Ergonomic Requirements for Input Devices

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Abstract. The aim of this literature research was to gather information on ergonomic requirements for input devices that are provided by investigations applying biomechanical criteria. Firstly, international and national standards, guidelines as well as checklist of this topic had been looked for and their propositions were summarised. Secondly, a query on Internet search engines and databases had been conducted. A ranking system for the selected articles had been installed in order to comprehensibly rate the information obtained from each study. For every regarded input device, i.e. keyboard, mouse, trackball, graphic tablet/stylus and additionally forearm/wrist support, biomechanically based assessment parameters were deducted and outlined. Finally, these findings were discussed with respect to the recommendations of the standards and an overall ergonomic design of office workplaces with VDTs. In conclusion, this will lead to the development of a checklist for keyboards and mice that should be evaluated by occupational health practitioner.

Keywords: office ergonomics - input devices - musculoskeletal disorders-biomechanical criteria.

1 Introduction

Nowadays, the use of a computer and consequently of input devices is hardly indispensable at most workplaces and therefore widespread. Even though computer work and operating input devices do not seem to be a physically demanding work, a link between work-related risk factors and musculoskeletal disorders especially of the upper limb is described in the literature [1]. In this context, national and international standards concerning ergonomics at office work with visual display terminals (VDTs) do not provide precise, physiologically/biomechanically based criteria to support practitioners in Occupational Safety and Health in evaluating the ergonomic suitability of input devices. Nevertheless, the standard EN ISO 9241-9 gives information on instruments and methods that could only be employed by experts and allow for objective analysis of the exposure to biomechanical stress. By this, researchers in the field of office ergonomics should be encouraged to use these methods during studying the ergonomics of input devices and to give scientifically based further recommendations. In order to gather and summarise the results of such studies, the VBG, the Institution of statutory accident insurance in the field of administration, initiated a literature review on this issue that was conducted by the BGIA.

2 Methods

At first, national and international standards as well as guidelines and existing checklists that treat “ergonomic” design of input devices had been found out.

Secondly, in search for international articles of the last twenty years a query on Internet search engines and databases, e.g. those of the Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (German Federal Institute of Occupational Safety and Health) and of the Berufsgenossenschaften as well as CiteSeer, Compendex, Forschungsportal.net, GoogleScholar, Inspec, and Pubmed, had been executed. English and German search terms had been the following nouns: keyboard, mouse, trackball, graphic tablet and pen and/or mouse, joystick and touch screen in various combinations with computer, office workplace, data input devices, input devices, ergonomics, peripheral equipment, and so on. If the query results exceeded the number of 1000 papers, the query would have been refined. As few papers that deal with the use of joysticks or touch screens at office workplaces could be found, these subjects were excluded from further investigation. The amount of query results necessary to carry out a sound appraisal of studies was only reached for the search terms keyboard, mouse and trackball. During the literature research, forearm and/or wrist supports emerged as an important influencing factor on assessment of input device ergonomics, so that the search terms arm rest, arm support and similar expressions had been added.

First selecting criterion for papers had been the relevance of the topic in the underlying study. Papers had been sorted out, if the underlying studies did not deliver information on ergonomic requirements for input devices and if no biomechanical criteria had been applied for the assessment. Then the study design and the applied methodology of each remaining article had been assessed and ranked in order of relative quality. For this procedure, six criteria (number of test subjects, collection of data, investigation schedule, kind of work/task, control group/comparison group, statistical analysis) and the conditions under which they were met or not had been defined. If all criteria were fulfilled the quality of the study was estimated as very good (3); studies that achieve the conditions of at least three criteria were marked as good (2); otherwise (less than three criteria met) the score was fair (1). This ranking was installed to comprehensibly rate the information obtained from a study.

3 Results

The results will be outlined once as a summary extracted from existing standards, guidelines or checklists and once as findings drawn from the appraisal of the literature.

