse to determine the physical strain or load of the musculoskeletal system in comparison to a reference workplace:<br>• A: Mouse pad rotated 45º inwards towards the keyboard at the same height as the keyboard<br>• B: Mouse pad in a straight-line extension of the keyboard at the same height<br>• C: Keyboard adjustable for height and slope together with a mouse pad of adjustable height<br>• D: Mouse pad approximately 5 cm above the keyboard numeric keys; pad in swing-out design<br>• Reference workplace with a flat, non-adjustable desktop surface<br>Eight test subjects were asked to perform word processing activities for a 30-minute study; muscle activity (*M. flexor carpi radialis, M. extensor carpi radialis*) was recorded by EMG, hand and arm postures by electrogoniometer; video recordings were made, comfort surveyed and productivity measured.<br><br>The reference workplace yielded the worst results on all parameters. Of the other four arrangements, none could be singled out as the best. B performed best in terms of wrist extension and flexion and with regard to comfort. The EMG of flexors, elbow flexion and shoulder abduction were best on D. These two arrangements were judged nearly identically in terms of comfort. Although C allowed a greater range of adjustments, this arrangement did not produce better results. This indicates that an integrated keyboard and mouse arrangement corresponds better to the habits of the users. | 2 |
| *Pekelney, R.; Chu, R.*: Design criteria of an ergonomic mouse computer input device. In: Proceedings of the Human Factors and Ergonomics Society. 39th Annual Meeting, 9 to 13 October 1995, San Diego, USA, pp. 369-373 | 63 | This article discussed the development of criteria for redesigning a mouse, the Kensington Thinking Mouse. The article presented the considerations on design and on software and took various studies into consideration so as to minimize the potential strains of mouse use (force/effort; poor, static or forced postures; repetitions; lack of suitable periods of rest; stress).<br><br>The Kensington Thinking Mouse was given the following characteristics: depressions on the sides, a flatter and smaller shape in the front than in the back, four buttons (two in front, two set farther back) symmetrical design, software for programming the buttons, for acceleration, for targeting with the cursor and for reminding users to take breaks. | Not a scientific study |

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| | | This article provides a good example of how the design of an input device could be organized. Initial users responded positively, according to the authors. In *Woods* (2002), however, the Thinking Mouse performed very poorly. The altered arrangement of the four buttons required some practice, and the specific software could cause problems. | |
| *Peters, M.; Ivanoff, J.*: Performance asymmetries in computer mouse control of right-handers, and left-handers with left- and right-handed mouse experience. J. Mot. Behav. 31 (1999), pp. 86-94 | 71 | This study investigated the performance differences between right- and left-handed mouse users (a total of 73 test subjects) and their experience in using the mouse with the non-dominant hand.<br><br>Compared across all tasks, the differences between the dominant and non-dominant hands were less than 0.2 s. It should thus not be a problem for users to switch hands for using the mouse. | 2 |
| *Smith, W.; Edmiston, B.; Cronin, D.*: Ergonomic test of two hand-contoured mice. Ed.: Global Ergonomic Technologies, Palo Alto (California) 1997 | 62 | Seventy-six test subjects compared two mice:<br>• Contour Design Mouse:<br>A shape rising to the tip in order to reduce pressure on the palm; mouse shaped flatter on the little-finger side in order to reduce pronation; support provided for the thumb and three buttons; larger than the Microsoft mouse; force required to move the mouse smaller than for the Microsoft mouse<br>• Microsoft Ergonomic Mouse:<br>Taller than a conventional mouse; kidney-shaped, outward button slope; a surface that is more conformant to the hand; two buttons<br>Tests were performed over four hours while data were gathered on the muscle activity (EMG), postures (two cameras) and subjective impressions (questionnaires).<br><br>On the Contour Mouse, significantly lower muscle activity was registered for most positions and tasks, while the differences in posture and performance were small. Subjective impressions were better above all for the Contour mouse with regard to comfort, fatigue and pain.<br><br>Summary: The Contour Mouse received the best evaluation thanks to its lower biomechanical strain or load (lower muscle strain and poor postures) and achieved high scores for comfort (rated "good"), even though the mouse was somewhat larger than the Microsoft mouse. Despite their sizes, both of these mice performed better than the smaller conventional mouse. | 2 |
| *Thomsen, J.*: Carpal tunnel syndrome and the use of computer mouse and keyboard. Ed.: Dansk Selskab for Arbejds- og Miljømedicin, Glostrup 2005 | 54 | This article was a review article that investigated the causal relationship between CTS and working with a computer.<br><br>Wrist postures:<br>In using the mouse: wrist extension of 23 to 30°, ulnar deviation 3.2 to 5.2°<br>In using the keyboard: wrist extension of 14 to 20°, ulnar deviation 18.9 | Review article |

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| | | The required amount of finger force for typing was from 1 to 7 N (mostly 1 to 4 N). This yields a median force on the tendon of 7.2 N. The force for the mouse button was below 1 N (= 0.4 to 1.5% MVC).<br><br>Carpal tunnel pressure (CPT) for wrist postures ranging from -30º (extension) to +30º (flexion) and slight ulnar deviation is 3 to 13 mmHg; for CTS patients from 10 to 43 mmHg. The CPT is independent of the postures in the forearm, wrist and the joints between the centre of the hand and the fingers (metacarpophalangeal joints, MCP). In supination and MCP flexion there is higher pressure. CTP does not rise above 20 mmHg for wrist postures between -40º (extension) and +40º (flexion) and various joint positions in the MCP. Ulnar and radial deviation have no bearing on CTP.<br><br>In finger typing with 0, 5, 10 and 15 N, CTP rises correspondingly to 7.8, 14.1, 20 and 33 mmHg, respectively. CTP in healthy test subjects when working with the computer is 5.3 mmHg at rest; CTP values rise to between 16.8 and 18.7 mmHg when the hand lies in a static posture on the mouse, and to between 22.8 and 33.1 mmHg when dragging and clicking with the mouse.<br><br>The prevalence of CTS amongst computer users based on those diagnosed in the nerve conduction test (NCT) is approximately 1%.<br><br>The studies reviewed had many limitations. No study managed to find evidence of the causal relationship between computer work using a keyboard and mouse and CTS, and, even from a general perspective, there is too little evidence. | |
| *Ullman, J.; Kangas, N.; Ullman, P.; Wartenberg, F.; Ericson, M.*: A new approach to the mouse arm syndrome. Int. J. Occup. Saf. Ergon. 9 (2003), pp. 463-477 | 61 | In order to minimize the risk of RSI, an input device should satisfy the following criteria: extreme postures such as wrist extension, radial and ulnar deviation or pronation should be minimized; the completion of tasks requiring a high degree of precision should be facilitated without involving the upper arm and shoulder muscles, i.e., with a supported forearm; clicking functions should be provided that involve other muscles than only the flexors of the pointer finger; clicking with outstretched fingers should be avoided (requires static tension in the extensors); patterns of movement should be promoted that differ from those used on the keyboard; movements should be supported that resemble skills already learned. Arm movements should be reduced by reducing space needed to move the cursor. Perceived comfort should be optimized; operation of the mouse should be intuitive.<br><br>Twenty-six test subjects used a pen-shaped mouse (Ullman mouse) in a comparison test with two conventional mice (Microsoft Intellimouse Optical and Apple Standard Ball Mouse). EMG measurements were registered for *M. trapezius, M. levator scapulae, M. extensor digitorum* and *M. pronator teres*, and performance was measured. | 2 |

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| | | Results:<br>The muscle activity recorded in the EMG was significantly lower on the pen-shaped mouse for all muscles than on the comparison mice (reduction in muscle activity in *M. trapezius* by 69%, *M. levator scapulae* by 81%, *M. extensor digitorum* by 46%, *M. pronator teres* by 46%). The reduced muscle activity in *M. trapezius* and *M. levator scapulae* indicates that the pen-shaped mouse is operated more by hand movements than by arm movements. The lower activity in *M. extensor digitorum* in the EMG indicates a reduced strain caused by bad wrist extension movements. The data were gathered on the first or second day that the test subjects worked with the pen-shaped mouse for the first time. With more practice, it may be that the EMG measurement values would be even lower. Moreover, performance in terms of speed improved in these first two day in comparison to the conventional mouse. A study exploring everyday use would still be helpful. | |
| *Wahlström, J.*: Physical load in computer mouse work. Ed.: National Institute for Working Life, Stockholm 2001 | 52 | The influence that gender has on mouse use and work technique was studied on 36 test subjects. Two laboratory studies and a field study were performed. Used for the study were an EMG, force measurements on the mouse, electrogoniometer, checklists for working methods, questionnaires, observations by way of video recordings, measurements of blood pressure and heart rate.<br><br>For the comparison of the genders, the women worked at the same place that the men worked. Women exerted nearly twice the amount of force relative to MVC than the men. Women also moved the hand in a larger ROM (range of motion), above all in wrist extension (30.3° to 25.9°) and ulnar deviation (11.2° to 7.2°) – most likely due to the women's smaller bodily dimensions.<br><br>Work techniques in the laboratory:<br>Three methods of mouse use were compared:<br>• Wrist-based (WB): whole forearm supported, movement from the wrist<br>• Arm-based (AB): only wrists supported, movement from the shoulder joint<br>• Own method (OW): the work technique commonly used by each individual<br>Results:<br>Greater median forces and peak forces (in percentage of MVC) were registered in a sideways direction against the mouse in the WB technique. The wrist extension was greater for AB. The greatest muscle activity was registered in *M. trapezius* for AB; the lowest for WB. The perceived strain was reported as more in the proximal area of the upper extremity for AB, but the greatest strain for WB, in contrast, was perceived in the distal area. OW was reported as the most comfortable technique, and AB as the least comfortable. Work was slowest for WB and fastest for OW. | 3 |