3.1 Review of Standards, Guidelines and Checklists

Table 1 gives an overview of the relevant standards, guidelines or checklists that define parameters of input devices’ design and propose certain metrics.

Table 1. Relevant standards, guidelines or checklists and their topics

Standard/Guideline/Checklist	Topic
EN ISO 9241-400 [3]	Input devices in general
EN ISO 9241-4 [4]	Keyboard
EN ISO 9241-5 [5]	Forearm/wrist support
EN ISO 9241-9 [2]	Various input devices, excepting keyboard
ISO/CD 9241-410 [6]	Various input devices
Arbeit mit dem Bildschirm aus dem Handbuch der Arbeitsmedizin [7]	Keyboard, mouse
Bildschirm- und Büroarbeitsplätze. Berufsgenossenschaftliche Information (BGI) Verwaltungs-Berufsgenossenschaft (VBG) [8]	Keyboard, mouse
Guidelines to the selection and purchase of workstation furniture and equipment. Human Resource Management Division (HRM), New Zealand [9]	Keyboard
Health and safety regulations. Workstation risk assessment questionnaire. Health and Safety Executive (HSE), England [10]	Keyboard
Ergonomics for the Prevention of Musculoskeletal Disorders. Swedish National Board of Occupational Safety and Health, Sweden [11]	Various input devices
Guidelines on office ergonomics, CSA-Z412. Canadian Standards Association (CSA) International, Canada [12]	

Summary for keyboard. Regarding the tilt of a keyboard a front-to-back inclination is generally recommended and mostly in the range from 0° to 15° [4], [6], [8], [9], [11]; only one guideline prefers a smaller tilt of 10° at maximum [7].

Although 30 mm are frequently defined as the limit for the height [7], [8], [9], [11], two standards find 35 mm also acceptable as maximum, but would advise 30 mm [4], [6].

The width is not specified in the mentioned references, the single allusion concerning this measure is the vague expression “not further extended than required by mechanical considerations” [6].

If the depth of the desktop - that means the space between the computer display and keyboard is restricted, the keyboard should be as small as possible [6].

The appropriate key switch design is described in terms of key displacement (acceptable 1,5mm - 6 mm and optimum 2 mm - 4 mm) [4], [6], [8], key switch make force (tolerable 0,25 N- 1,5 N, ideal 0,5 N - 0,8 N) [4], [6], [7], and key switch force-displacement characteristics like snap action, ramp action, and initial resistance (25 % - 75 % of the force at the character generation point for ramp action or at the snap point for snap action) [4, 6].

Summary for mouse. With regard to the ergonomically relevant properties of the mouse the following more or less detailed propositions from the standards and checklists could be condensed.

The mechanical design of the housing and the buttons should allow for a relaxed, comfortable posture of the hand and fingers [9]. Buttons should have a displacement force within the range of 0,5 N - 1,5 N until actuation and a displacement from a minimum of 0,5 mm to a maximum of 6 mm [6], [12] The fingers should be able to make contact and actuate buttons without excessive deviation from a neutral posture [2]. Input devices should be operable by either hand; or right and left-handed devices should be available [6], [8], [11]. Mouse should be placed at the same level as the keyboard [9] and in such way, that it could be handled without arm abduction or wrist extension [12].

Summary for trackball. In addition to the recommendations for general design aspects of input devices like housing, button design, handedness and so on (see Summary for mouse) the special design requirements for trackballs are mentioned below.

The chord length of the exposed area of the trackball should be at least 25 mm [2], [6]. The exposed arc, measured from the centre of the trackball should be not less than 100° and not greater than 140°. The recommended exposed arc is 120° [2], [6], [12].

The permitted range of actuation rolling force goes from 0,2 to 1,5 N; the starting resistance should be 0,2 to 0,4 N [2], [6], [12].

Comparing mouse and trackball user compatibility the trackball use achieves a lower level of effectiveness and efficiency. Unintended loss of control may occur more often as well. Trackballs may prove more appropriate for most applications with a graphical interface or in any environment with limited space. As trackballs are susceptible to environmental influences, i. e. vibration, instable work surface, and especially dust, the ball shall be easily removable for cleaning [6].

Summary for graphic tablet/stylus. The peculiar design requirements on graphic tablet/stylus are outlined herewith.

The design (height depth and slope) of the tablet that is incorporated into the workstation should allow the user to adopt the design reference posture [6].

Cylindrical styli should have a length between 120 mm and 180 mm and a diameter from 7 mm to 20 mm. The mass should be between 10 g and 25 g [2], [6], [12]. Buttons surfaces should be perpendicular to the displacement direction and to the motion of the finger during flexion [6], [12]. A selector button should feature a contact surface with a circular area not smaller than 5 mm in diameter [2], [6], [12]. The displacement force of buttons may range from 0,3 N to 1,5 N until actuation and the displacement may vary from 0,5 mm to 6 mm [2], [6].

For intermittent input against the tablet, the maximum force required for input should not exceed 1,0 N and for continuous input using styli, the activation force for the stylus on the tablet should not be greater than 1, 5 N [2], [6]. However, the Canadian Guidelines on office ergonomics prefer an activation force limit for styli on he tablet during continuous input of 0,5 N[12].

Summary for forearm/wrist support. Instructions how to realise sufficient support for the forearm and/or wrist are given in very different ways. The most tentative statement was to provide enough place for the hands and arms [10]. Other standards and guidelines specify the interspace needed in front of a keyboard from over 50 mm [7] up to 100 mm at minimum [4], [5], [6], or in front of a wrist support from 100 mm to 150 mm [8].

3.2 Review of the Literature

Table 2 shows the number of papers found for several input devices and forearm/wrist supports in order of quality score.

Table 2. Number of papers categorized by type of input device in order of quality score

Number of papers for (total number)					
Score	Keyboard (30)	Mouse (34)	Trackball (14)	Graphic tablet/stylus (5)	Forearm/wrist support (21)
1	2	3	4	1	0
2	19	20	7	6	14
3	6	6	2	0	6

Remark 1. This literature could be asked for at the author.

The risk factors of the work with input devices that are accused to cause musculoskeletal disorders of the upper extremity had been identified as awkward respectively static postures, exerted force and repetitiveness. While in most cases an improvement of repetitiveness could be achieved by organisational restructuring of the office work and tasks, an “ergonomic” design of input devices could help to tackle both first mentioned problems. In the reviewed literature such design solutions had been investigated and evaluated by means of measurements of postures, electrical muscle activity (EMG), and performance, as well as of subjective ratings of perceived exerted force or comfort/discomfort and disorder questionnaires.

Summary for keyboard. The observed postures of the upper extremity during keyboard use had been described as extension of 8° - 20° and ulnar deviation of 10° - 20° for the wrist and a nearly wholly pronation (80°) of the forearm [13], [14], [15]. New designs of keyboards that enable the user to adopt a more neutral posture had been launched: keyboards with a negative slope target the extension, angling or separating two halves of the keyboard and for example synclinal shaped keypads should reduce the ulnar deviation, lateral tilted or vertical orientated keyboard sections should promote the neutral forearm posture. The analysis of the study results on these keyboard designs suggests an ergonomic benefit by using keyboards with a slightly changed design, i. e. negative slope of ca. 7°, angling of halves of about 25° and a slight lateral tilt. This recommendation is especially valid for VDU workers who know ten-key typing.

For keyboard users who already report health complaints like paraesthesia of the hand, changes of the key switch displacement-force characteristics might to be useful

[16]. Furthermore, a decrease of exerted force seemed to be achieved more efficiently by reducing the typing speed [17].