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| | | Work technique in the field study (with observation protocol):<br>A lower level of muscle activity was found amongst the group with good work techniques than amongst those with poor work techniques. More breaks in activity were registered amongst the group with good work techniques in the EMG of the trapezius muscles on the side of the arm that used the mouse, and a more neutral wrist posture was observed in this group. The group with the poor work techniques had support for their forearms less frequently. The perceived comfort between the two groups was not significantly different.<br><br>In summary, it can be concluded that different work techniques for using the mouse has an influence on physical strain. Support for the forearm leads to a lower amount of muscle activity in *M. trapezius* and less wrist extension. Women worked with greater relative muscle activity in *M. extensor digitorum* and exerted more force (as a percentage of MVC) on the mouse than did the men.<br><br>Stress had a large influence on physical strain.<br><br>Conclusion: Good work techniques are worth it! | |

## Annexe C: Contents of the literature – Trackball

| Literature section | No. | Content | Score |
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| *Bertuca, D.*: Letting go of the mouse: using alternative computer input devices to improve productivity and reduce injury. OCLC Systems und Services 17 (2001), pp. 79-83 | 78 | This article introduced alternative input devices to the computer mouse that the author believed to be better. It is was not a scientific article.<br><br>Trackball:<br>This takes up little space and can be moved closer to the centre of the body. Further-more, the trackball does not require an even surface and can, for instance, be placed in the user's lap. In the author's opinion, fine movements are easier to achieve using the trackball than with the mouse, and moving the ball requires less force of effort than do mouse movements. The larger the ball, the easier movement is. A disadvantage of the trackball is that dirt easily collects around the ball.<br><br>Touchpad:<br>Today's touchpads are too small in design to offer a sensible alternative to the mouse.<br><br>Pen-tablet systems:<br>This is actually the "most natural", but also the least-used input device. It is a device for more than just working with graphics. In the author's opinion, it is the best alternative for nearly any computer activity. "Buttons" can be arranged on the tablet for different func-tions. It requires little practice to learn to operate the pen-shaped stylus. A little bit of dirt on the tablet does not impede its functioning. The author managed to considerably reduce stress on the hand by using the pen-tablet device.<br><br>Joystick:<br>A joystick is suitable for games that call for rapid cursor movements and special game function buttons. Joysticks do not play a role at computer workplaces.<br><br>The author recommends using multiple different input devices. | Review article, not a scientific article |
| *Burgess-Limerick, R.; Green, B.*: Using multiple case studies in ergonomics: an example of pointing device use. Int. J. Ind. Ergon. 26 (2000), pp. 381-388 | 79 | The objective of the study was to describe the individual nature of postures and move-ment patterns amongst computer users.<br><br>For the study, six test subjects were given click-and-point tasks to complete with two input devices (see below). Wrist extension and ulnar deviation were measured during these activities.<br><br>Mouse: Apple Desktop Bus Mouse II<br>• Average value for wrist extension: 18.2° (standard deviation = 6°)<br>• Average value for ulnar deviation: 11° (standard deviation = 4°) | 2 |

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| | | Trackball: Kensington Turbo Mouse<br>• Average value for wrist extension: 23.1° (standard deviation = 4°)<br>• Average value for ulnar deviation: 5.7° (standard deviation = 5°)<br>Horizontal cursor movements forced a greater maximum and average ulnar deviation; the effects on wrist extension were not consistent. The results described only represent average values for a very large array of individual differences. In reviewing the measurements for individual test subjects, it becomes clear that, for instance, the trackball did not lead to appreciable reductions in ulnar deviation for all test subjects. The sources of these individual differences remain unclear.<br>As a result, especially any time that an alternative input device is used, it must be determined on a case-by-case basis whether the new input device actually results in improvements, for instance when the aim is to avoid posture problems related to mouse use. | |
| *Burgess-Limerick, R.; Shemmell, J. S.*: Wrist posture during computer pointing device use. Clin. Biomech. 14 (1999), pp. 280-286 | 55 | Measurements of wrist extension and ulnar deviation were performed on 12 test subjects. Two different input devices were used to perform standardized point-and-click tasks (see below).<br>Mouse: Apple Desktop Bus Mouse II<br>• Average value for wrist extension: 19.1° (standard deviation = 6.8°)<br>• Average value for ulnar deviation: 10° (standard deviation = 6.9°)<br>Trackball: Kensington Turbo Mouse<br>• Average value for wrist extension: 25.1° (standard deviation = 5.8°)<br>• Average value for ulnar deviation: 6° (standard deviation = 7°)<br>Greater angles for wrist extension and smaller angles for ulnar deviation were measured for the trackball. Nevertheless, major individual differences were observed.<br>The trackball can thus serve as an alternative for some individual users, but not for others. It must be determined on an individual bases to what extent hand postures change or improve. The cause of the individual differences remains unclear. The question arises as to whether training could help modify posture or whether the postures would change after longer trackball use, as the test subjects in this study only used a computer mouse and no trackball in their everyday work.<br>Problem:<br>The results only apply for the two tested pointing devices and not for trackballs and mice in general because the postures can also be influenced by newly designed housings. | 2 |

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| *Chaparro, A.; Bohan, M.; Fernandez, J.; Kattel, B.; Choi, S.*: Is the trackball a better input device for the older computer user? J. Occup. Rehab. 9 (1999), pp. 33-43 | 83 | Twenty test subjects (ten younger, ten older) completed standardized point-and-click and click-and-drag tasks using a Microsoft two-button mouse and then with a Kensington Expert Mouse Trackball. EMG measurements were taken of the forearm muscles, and the test subjects each filled out a survey questionnaire.<br><br>Comparing the mouse and trackball:<br>The movements with the mouse were significantly faster than with the trackball. The variability did not differ. Significantly higher levels of fatigue were reported for the mouse, in particular in the regions of the forearm, wrist and hand.<br><br>Comparing young and old:<br>Older test subjects took significantly more time for the tasks, but their movements were less variable in return (yet significant only in movements towards larger target objects). No differences were identified between the age groups in the EMG measurements. For both groups, the flexors showed stronger signals than did the extensors. Older test subjects reported greater strain or load in completing the click-and-drag tasks with the mouse than did younger subjects.<br><br>Comparing point-and-click and click-and-drag tasks:<br>Click-and-drag tasks took more time to complete than point-and-click tasks, and the former produced greater electrical activity in the EMG and greater fatigue; the variability did not differ.<br><br>Three quarters of the test subjects preferred the trackball, depending on their age and the task involved. | 3 |
| *Chase, D.; Casali, S.:* A comparison of three cursor control devices on a cursor control benchmark task. Ed.: Industrial and Systems Engineering, Virginia Polytechnic Institute and State University Blacksburg, 1991 | 84 | The performance of three input devices was compared:<br>A one-button standard mouse (Macintosh), a trackball with a mouse button (Kensington Turbo Mouse) and the cursor buttons on the Macintosh SE keyboard defined using Easy Access (eight arrow keys and three selection keys). Twelve test subjects com-pleted various click-and-point tasks or dragging to the start and target fields. The time needed to complete each task was measured. Variables: input device, size of the target objects, distance of the target objects, direction, button mode (clicking the button or holding it depressed).<br><br>According to the results, the mouse and trackball resulted in almost identically good performance in terms of target object size, distance and direction. The two input devices were faster than the cursor buttons on the keyboard. | 1 |