Summary for mouse. The deviations from the neutral posture during mouse use could be characterised as the following: wrist extension in the range from 15° - 30°, ulnar deviation between 5° and 18°, shoulder flexion up to 30° and arm abduction of 30° to over 40°, outer rotation in the range from 5° to 45° [18], [19], [20], [21], [22], [23], [24], [25]. Hand-contoured mouse design - sometimes adapted to individual hands - and ideas to shape the mouse like a joystick or a pencil in order to avoid the pronation of the forearm had been realised. Several investigations approve the positive effects on disorders and muscle activity brought about by such new designs. [21], [26], [27] [28], [29], [30], [31].

Other factors sustainably influencing the ergonomics of mouse use are the position of the mouse on the desk top, the combined use with other input devices and the operation methods.

Summary for trackball. Often, the examinations of trackballs were comparisons between trackball and mouse. The results of these studies were somewhat contradictory in dependence of particular designs of the used trackball, individual differences in test persons and the tasks carried out during the tests. Overall, it seems that the trackball requires more finger movements than a mouse [32], the ulnar deviation is smaller but the dorsal flexion of the hand is greater. An easier change from the dominant hand to the other in operating a trackball [33] and the option of stationary use are estimated advantageous.

Summary for graphic tablet/stylus. Study results support the opinion that graphic tablets handled with a stylus represent a real alternative to the mouse.

Summary for forearm/wrist support. The possibility to perform data input using any devices with supported forearm are released favourable. Forearm supports could be implemented in the workstation by providing a desktop of sufficient depth, arm rests of the office chair or separated arm rests. In every case the overall workplace ergonomics must be taken into account.

4 Discussion

Physiologically/biomechanically based criteria to assess the design of input devices from the ergonomic perspective could be extracted from the reviewed literature. Nevertheless, some criteria were ambiguous, when the whole workplace setting is regarded and seemed to be contradictory to the aforementioned standards. For example, the recommended negative slope of the keyboard conflicts with the propositions of the standards and guidelines. This contradiction derives from the necessity of valid standards in general for all (or at minimum most) workplaces and the whole workplace setup. In fact, the reverse slope provokes a lower adjustment of the desktop surface or a higher sitting position and consequently, additional adjustments like foot rests are necessary. Additional to this, during the conduction of

other tasks, e.g. operating the mouse, writing, reading or anything else without computer use, the higher sitting position hinders to adopt the reference posture and might be uncomfortable. One solution for this dilemma might be to produce desks where only a segment of the desktop where the keyboard is placed could be inclined, so that the level of the remaining desk top is suitable for all tasks. However, the fixed position of the keyboard and consequently of the user could be estimated as disadvantage.

This discussion reveals that the recommendations for the ergonomics of input devices found and evaluated in the literature only works under specified conditions taking into account the tasks, method of operating, individual health problems and so on and have to be given in a very sophisticated way.

5 Conclusion

The approach to give complicated advice concerning ergonomics of input devices in a comprehensible and practicable way had been made by compiling a checklist introduced by a code of practice. At first, occupational health practitioners are requested to specify occurring health problems and the underlying reasons in terms of risk factors (awkward posture and so on) and to investigate the workplace. When the most relevant risk factor is identified, based on the results of the literature review - proposals how and under which condition the problem could be resolved are listed in the checklist with respect to the overall workplace ergonomics. The checklist had been worked out for every single risk factor in relation to the use of keyboards and/or mouse as well. The information on other input devices regarded in the literature review was also implemented in the checklist because they were mentioned as alternatives to the both aforementioned input devices most in use. The checklist will be subject of an evaluation in collaboration with occupational health practitioners who will experimentally apply it.

Aside from this, the literature review highlights a field of interest for further research on this issue of wrist/forearm support. It had been shown that even the standards and guidelines deliver inconsistent information how a wrist/forearm should be realized. From the studies that deal with this topic it could be deducted that somewhat larger space to support the forearm should be provided at the workplace but no measure could be quantified.

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