<table>
<tr><th>Literature section</th><th>No.</th><th>Content</th><th>Score</th></tr>
<tr><td>Hancock, P.: Effects of control order, augmented feedback, input device and practice on tracking performance and perceived workload. Ergonomics 39 (1996), pp. 1146-1162</td><td>85</td><td>In this study, of which only parts were relevant to the ergonomics of input devices, several experiments were performed to investigate the relationship between performance and subjective perceptions of strain. Six test subjects participated. The following variables were combined in different ways: input device (mouse, trackball), task instruction (stage 0 = position, stage 1 = speed, stage 2 = acceleration), feedback (only the cursor in a relative position to a target field, cursor with additional error information).<br><br>Performance:<br>The higher the stage in the task instruction, the more errors occurred. Better performance was achieved by using the trackball than by using the mouse. No differences were identified in a comparison of feedback.<br><br>Interactions:<br>Under instructions at stage 1, the comparative performance of the mouse and trackball was the same; the error rates increased more on the mouse than on the trackball at higher stages. Efficiency improved with additional feedback on the trackball, but efficiency worsened on the mouse. Perceived strain increased at higher stages of instruction. No difference in strain was found between the mouse and trackball at stage 0. Perceived strain on the trackball was lower at stages 1 and 2 than on the mouse. Better performance corresponded to lower impressions of strain.<br><br>In summary, the trackball produced better results than did the mouse in this study.</td><td>1</td></tr>
<tr><td>Hsu, P.; Wang, M.: Trackball evaluation under different tasks. Ed.: Department of Industrial Engineering and Engineering Management, National Tsing-Hua University, Taiwan</td><td>82</td><td>In this study, 12 test subjects performed trials on three trackballs and one mouse (conventional design) to compare the devices with one another. The balls in the different trackballs were operated with the thumb (DT), the pointer finger (ZT) or with the middle finger (MT). Test subjects were all only used to working with a computer mouse.<br><br>The study measured body posture, muscle activity, performance and subjective perceptions.<br>• MT:<br>This trackball resulted in the poorest body postures and subjective feedback. Moreover, higher muscle activity was registered. In slow, precise cursor movements this trackball proved to be good in terms of performance; in fast, precise movements it proved to be a poor input device.<br>DT:<br>A good body posture and low muscle activity were observed with the use of this trackball. The subjective feedback was positive. The thumb-operated trackball was recommended for longer work periods, even if it only allowed slower work speeds to complete tasks requiring precision.</td><td>2</td></tr>
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| | | • ZT:<br>Large finger extensions were registered on this device. Nevertheless, test subjects offered positive feedback, probably because they had the sense that they had the most control over the ball by using their pointer fingers. Yet this trackball was only recommended for short periods of computer use.<br>• Mouse:<br>The mouse performed better than all three trackballs, but it also earned the poorest subjective feedback. A tendency towards wrist extension and many arm movements were observed; greater space for users to move the device around is thus required. The mouse was recommended for tasks requiring greater precision and faster-paced work over shorter working periods.<br>Summary:<br>Thumb-operated trackballs were recommended for longer periods of work. | |
| *Kabbash, P., MacKenzie, I. S.; Buxton, W.*: Human performance using computer input devices in the preferred and non-preferred hands. In: Proceedings of the ACM Conference on Human Factors in Computing Systems – INTERCHI, New York (1993) | 72 | *See Annexe B* | 2 |
| *Karlqvist, L.; Bernmark, E.; Ekenvall, L.; Hagberg, M.; Isaksson, A.; Rosto, T.:* Computer mouse and track-ball operation: Similarities and differences in posture, muscular load and perceived exertion. Int. J. Ind. Ergon. 23 (1999) pp. 157-169 | 80 | This study compared a mouse and a trackball with regard to posture (measured), muscle load (EMG), perceived exertion and performance used by 20 test subjects (ten women, ten men) during a 15-minute text editing exercise. The mouse in question was an Apple Bus Mouse II, and the trackball was a Kensington Trackball.<br>Posture:<br>Only minor posture differences were found between mouse and trackball use. The angles of the wrist extensions were larger when using the trackball, but lower shoulder lifting was also registered. On both input devices, women made larger movements in terms of outward shoulder rotation and shoulder lifting than the men did.<br>EMG:<br>The EMG measurement data for the right *M. trapezius* showed less activity in using the trackball than in using the mouse. Women generally worked with more muscle activity relative to MVC than did the men (25% of MVC for men, 71% of MVC for women). Of those who worked with their forearms supported (five with the trackball, five with the mouse), all five working with the trackball had the lowest percentage of MVC in the right *M. trapezius*.<br>Height of work surface:<br>Nine test subjects adjusted the workplace in such a way that the desk surface was from | 3 |

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| | | 30 to 90 mm above elbow level, nine set it at less than 30 mm – these showed less activity in *M. trapezius* and *M. deltoideus*.<br><br>Perceived exertion:<br>Only minor differences were found between the two input devices. More fatigue was reported in the hand and forearm regions for working with the trackball than working with the mouse. Twelve test subjects preferred the mouse, eight the trackball, whereas women gave more positive feedback on the trackball than did the men.<br><br>Performance:<br>The mouse and trackball produced only slightly different results in terms of productivity.<br><br>As a general conclusion based on the results, it was found that the input device that allows little movement in the arm with natural shoulder joint postures by way of a supported forearm results in a reduction in muscle activity as measured in the EMG. An input device that allows natural hand and wrist postures with the forearms/hands supported and that is matched to the size of the hand results in a reduction in forearm muscle activity.<br><br>However, the study results also showed major differences for individuals along almost all parameters. They were not consistently positive for one input device. When working with the trackball, for instance, a lower amount of lift and muscle activity was registered for the shoulder, but there were larger angles for wrist extension as well. The use of an arm support reduced the strain or load on the neck and shoulder regions. A work surface that was less than 3 cm higher than the elbows also allowed arm support, thereby lessening the strain in the shoulder muscles without causing test subjects to raise their shoulders unnecessarily.<br><br>Problems:<br>Fifteen minutes of work was judged to be too short for a test period. Only two specific designs of a trackball and one mouse were studied, meaning that the results may not necessarily be transferable to other such devices. | |
| *Keuning, H.; Monne, T. K.; IJsselsteijn, W. A.; Houtsma, J. M.*: The form of augmented force-feedback fields and the efficiency and satisfaction in computer-aided pointing tasks. Hum. Factors 47 (2005), pp. 418-429 | 89 | Other studies found that pointing tasks on the computer could be completed up to 25% faster with the support of force feedback, e.g., when the target area produces the sensation on the pointing device that feels as if a ball were rolling into a hole. This study aimed to determine whether there was an optimum for force feedback and in what manner it should be realized. Twelve test subjects completed directed click-and-point tasks under the following force-feedback conditions:<br><br>• A: Gradual force increase and/or decrease at the beginning and end of a movement<br>• B: Gradual force increase, abrupt force decrease | 2 |

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| | | • C: Abrupt force increase, gradual force decrease combined with two different force levels (340 mN and 140 mN).<br>The efficiency (speed) and satisfaction (assessed by questionnaire) of the test subjects were the parameters for the evaluation.<br>Satisfaction:<br>The test subjects were separated into two groups by the data: one that preferred the higher force feedback level and one that preferred the lower level. No further differentiation in the preferences of the force curve in this group was identified. Force feedback that began abruptly was, however, liked less.<br>Efficiency:<br>The group that preferred the higher level of force completed the tasks faster. The progression of the build-up in force did not appear to influence efficiency; no difference in efficiency was found between A and C. An abrupt decrease in feedback force, however, appeared to be helpful.<br>Various literature sources suggest that force feedback influences performance. This study managed to show that the form of the force feedback also plays a role. | |
| *Kliewer, B.:* More than upside-down mice. Byte 15 (1990), pp. 175-180 | 76 | This was not a scientific article, but instead an opinion review on five (somewhat older) trackball designs.<br>Trackballs should actually be more comfortable than computer mice because the mouse is moved by the entire hand or even the arm, whereas moving a trackball only requires manipulating the ball with the fingers. A trackball also takes up less space because it is in one fixed place. The disadvantage is that a trackball cannot be moved aside as quickly as a mouse can when not in use because the friction under the trackball is greater.<br>General remarks on what criteria should matter when selecting a trackball:<br>• The size of the trackball should match the anthropometrics of the user.<br>• The acceleration curve of the ball is important and partly adjustable.<br>• The smoothness of the ball's movement under good control is necessary for precision work.<br>• The size of the ball, or how much of it protrudes from the housing, plays a role: Larger balls were preferred.<br>• Arrangement, number and functions of the buttons should be taken into account.<br>• It is essential for the software to be compatible.<br>• The ease of cleaning the trackball helps to avoid obstructive dirt build-up inside the trackball; some of the devices allow the balls to be removed easily from the housing socket. | Not a scientific article |

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| | | Can a trackball replace a mouse? It is at least an alternative in case a user experiences problems with using a mouse. | |
| *Lorenz, J.:* Auf Mäusejagd. Tabletts, Trackballs und andere Spezialitäten. Eingabegeräte. Chip, Das Mikrocomputer-Magazin (1992) No. 9, pp. 134-148 | 77 | This was not a scientific study, but instead a trial reviewing various products: two track-balls, a pen-shaped mouse and two pen-and-tablet devices for graphics applications.<br><br>The input devices were each tried out by one man and one woman.<br><br>General conclusions:<br>The advantage of the trackball is its smaller space requirements. Users should try to match the size of the ball to the size of their hands. Significant also is the ease of cleaning the device; e.g., whether the ball can be easily removed.<br><br>The trackballs and the pen-shaped mouse are the most competitive with the traditional mouse. Tablets are unrivalled for graphics applications. | Not a scientific article |
| *Morag, I.; Shinar, D.; Saat, K.; Osbar, A.:* Trackball modification based on ergonomic evaluation: a case study in the sociology of ergonomics in Israel. Int. J. Ind. Ergon. 35 (2005), pp. 537-546 | 81 | The study was performed at workplaces where workers used a trackball while standing. Elbow flexion of more than 30° was found amongst 45% of workers using the trackball, and wrist extension of more than 30° was found amongst 70%. In response to this finding, the following measures were applied in the framework of an intervention:<br>• Increase in the already existing negative slope of the trackball from 9 to 24°<br>• Lateral slope of the trackball around 45° so that a "handshake posture" was achieved<br>• Increase in the height of the work surface, and training in work techniques so that work could be performed with a forearm posture in a median position.<br>A total of 62 test subjects were observed by video over 18 weeks during five shifts of 12 hours each.<br><br>Relevant results: The negative slope of the trackball on the sagittal plane managed to reduce wrist extension (from 34 to 26°). Discomfort was reduced in the test group, but increased in the control group. It was found that a higher degree of wrist extension resulted in all the more discomfort reported by test subjects. After discomfort was reduced, the workers supported themselves less by leaning on the trackball.<br><br>As was the case with the keyboard, benefits were also found here to derive from a reduction of wrist extension by placing the trackball on a negative slope. | 2 |
| *Tittiranonda, P.; Martin, B.; Burastero, S.:* Comparison of muscle activity during use of computer pointing devices in cad operators. In: Proceedings of the Human Factors and Ergonomics Society. 44th Annual Meeting, 29 July to 4 August 2000, San Diego, USA, pp. 633-636 | 4 | Four different computer input devices were compared in this study:<br>• Conventional three-button mouse (which was also otherwise used by test subjects)<br>• Trackball (Logitech)<br>• Joystick mouse (Animax International AS)<br>• Experimental mouse | 2 |

| Literature section | No. | Content | Score |
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| | | Twelve test subjects completed three different tasks (data entry, pointing, tracking) of five minutes in duration at their own respective workplaces. The muscle activities of *M. flexor digitorum superficialis* (FDS), *M. extensor indicis proprius* (EIP), *M. extensor carpi ulnaris* (ECU) and *M. trapezius* (upper portion, UT) were measured by EMG and then evaluated for tonic level, median and peak force. The forearms were rested either on the desk or on the arm rests of the chair.<br><br>In comparison with the other input devices, the use of the conventional mouse was found to result in a tendency towards greater activity in all four muscles measured and along all three evaluation criteria (tonic, median, peak force). The difference for ECU and UT were significant, which indicates an elevated level of ulnar deviation and shoulder lift. The use of the joystick mouse corresponded to higher measurements for activity in ECU and EIP. These results contradict those of *Aaras*. During trackball use, one would expect the pointer finger to be exposed to greater strain. Yet this could not be confirmed in the EMG for EIP. Good values were found in the rest of the results after the EMG readings were evaluated for the trackball in comparison to other input devices: lower tonic strain for ECU than with the joystick mouse and lower activity (median and peak force) for UT than for the conventional and experimental mice.<br><br>In summary, it should be observed that the conventional mouse tended to perform poorly, and the trackball tended to perform well. A specific pattern of strain was identified for each input device. When choosing an input device, decision-makers should not only pay attention to its design, but also to the individual patterns of use and the amount of space available.<br><br>Problem: The provided information is partially inclomplete, e.g., in the design of the experimental mouse. | |
| *Woods, V.; Hastings, S.; Buckle, P.; Haslam, R.:* Development of non-keyboard input device checklists through assessments. Appl. Ergon. 34 (2003), pp. 511-519 | 88 | Eight different computer input devices were evaluated by 27 experts. The selection of devices consisted of two trackballs, one joystick mouse and five other mice with different shapes and numbers of buttons. The tasks to be performed for the tests included clicking, dragging, cutting, pasting, highlighting and scrolling. The tests were each from three to six minutes in duration. The input devices were assessed by way of a questionnaire on handling, performance, design and comfort. The questionnaires also allowed subjective impressions to be recorded in the form of free comments.<br><br>The mice received higher marks overall than the trackballs or the joystick mouse. The standard two-button mouse was the most popular. Two relatively simple three-button mice also received good ratings. Points of criticism that led to the poorer marks for the other input devices were shapes and sizes that were poorly matched to the users' hands, complicated use, imprecise operation, too much force exertion required, pressure points and fatigue arising in the fingers, wrist, arm and shoulder (e.g., for | 1 |

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| | | the joystick mouse), poor reachability for the buttons and inconvenience in grasping the device with the hand.<br><br>Problems:<br>The familiar models were possibly received better than the others because these experts may have been more used to working with them. With a longer period of adjustment to the trackballs and the unusual mouse designs, the evaluations might have been different. Not all of the input devices were tested by all of the experts.<br><br>A checklist was provided to offer support in selecting an input device. | |
| *Zöller, H.; Konheisner, S.*: Fitts' Gesetz bei Maus und Trackball: ein experimenteller Test zur ergonomischen Bewertung von Computereingabegeräten. Ed.: Institut für allgemeine und angewandte Psychologie, Universität Münster 1999 | 87 | A Microsoft Serial Mouse and a Logitech Trackman (button is depressed by the thumb, rolling is done with another finger) were compared with one another in terms of efficiency. The prior study indicated that the mouse is moved across the surface by movement of the wrist and/or forearm, whereas the ball in a trackball is set in motion and stopped by movements of the fingers.<br><br>In the main study, six test subjects completed so many test blocks that no further progress in acclimatisation could be discerned in terms of a reduction in movement time over multiple test blocks with the two input devices. Performance was then measured for move-and-click tasks (horizontal movements only).<br><br>After long periods of practice, the error rates for the trackball and the mouse were nearly identical. The mouse was found to be an average of 129 ms faster than the trackball (for a task duration of around 800 to 950 ms). No significant relationship was established between the difficulty of the task and the input device in question. | 1 |

## Annexe D: Contents of the literature – Pen-tablet

| Literature section | No. | Content | Score |
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| Comparison of postures from pen and mouse use. Ed.: Global Ergonomic Technologies, Guerneville, USA 1998 | 90 | This article compared hand postures of subjects using a mouse with those of subjects using a pen-tablet system from Wacom. The information on postures during mouse use was compiled from a summary of several other studies, and that for the Wacom pen-tablet came from a Wacom study with eight test subjects. No more specific information on this study was given.<br><br>In contrast to mouse use, the use of the pen-tablet stylus did not produce any observed pronation and extension. Nonetheless, minor wrist extension was identified when subjects dragged the pen to draft short lines. Ulnar deviation with the pen was less than 4º, and with the exception of two tasks, it was even less than 1.5º. In contrast, studies with the mouse indicated ulnar deviation of more than 12º. Radial deviation did not appear to be inordinately large on the mouse. One study found median radial deviation of between 2 and 3º. This was less than 2.5º with the pen, and excluding two tasks, it was even less than 1º. Flat buttons on the mouse caused subjects to stretch their fingers. The shapes rounded to the back made a neutral posture more likely. No finger stretching was observed during pen use, and fingers were permanently in a bent posture – all the more the closer the hand grasped the pen near its point. Finger flexion was only observed on the mouse when the mouse was too small to fit the hand. Finger abduction was not observed on the pen, but it was smaller on mice when the buttons were closer together. The pen was mostly operated by the whole forearm. Wrist movements were used to guide the pen only for short cursor movements.<br><br>Overall, fewer deviations from neutral hand and forearm postures were observed with the pen than with the mouse. | 1 |
| *Coll, R.; Zia, K.; Coll, J.:* A comparison of three computer cursor control devices: pen on horizontal tablet, mouse and keyboard. Information and Management 27 (1994), pp. 329-339 | 94 | The contents of this study compared a pen-tablet, a mouse and a keyboard in terms of performance and the preferences of users. Sixty-three test subjects participated in the test. All were experienced in using keyboards as input or pointing devices, but not with using the mouse or the pen-tablet system. Four cursor buttons on the keyboard, tablet and mouse as well as on the pen were used. The scale of the tablet relative to the display screen was 1 : 0.8. The selection function on the pen was performed by tapping on the tablet with it. Subjects used the devices to work with a graphics software program. Three tasks were to be performed: Task 1 – clicking, task 2 – drawing lines, and task 3 – connecting objects. Each test subject completed these three tasks with one of the input devices (one third with the keyboard, one third with the mouse and one third with the pen tablet). As a fourth task, task 1 was repeated, but each test subject used each | 2 |

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| | | input device. This was performed to ascertain preferences, and not performance. The whole test with all four tasks took a total of 45 minutes. The test battery was repeated once again eight days later.<br><br>Tasks 1 to 3:<br>The mouse was the fastest input device, followed by the pen tablet. Tasks performed using the keyboard were completed the slowest. On the other hand, work with the keyboard showed the fewest errors, and the pen showed the most. The effect of learning (the experiments were repeated eight days later) was approximately the same for all three input devices.<br><br>Task 4:<br>For general tasks, the mouse was preferred significantly over the keyboard, and the pen tablet was preferred by significantly fewer test subjects than the mouse and the keyboard. The keyboard was preferred over the mouse for tasks requiring greater precision. Most test subjects avoided the pen tablet for such tasks.<br><br>Summary:<br>Sometimes the choice of the best input device depends on the task that is given! | |
| *Kabbash, P., MacKenzie, I. S.; Buxton, W.*: Human performance using computer input devices in the preferred and non-preferred hands. Proceedings of the ACM Conference on Human Factors in Computing Systems – INTERCHI, New York (1993) | 72 | *See Annexe B* | 2 |
| *Kotani, K.; Horii, K.:* An analysis of muscular load and performance in using a pen-tablet system. J. Physiol. Anthropol. Appl. Human Sci. 22 (2003), pp. 89-95 | 92 | Compared here were a mouse (conventional two-button design) and a pen tablet (Wacom Intuos I-600: 115 mm-long pen, 10 mm thick; tablet of 343 mm by 258 mm).<br><br>The five test subjects had no prior experience using a pen-tablet device. Muscle activity was measured using EMG (*M. trapezius pars descendens*, *M. biceps brachii*, *M. flexor digitorum superficialis, M. extensor digitorum*) along with performance. Test subjects were asked to complete two different tasks (SL and PT) on five different days once each: SL involved connecting two points by drawing a straight line between them with click and drag. PT involved tracing the contours of a polygon displayed on the computer screen. Subjects could rest their wrists on the desk surface.<br><br>Results for SL:<br>The EMG readings for *M. flexor digitorum superficialis* and *M. extensor digitorum* showed the greatest differences. Approximately 5 to 10% less activity was recorded in the EMG for the two muscles when using the pen tablet than when using the mouse. The same tendency was observed in *M. biceps brachii* (activity reduced by around 2.4%). The EMG data for *M. trapezius* showed no differences. Performance with the | 2 |

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| | | mouse was considerably better on the first day than with the pen-tablet. But this changed as early as the second day to the extent that the performance on the pen tablet was better than on the mouse in terms of error rates and time.<br><br>Results for PT:<br>The EMG measurement data showed significantly greater muscle activity in *M. flexor digitorum superficialis* and *M. extensor digitorum* during the mouse use. No differences could be identified for *M. biceps brachii* and *M. trapezius* on this device. The error rate on the mouse was greater than on the pen tablet.<br><br>Summary:<br>In comparison to the mouse, the use of the pen tablet reduced stress on the fingers. Performance, too, was at the same level as, or even higher, in two days on the pen tablet than it was on the mouse. | |
| *MacKenzie, I.; Sellen, A.; Buxton, W.*: A comparison of input devices in elemental pointing and dragging tasks. In: Proceedings of the Human Factors and Ergonomics Society. 35th Annual Meeting, 2 to 6 September 1991, San Francisco, USA. pp. 330-334 | 86 | A mouse (Macintosh mouse), a trackball (Kensington trackball, buttons depressed by the thumb, ball manipulated by the fingers) and a pen-tablet device (Wacom tablet and stylus) were all tested in use by 12 test subjects and compared in terms of performance. The tests in the study involved completing standardized point-and-click as well as dragging tasks.<br><br>Performance in the two tasks was poor when using the trackball; the performance on the mouse and pen-tablet was practically identical for the pointing task, and the dragging task using the pen-tablet was completed the fastest. With regard to error rates, differences between the three input devices were insignificant for the pointing task, and the trackball performed worst in dragging, where the mouse performed best.<br><br>Summary:<br>The trackball performed the worst in the performance tests. The performance for the pen-tablet suggested that it was a good alternative to the mouse. | 1 |
| *Wu, F.; Luo, S.*: Performance study on touch-pens size in three screen tasks. Appl. Ergon. 37 (2006), pp. 149-158 | 91 | Sixteen test subjects tested 12 pen styli of different lengths (80, 110, 140 mm) and different diameters (5.5, 8, 11, 15 mm). These were used with a touch-screen display (115 cm long, 70 cm wide, 74 cm high) that was laid on the desk like a sheet of paper. The tasks included pointing and clicking as well as writing alphabetic letters and tracing shapes (a square, an X and a circle). After ten to 15 minutes of practice, the three tests were performed in series with the 12 different pens. A break was taken after every second pen. The study investigated performance (time per error ratio) and preference.<br><br>Pointing and clicking:<br>The shortest times and fewest errors were achieved using the longest and thinnest pens. This pen was also the favourite of all test subjects. | 2 |

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| | | Writing:<br>Long pens with a median diameter led to better performance than short pens with a fat or thin diameter. Preferences were in line with good performance.<br><br>Tracing shapes:<br>Performance when using long and fat pens was the best. These pens also did best in the subjective impressions of test subjects.<br><br>The gender of the test subjects played no role in the performance on or preference for the any one of the different pens.<br><br>The 80 mm pen had the poorest performance in all three tasks. In comparing pen length with the width of the test subjects' individual hands, it was concluded that a pen should be larger than the width of the user's hand.<br><br>Summary: The long pens registered the better performance and preference values. A pen should not be shorter than the width of the hand. A length of 100 mm was recommended at this point. Thinner pens performed best on point-and-click tasks, fatter pens performed best in tracing shapes, and medium-sized pens performed best in writing. The thickness of the pen should be selected to match the focus of work activities. A thickness of 8 mm was recommended for a pen that is meant to perform various different tasks. | |
| *Wu, F.; Luo, S.*: Design and evaluation approach for increasing stability and performance of touch pens in screen handwriting tasks. Appl. Ergon. 37 (2006), pp. 319-327 | 93 | This study investigated hand posture assumed during the use of a pen-tablet and compared the postures on a conventional pen design and a newer pen design. The pens were used to write directly on a display screen laid horizontally on the desk.<br><br>Movements of the upper extremities and hand postures were observed using video of 30 test subjects who were used to working with pen-tablet input devices. The study asked the subjects to complete three tasks: pointing and clicking, writing and tracing figures. One pen was 140 mm long and 9 mm in diameter, and the newer design had indentations for the hand. The display screen was 10 cm back from the edge of the desk facing the user. In the tests of the newer pen design, performance and subjective perception were also recorded.<br><br>Pointing and clicking:<br>None of the test subjects rested their forearms on the surface; elbows and hands did not have support. The pen was held very loosely and closer to its top so that it was occasionally dropped or such that errors were made due to the unsure grip.<br><br>Writing:<br>Nearly 50% of the test subjects did not rest their forearms on the surface, the other half used the desk or the display screen for support. These supported themselves either on | 2 |

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| | | their wrists and the sides of their hands, on their elbows or – for the largest group (36.7%) – on their smallest fingers. The pen was often held very tightly.<br><br>Tracing shapes:<br>63% of the test subjects used no support, 30% rested the hand on the small finger. Some held the pen with three fingers, some with four or even all five fingers.<br><br>In comparison to these observations, other studies were cited as saying that individuals normally rest their full forearms on the desk surface when writing on paper.<br><br>Extreme wrist postures were observed amongst the various ways of holding the pen: wrist extension in particular when the wrist rested on the screen, wrist flexion when the elbow rested on the desk and extension of the small finger when it was used for support. When asked, test subjects said they did not rest their full forearms on the screen so as not to scratch it.<br><br>New pen with a indentations for the hand:<br>The error rate was reduced significantly for writing and point-and-click tasks, and the time taken to complete the tasks also decreased for the tracing task. The subjective satisfaction corresponded to the good objective results. Moreover, it was observed that the hand postures corresponded to those of neutral posture, and that the stability – without additional support by resting fingers or elbows on the surface – was increased.<br><br>Different designs of this new pen with a strap are described in: *Wu, F. G.; Luo, S.*: Performance of the five-point grip pen in three screen-based tasks. Appl. Ergon. 37 (2006), pp. 629-639. | |

## Annexe E: Contents of the literature – Hand/arm support

| Literature section | No. | Content | Score |
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| *Aaras, A.; Fostervold, K.; Ro, O.; Thoresen, M.; Larsen, S.:* Postural load during VDU work: a comparison between various work postures. Ergonomics 40 (1997), pp. 1255-1268 | 95 | This study investigated the influence of forearm supports on posture and muscle tension in the shoulder-arm system. The study compared seated and standing working positions with and without arm supports during keyboard and mouse use. Furthermore, the influence of the line of sight (15º or 30º below the horizontal plane) was explored. Twenty test subjects completed tests of 15 minutes each in duration. EMG measurements were taken in the area of the *M. trapezius pars descendens* and *M. erector spinae lumbalis* at the level of L3. Inclinometers were also affixed to the forearm, head and back of the test subjects.<br><br>EMG measurements:<br>The tension in *M. trapezius* was significantly greater with the use of a forearm support when working both with a mouse and with a keyboard, and this effect obtained also in the seated and standing positions (seated with forearm supports yielded 0.8% of MVC, seated and standing without forearm supports yielded 3.6 and 2.3% of MVC). The number of periods relative to the overall duration of the tests in which the measured exerted force was beneath 1% of MVC increased significantly with the use of a forearm support, for instance in the right *M. trapezius* it was 35 per minute, or 44% of total time, in comparison to 21 per minute and 10% of total time without the use of forearm supports when seated. The results of *M. erector spinae* also pointed to reduced strain due to the forearm supports. When the mouse was used, the strain or load in the right *M. trapezius* was reduced in the presence of the forearm support (0.1% MVC vs. 1.2% MVC). The time with static tension below 1% of MVC was 79% of total time with support, and only 31% of total time without support.<br><br>Upper arm angle:<br>With the forearm support, the upper arm was more often in the range of -5º (extension) and +5º (flexion) than without, both in the seated and standing positions. The flexion in the back was significantly greater with the rest's support than without (9º when seated with the support, 1º when seated without the support, -3º when standing without the support).<br><br>The angle of the line of sight had no significant effects on the posture and tension in the muscles studied.<br><br>Summary:<br>A forearm support provides advantages in terms of load in *M. trapezius* and *M. erector spinae* independently of whether a mouse or a keyboard is used as the input device. | 3 |

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| *Bendix, T.; Jessen, F.:* Wrist support during typing – a controlled, electromyographic study. Appl. Ergon. 17 (1986), pp. 162-168 | 108 | Twelve secretaries with complaints in the neck-and-shoulder region and/or the radial elbow area were studied as they typed on typewriters, and the influence of wrist supports was investigated with regard to muscle strain or load, performance and acceptance. The wrist supports measured 11 x 65 cm in size and were fitted with load sensors. These supports were placed between the test subject and the desk at a distance of 7 cm from the space bar on the keyboard. Four different situations were tested in which each test subject was allowed to adjust to the set-up for one to two weeks: A – without a support, B – with the support at 1 cm below the space bar (lowest row), C – with the support 0.5 cm above the space bar, D – with the support placed as in C but with the typewriter and support elevated by 3 cm. The conditions for A through C had the lowest row of keyboard keys at the same elevation as the elbow. A task of 15 minutes in duration was performed under each scenario. EMG measurements were recorded for the descending portion of *M. trapezius* and for the proximal portion of the radial wrist extensor.<br><br>Results:<br>The activity in *M. trapezius* was the lowest without a support, and increased in the presence of a support the higher it was placed; the highest values were recorded for the D scenario. The activity in the radial wrist extensor appeared to decrease slightly with the use of a support. When the support was elevated (C scenario), it was used more frequently (contact for 72% of the time as compared with 55% in B). Working under the conditions of D found the least acceptance. Eight test subjects liked the wrist supports, two did not. The performance measurements indicated no significant differences.<br><br>Summary:<br>According to this study, supportive wrist supports should be used with special caution for individuals with pre-existing conditions. If they are used, then, according to the author, it should be a larger support (20 cm) so that the elbows are also supported. Wrist/ forearm supports are probably more useful for tasks requiring more stability (smaller range of motion when working). The keys should also be as low as possible relative to the elbow.<br><br>Problem:<br>This study is dated, and it only considered work on typewriter keyboards, which makes it particularly difficult to transfer the results to computer working conditions with regard to the height of the supports. | 2 |
| *Cook, C.; Burgess-Limerick, R*.: The effect of forearm support on musculoskeletal discomfort during call centre work. Appl. Ergon. 35 (2004), pp. 337-342 | 96 | A group of 59 test subjects recruited at a call centre was divided into two groups; the test subjects of group 1 were given forearm supports starting in the first week and those of group 2 received the forearm supports only starting in the sixth week. The study lasted for 12 weeks. The keyboard was moved into a position in which the forearms could be rested on the desk surface (only the forearm, without the elbow). | 2 |

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| | | Questionnaires on discomfort were filled out by the test subjects before the study, after the sixth week and after the twelfth week. Shoulder flexion was also measured using a goniometer.<br><br>First week:<br>All but one of the test subjects reported having experienced some type of discomfort in the musculoskeletal system within the prior 12 months; one-third were in treatment for such complaints.<br><br>Sixth week:<br>At the beginning of the study, 79% of the subjects in group 1 reported having had some type of complaint within the prior seven days. After the first six weeks of the intervene-tion, this was still 62%. Group 2 saw a slight increase in complaints by 4% after the first six weeks.<br><br>Twelfth week:<br>For both groups, a reduction from 75 to 45% was registered in general discomfort. The share of test subjects that complained of discomfort and pain in the neck, wrists and forearms declined substantially. There was also a reduction identified in the shoulder and back problems, but this reduction was not significant. There were no significant differrences between groups 1 and 2.<br><br>If a computer mouse was used, the complaints in the wrist area for those using a fore-arm support declined from 20 to 6%, in the forearm area from 17 to 6%.<br><br>Subjective feedback: Two test subjects rarely used the wrist supports, 32% used it part of the time, and 64% used it the whole time. Two found the position when using the support less comfortable, 18% judged it the same and 72% found it more comfortable.<br><br>Posture: The median shoulder flexion with the forearm support was 21º.<br><br>Summary:<br>A forearm support can reduce complaints and discomfort within six weeks and is thus to be recommended. | |
| *Cook, C.; Burgess-Limerick, R.; Papalia, S.*: The effect of upper extremity support on upper extremity posture and muscle activity during keyboard use. Appl. Ergon. 35 (2004), pp. 285-292 | 97 | Thirteen test subjects were studied as they typed for 20 minutes under three sets of conditions – with forearm and wrist supports, with only wrist supports and without any supportive rests (control group). The wrist support rests (17 mm high, 65 mm wide, 67 mm long) were placed before a keyboard of equal height. In order to create space for the forearm supports, the keyboard along with the wrist supports were moved toward the keyboard until the forearm could rest on the surface of the desk. To create the conditions without any supportive rests or only with a wrist support, the keyboard was placed 100 mm back from the edge of the desk. The workplace height was set so that the elbow was in approximately 90º of flexion. Measured here were the postures of | 2 |

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| | | the wrists (extension/flexion and ulnar/radial deviation), the postures of the shoulders and elbows (extension and/or flexion), muscle activity (*M. extensor digitorum communis, M. extensor carpi ulnaris, M. trapezius* (upper portion), *M. deltoideus* (front portion)) and discomfort.<br><br>Posture measurements:<br>The forearm support significantly increased shoulder flexion and elbow extension. This was achieved by positioning the keyboard away from the user in the direction of the display screen. The use of a wrist support increased wrist extension by 6 to 8°. With a forearm support, the left wrist extension, in contrast, was significantly lower than in the absence of the support; ulnar deviation decreased under these conditions – albeit insignificantly – by 3°. The proportion of time spent with the wrist in extreme ulnar deviation (< 15°) was nevertheless reduced substantially by 20%.<br><br>EMG measurements:<br>A wrist support resulted in significantly lower muscle activity in *M. trapezius* and *M. deltoideus anterior*. There were no significant differences between the group with forearm supports and the control group.<br><br>Discomfort:<br>All test subjects reported discomfort in one or more body regions during the test. This discomfort was significantly higher in conditions with no supportive supports. The forearm support increased the perception of comfort.<br><br>Summary:<br>The forearm support reduced ulnar deviation, the wrist support reduced the activity in proximal muscles measured in the EMG. The perceived discomfort was greatest in conditions with no supports. | |
| *Delisle, A.; Larivière, C.; Plamondon, A.; Jetté, C.; Marchand, D.; Stock, S.*: The effect of forearm support during computer work: a field study. In: *Pikaar, R. N.; Koningsveld, E. A.; Settels, P. J.* (Eds.): Proceedings of the 16th World Congress of the International Ergonomics Association (IEA) 10 to 14 July 2006, Maastricht, Netherlands. Elsevier, Amsterdam 2006 | 98 | It can take a period of adjustment for an individual to get used to working with his or her arms resting on the work surface (during typing and mouse use), as this requires a change in work technique. A brief laboratory trial may thus not establish any presumed effects of the forearm support. This intervention study was therefore performed over a period of 30 weeks. Twenty-five test subjects were separated into two groups. The keyboard and mouse were moved away from the front edge of the keyboard for group A so that the forearms rested on the desk surface for support (intervention A). The arm supports of the chair were available as forearm supports for group B (intervention B). Both groups were provided additional information on the correct arrangement of the workplace. The measurements were performed before the study, three weeks and 30 weeks after it began. The measurements were taken by EMG derivations of *M. trapezius, M. deltoideus anterior* and *M. extensor digitorum*; posture (inclinometer) of the head, upper trunk and the arm that operated the mouse and the wrist on the | 3 |

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| | | same side (goniometer). Questionnaires were also filled out. For the measurements, standardized computer tasks and normal everyday work was performed for 15 to 45 minutes.<br><br>Greater upper arm flexions were registered in intervention A. Both interventions led to an increase in the pause or break times indicated in the EMG measurements of the front *M. deltoideus* and to a reduction in the pain symptoms in the neck, shoulder and upper back.<br><br>Summary:<br>Both types of forearm supports had roughly the same positive effects on reducing strain and load. The only difference was in the higher upper arm flexion registered with the support placed on the desk. | |
| *Erdelyi, A.; Sihvonen, T.; Helin, P.; Hanninen, O.:* Shoulder strain in keyboard workers and its alleviation by arm supports. Int. Arch. Occup. Environm. Health 60 (1988), pp. 119-124 | 99 | This study was performed with 20 test subjects, of which 12 suffered from pain in the shoulder and the neck. The subjects were asked to type a text under different condi-tions: without or with two different arm supports (fixed and hanging) and with different degrees of elbow flexion (70º, 90º and 105º angles). The muscle activity in the upper right *M. trapezius* was measured, and the test subjects reported on their subjective impressions.<br><br>The EMG readings decreased with an increase in elbow angle. Amongst the test subjects with pre-existing complaints, muscle activity in *M. trapezius* was reduced with both types of supports. This effect was not consistently found amongst the healthy test subjects.<br><br>Although the supports resulted in reductions in muscle activity at least amongst the test subjects with pre-existing complaints, these subjects still reported that typing under these conditions was uncomfortable; typing without any supports was perceived as the most comfortable subjectively.<br><br>Summary:<br>In the elbow flexion range that was measured here, greater angles resulted in less acti-vity of the *M. trapezius* in the EMG readings. Forearm supports were recommended for individual with existing complaints. | 2 |
| *Feng, Y.; Grooten, W.; Wretenberg, P.; Arborelius, U.*: Effects of arm support on shoulder and arm muscle activity during sedentary work. Ergonomics 40 (1997), pp. 834-848 | 100 | Different forearm support rests were tested on 12 test subjects performing different seated tasks. The test subjects were asked to depress a keyboard combination of five keys for 20 seconds. The muscle activity in *M. deltoideus pars anterior* und *pars lateralis, M. trapezius pars descendens* (upper portion) and *M. extensor carpi radialis brevis* was measured using EMG. Three different supports were tested. FIX: a fixed 280 x 130 mm large plate that supported the forearm/elbow and could be affixed to the edge of the desk; SLA: a 200 mm long "see-saw" that was adjustable in all directions | 2 |

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| | | and with a spring force of 10 N to support the elbow and forearm; HOR: a horizontally movable, concave-shaped support for elbow and forearm that could be attached to the edge of the desk. Measurements were also taken in the absence of the arm supports.<br><br>A significant reduction in the muscle activity of *M. deltoideus anterior* was apparent when subjects typed with a forearm support in comparison to typing without any support. In this muscle group, there was an apparent reduction in activity between FIX and the other two supports. No significant differences were registered for *M. extensor carpi radialis* with or without the arm supports. The upper portion of *M. trapezius* showed a slight increase in activity with the presence of an arm support.<br><br>Problem: The tests were very brief, and the study is less definitive for this reason. | |
| *Fernström, E.; Ericson, M.:* Computer mouse or trackpoint – effects on muscular load and operator experience. Appl. Ergon. 28 (1997), pp. 347-354 | 101 | Five different situations were tested with 20 test subjects:<br>• Use of a keyboard<br>• Use of a keyboard with a Microsoft Serial Mouse 2.0<br>• Use of a keyboard with a Microsoft Serial Mouse and an arm support (affixed to the chair) that was adjustable on three planes<br>• Use of a keyboard with a Trackpoint (small joystick) in its centre<br>• Writing with a normal pen<br>The given tasks were for 15 minutes each and consisted of typing and editing text, or using the pen to write out a text. EMG measurements were taken of muscle activity (in *M. trapezius pars descendens* left and right, *M. deltoideus* right, *M. flexor digitorum superficialis* right, *M. extensor digitorum* right, *M. extensor carpi ulnaris* right). Postures and movements were determined using video images. Furthermore, the test subjects were asked to fill out a questionnaire.<br><br>Trackpoint vs. mouse without supports:<br>Use of the trackpoint did reduce shoulder strain, but, contrary to expectations, it increased strain in the forearm in the form of greater muscle activity in the EMG. The actually presumed, more neutral postures in using the trackpoint rather than the mouse were also disproved in the video images, and this helped to explain the results. The hand of the test subject was always very close to the trackpoint, and this required ulnar deviation to operate the buttons on the right.<br><br>Keyboard alone vs. trackpoint:<br>Use of the keyboard alone resulted in greater strain on the right-side shoulder muscles in contrast with use of the trackpoint.<br><br>Keyboard alone vs. mouse:<br>The EMG measurement figures in this comparison indicated greater strain in the forearm muscles during work with the keyboard. | 3 |

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| | | Mouse with forearm support vs. without support:<br>The forearm support reduced the strain in shoulder muscles, but increased strain in the forearm in return. The movements were thus not performed by utilising the movable support for the arm, but instead performed by using the wrist. The positive effect for the right-side trapezius muscle was low, presumably because most of the test subjects automatically rested their forearms on the desk surface while working. Despite the presence of the forearm support, the test subjects did not perceive any relief for the shoulder region.<br><br>Keyboard without supports and the trackpoint:<br>The finger flexors here were under greater strain than with the mouse. The test subjects reported greater strain in these situations.<br><br>Handwriting with a pen:<br>Muscle activity in the forearm and in the extensors and flexors was elevated.<br><br>Summary:<br>One possibility for reducing strain in the shoulder muscles, according to this study, is to use a trackpoint device that is integrated into the keyboard or to use a mouse with a forearm support. Muscle activity in the hand and forearm, however, increased in return when using these two work methods. | |
| *Hasegawa, T.; Kumashiro, M.:* Effects of armrests on workload with ten-key operation. Appl. Hum. Sci. 17 (1998), pp. 123-129 | 102 | A chair with height-adjustable arm rests that were to be used for arm support during keyboard work was tested by eight test subjects. The arm rests here were 8 cm wide and 31 cm long. Two keyboard positions were tested: The keyboard was placed right against the edge of the desk or set 8 cm back from the edge so that the test subjects could rest their wrists on the desk surface. These two keyboard positions were each combined with different arm rest settings during the series of trials: with a vertical distance of the arm rests to the char seat of 22 cm, 24 cm, 26 cm and no arm supports. Each task lasted for 60 seconds. Five-digit numbers were to be entered into a numeric keypad to the right of the keyboard using the subject's right hand. Measurements were taken of the performance and the electrical activity of the muscles using EMG: *M. trapezius* upper and middle sections (right and left), *M. deltoideus* (both sides), *M. biceps brachii* (right) and *M. flexor carpi radialis* (right). This was followed by an interview on the perceived comfort. Force measuring sensors were to provide insights into the loads on the arm rests during typing.<br><br>Performance:<br>In the scenario with the arm rests (24 cm above the chair seat) and with the keyboard set 8 cm back from the edge of the desk, significantly more numbers were entered than in the trial series without arm rests on the chair or with the arm rests (22 or 26 cm above the chair seat) and the keyboard at the edge of the desk. | 2 |

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| | | EMG:<br>Significant differences in muscle activity were only identified on the right side of the body. The greatest amount of muscle activity was measured in the scenarios without arm rests and the keyboard positioned at the edge of the desk.<br><br>Force on the arm rests:<br>When the keyboard was placed at the edge of the desk, greater force was measured on the arm rest than when the keyboard was moved back from the edge by 8 cm.<br><br>Subjective perception:<br>Over half of the test subjects reported fatigue in the right shoulder and in the right upper arm after completing the task without chair arm rests and with the keyboard positioned at the edge of the desk. Only around 50% reported the same fatigue without chair arm rests and with the keyboard positioned 8 cm back from the edge of the desk. All subjects preferred to work with the chair arm rests. The shortest test subject preferred the keyboard positioned at 0 cm, all others at 8 cm.<br><br>Summary:<br>The strains on *M. trapezius* (upper and middle sections), *M. deltoideus* and *M. biceps brachii* on the right side were reduced by allowing the wrist to rest on the desk for support by moving the keyboard a little bit back from the edge of the desk. Furthermore, the use of the chair arm rests as forearm supports helped to lower muscle strain. The more advantageous height of the chair arm rest for reducing muscle activity was different for each individual; no clear correlation could be established with bodily dimensions. Chair arm rests are to be recommended in particular whenever the desk cannot be adjusted for height and the users cannot rest their wrists on the desk.<br><br>Problem:<br>The study was only performed on a small number of test subjects. Moreover, only a numeric keypad was used with only the right hand. | |
| *Hedge, A.; Powers, J.*: Wrist postures while keyboarding: effects of a negative slope keyboard system and full motion forearm supports. Ergonomics 38 (1995), pp. 508-517 | 32 | *See Annexe A* | 2 |
| *Karlqvist, L.; Bernmark, E.; Ekenvall, L.; Hagberg, M.; Isaksson, A.; Rosto, T.*: Computer mouse position as a determinant of posture, muscular load and perceived exertion. Scand. J. Work Environm. Health 24 (1998), pp. 62-73 | 68 | *See Annexe B* | 2 |

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| *Karlqvist, L.; Bernmark, E.; Ekenvall, L.; Hagberg, M.; Isaksson, A.; Rosto, T.:* Computer mouse and track-ball operation: Similarities and differences in posture, muscular load and perceived exertion. Int. J. Ind. Ergon. 23 (1999) pp. 157-169 | 80 | *See Annexe C* | 3 |
| *Kotani, K.; Barrero, L.; Lee, D.; Dennerlein, J.:* Effect of horizontal position of the computer keyboard on upper extremity posture. Ed.: Department of Systems Management Engineering, Osaka, Japan and Department of Environmental Health, Boston, USA | -- | This study investigated the influence of the keyboard's position on the desk – its distance from the edge of the desk – with 20 test subjects. Four conditions were tested under which subjects were asked to type and read and fill out forms for two minutes:<br>• NEAR: the keyboard was at the edge of the desk<br>• MID: the keyboard was 8 cm back from the edge of the desk<br>• FAR: the keyboard was 15 cm back from the edge of the desk<br>• FWP: as in FAR, but with a wrist support dimensions: 130 mm x 520 mm and 12.7 mm thick<br>Wrist postures (extension/flexion and ulnar/radial deviation) were measured using an electrogoniometer and electromagnetic movement analysis was performed of supination/pronation in the forearm and of the elbow angle as well as the flexion and abduction in the forearm.<br>Ulnar deviation was reduced the farther the keyboard was placed back from the edge of the desk. The angle of the wrist extension was all the greater in return. The extension in the wrist when using the wrist support, however, was reduced when using the FWP down to the value that was measured in NEAR. Supination did not change. The elbow angle increased from 89.9 to 107° with an increase in the distance of the keyboard away from the edge of the desk. The wrist support had no effect here. Shoulder flexion also increased with the distance between the keyboard and the edge of the desk. Abduction and inward rotation were greatest for NEAR.<br>Summary:<br>Ulnar deviation was reduced to nearly neutral wrist posture at greater distance between the keyboard back from the edge of the desk (FAR 4°, MID 5°). Yet, because wrist extension also increased in the process, the use of a wrist or forearm support was recommended that had brought the extension values back down to the NEAR level due to the height of such supportive rests. Important in making a choice for a support is making certain that it has no sharp edges that could cause pressure points against the skin. | 2 |
| *Lintula, M.; Nevala-Puranen, N.; Louhevaara, V.*: Effects of Ergorest arm supports on muscle strain and wrist positions during the use of the mouse and keyboard in work with visual display units: a work site | 103 | This study tested forearm supports from Ergorest. These can be affixed to the edge of the desk, are adjustable for height and provide moveable concave supports in which users can place their forearms. Twenty-one test subjects tested the supports over six weeks; the subjects were divided into three groups: Group 1 worked with an Ergorest | 3 |

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| intervention. Int. J. Occup. Saf. Ergon. 7 (2001), pp. 103-116 | | only for the arm that operated the mouse. Group 2 had two Ergorests. Group 3 was not provided with any supports.<br><br>Before and after the six weeks during which standardized tasks were performed, measurements were taken on muscle activity (*M. trapezius descendens* and *M. extensor digitorum* each for right and left), wrist postures (extension/flexion and ulnar/radial deviation) and subjective perception of muscle tension (in the neck, shoulders, upper arms, forearms, wrists, hands, fingers). The measurements were performed as subjects used the mouse and the keyboard over a period of ten minutes.<br><br>EMG measurements:<br>The use of forearm supports significantly reduced the muscle activity in the left *M. trapezius* in group 2 during mouse and keyboard use. Yet the measured values for the control group also decreased after the six weeks for keyboard use.<br><br>Wrist posture:<br>The measured angles in the right-side wrist extension for group 2 came in at approximately 10º smaller than in groups 1 and 3. The left-side ulnar deviation decreased slightly during typing for groups 1 and 3, whereas it increased slightly for group 2.<br><br>Subjective muscle tension:<br>No significant differences between the groups were identified either before or after the intervention.<br><br>The Ergorests were received very differently by different individuals. Yet there were no negative comments from group 2, and the advantages were particularly noted during longer periods of typing. If the typing was interrupted frequently and the job tasks were changed more often, the test subjects found the Ergorests to be inconvenient because it took too long to find a comfortable position again when readjusting the Ergorests. Group 1 complained that the use of only one Ergorest caused them to make too many mistakes.<br><br>Summary:<br>Major differences between individuals were observed. The Ergorest arm supports are only recommended for use on both sides, in particular for longer periods of typing. Ergorests are not recommended for ergonomic workplaces in which other types of forearm supports can be used. | |
| *Marcus, M.; Gerr, F.; Monteilh, C.; Ortiz, D.J.; Gentry, E.; Cohen, S.; Edwards, A.; Ensor, C.; Kleinbaum, D.:* A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. Am. J. Ind. Med. 41 (2002), pp. 236-249 | 34 | *See Annexe A* | 3 |

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<tr><th>Literature section</th><th>No.</th><th>Content</th><th>Score</th></tr>
<tr><td>Rempel, D.; Krause, N.; Goldberg, R.; Benner, D.; Hudes, M. Goldner, G.: A randomised controlled trial evaluating the effects of two workstation interventions on upper body pain and incident musculoskeletal disorders among computer operators. Occup. Environm. Med. 63 (2006), pp. 300-306</td><td>104</td><td>This prospective study investigated 182 workers at a call centre over a period of one year; none of the workers had any complaints of pain in the neck, shoulders or upper extremities. Four interventions were performed for the study.<br>• A: Ergonomic training<br>• B: Trackball and ergonomic training<br>• C: Forearm support and ergonomic training<br>• D: Forearm support, trackball and ergonomic training<br>The ergonomic training consisted of instruction in how to correctly arrange the workplace with respect to the position of the mouse or trackball, seated posture, settings for the height and tilt of the computer monitor, etc. The trackball in the study was a Marble Mouse by Logitech with a ball of 4 cm in diameter. The test subjects reported weekly on their incidents of pain: If such complaints exceeded a specified limit, medical tests were undertaken.<br><br>Over the 52-week period, 102 test subjects reported incidents of pain in the upper body regions. Specific diagnoses were made on 77 of these after a physical examination, 39 of them pertained to the neck/shoulder region, 29 the upper right extremity and 17 the upper left extremity.<br><br>The test subjects in the intervention groups reported fewer incidents in comparison to the control group. The arm supports reduced the risk of neck/shoulder problems by nearly half. The supports also provided marginal advantages in the upper extremities. The B intervention only yielded modestly significant reductions in incidents of pain in the upper left extremities, but not in the upper right extremities, even though 98% of the test subjects used the mouse or trackball with their right hands. No significant differences in productivity were identified.<br><br>It is important for an arm support to be of the proper shape and dimensions in order for positive effects to be achievable. The forearm supports in this study were affixed in front of the keyboard, and were designed to be narrow in the middle, 30.5 cm deep from the side and 76.2 cm in overall length (thus longer than the keyboard itself). The supportive rest supported the middle of the forearm, and not just the wrist, where the tendons and nerves are relatively close to the skin. The forearm support also helped to reduce wrist extension, as it reduced the relative height of the keyboard.<br><br>Summary: An arm support helped to reduce the incidents of pain in particular in the neck/shoulder region. It was noted that it would take several weeks before any positive effects would become apparent. The trackball only provided modestly significant relief for the upper left extremity. The study made no mention of the results of the other ergonomic interventions.</td><td>2</td></tr>
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| *Sillanpää, J. N.; Uitti, J.; Takala, E.; Kivi, P.; Kilpikari, I.; Laippala, P.*: Muscular activity in relation to support of the upper extremity in work with a computer mouse. Int. J. Hum.-Comp. Interaction 15 (2003), pp. 391-406 | 106 | Laboratory studies were performed on 14 mouse users as they worked with a mouse in conjunction with forearm and wrist supports. In studies with forearm supports, the mouse pad was placed directly beside the keyboard at the back end of the desk so that the forearm could be rested on the surface of the desk. In studies with wrist supports, a mouse pad with a wrist cushion (20 mm thick) was used that was placed beside the keyboard at the edge of the desk. The desk surface was adjusted at 1 cm above the level of the elbow. The tasks carried out for the studies were short, i.e., lasting 75 seconds, in which the fatigue caused by changes in posture was to be avoided. An EMG was derived for the following muscles: *M. extensor carpi radialis, M. extensor carpi ulnaris, M. flexor carpi radialis, M. flexor carpi ulnaris, M. deltoideus anterior* and *medialis, M. infraspinatus, M. trapezius pars descendens*. In addition to the EMG measurements, the test subjects were equipped with reflective markers and recorded on video as they worked. Furthermore, the test subjects reported on their subjective impressions.<br><br>EMG measurements:<br>The muscle activities of *M. trapezius* (static, medium and maximum) and the static loads on *M. deltoideus anterior* were significantly lower when work was performed using the forearm supports. An increase in loads, however, was indicated for *M. infraspinatus* (shoulder outward rotation). EMG measurements showed a lower level of activity in *M. extensor carpi radialis* with forearm support and in the flexors with a wrist support.<br><br>Hand postures:<br>Wrist extension was the same under both sets of conditions. With the use of forearm support, ulnar deviation was more pronounced (5.7 to 2.9º) and present over a longer period of time (30 to 25% of the time > 5º).<br><br>Subjective impressions:<br>The test subjects favoured the use of forearm support by a small margin.<br><br>Summary: The forearm support, in comparison with the wrist support, led to a decreased strain on the musculature of the shoulder region. The extensors in the forearm region were under less strain during work with the forearm support, and the flexors were under more strain. This finding correlated with the results of the wrist analysis; here, the use of a wrist support corresponded to lower ulnar deviation. The test subjects saw moderate advantages in using the forearm support. | 2 |
| *Smith, M.; Karsh, B.; Conway, F.; Cohen, W.; James, C.; Morgan, J.; Sanders, K.; Zehel, D.:* Effects of a split keyboard design and wrist rest on performance, posture, and comfort. Hum. Factors 40 (1998), | 105 | Eighteen test subjects tested two keyboards over five days: a conventional keyboard and an alternative that featured a split numeric block and split halves that were turned outward. Half of the test subjects worked with wrist supports, the other half worked without any. | 2 |

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| pp. 324-336 | | Performance:<br>Test subjects who did not use any supports showed no signs of any difference between the first and second day; performance amongst those using the support improved. The test subjects using the wrist support reported having more control over their typing and reported experiencing greater comfort. Among test subjects who worked without any supports, a more pronounced extension in the wrist (left) was observed. All differences, however, were only slight. | |
| *Stack, B.*: Keyboard RSI: the practical solution. Muden Publishing Company, Tasmania, 1987 | 31 | *See Annexe A* | Not a scientific study: book version of an individual's personal experiences |
| *Visser, B.; de Korte, E.; van der Kraan, I.; Kuijer, P.*: The effect of arm and wrist supports on the load of the upper extremity during VDU work. Clin. Biomech. 15 (2000), pp. 34-38 | 107 | Ten female test subjects completed a task lasting eleven minutes while using a mouse and then using a keyboard under five sets of conditions: no hand/arm support (WS), with two different forearm supports (EA and ER) and wrist supports (TT and TC). The forearm supports consisted of two concave holders that could be affixed to the edge of the desk and were movable on the horizontal plane. There were differences in the size and structure of the joints. The two wrist supports were also affixed to the edge of the desk and were made of different materials and in different sizes. The activity of *M. trapezius descendens* on the right was measured and evaluated; measurements were described relative to MVC: in the tenth percentile (P10) as static values, in P50 in the median and in P90 in the extreme. Subjective assessments of the test subjects were also recorded.<br><br>Keyboard: P10, P50 and P90 values were significantly lower during the use of the fore-arm support EA in comparison to the other four sets of conditions. The use of ER led to a lower P90 level in comparison to TT, TC and WS. The values under conditions of TT were higher for P10, P50 and P90 in comparison to WS and with the other supports. The value for P90 with TC was lower than with WS.<br><br>Mouse: The use of TT also led to higher values during mouse use in comparison to those that were measured under all the other test conditions. P10, P50 and P90 were lower under EA and EC than under TT and TC. The P90 value was lower without supports than when TC was used to support the wrist.<br><br>Subjective assessmemts: Only one significant difference was identified here: TC was preferred over EA because of the former's higher evaluations for comfort in the hand/wrist region. | 2 |

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| | | Summary:<br>The results from the EMG measurements speak for a positive effect of arm supports on muscular loads. Wrist supports in part even coincided with negative influence on the loads of *M. trapezius*. The assessment according to the subjective impressions of the test subjects did not agree with the EMG results. This may have been due to the short test phases.<br>Problem: No number of test subjects was stated. | |
| *Woods, V.; Hastlings, S.; Buckle, P.; Haslam, R.*: Ergonomics of using a mouse or other non-keyboard input device. Ed.: University of Surrey and Lough-borough University 2002 | 3 | *See Annexe A* | 2 |