Draft for review and comment

DOT/FAA/CT-xx/xx

FAA William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

Human Factors Criteria for the Design and Acquisition of Keyboards: A Revision to Chapter 9 of the Human Factors Design Standard

Vicki Ahlstrom, NAS Human Factors Group
Bonnie Kudrick, Titan Corporation

June 2004

Final Report and Standard

U.S. Department of Transportation
Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

Draft for review and comment

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CTxx/xx		

4. Title and Subtitle Human Factors Criteria for the Design and Acquisition of Keyboards: A Revision to Chapter 9 of the Human Factors Design Standard	**5. Report Date** June 2004 **6. Performing Organization Code** NAS Human Factors Group
7. Author(s) Vicki Ahlstrom & Bonnie Kudrick	**8. Performing Organization Report No.** DOT/FAA/CTxx/xx
9. Performing Organization Name and Address NAS Human Factors Group Federal Aviation Administration William J. Hughes Technical Center Atlantic City International Airport, NJ 08405	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address Federal Aviation Administration Human Factors Research and Engineering Division 800 Independence Ave., S.W. Washington, DC 20591	**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code** ATO-P

15. Supplementary Notes

16. Abstract

This document contains updates and expands the design criteria on keyboards from Chapter 9 of the Human Factors Design Standard. A research team of human factors experts evaluated the existing guidelines for relevance, clarity, and usability. They drafted new design criteria as necessary based on relevant sources, and they reorganized the document to increase usability. This resulted in extensive changes to the original document, including the addition of new design criteria, sources, and topic areas. This report contains a brief introduction along with the modified design criteria.

17. Key Words	18. Distribution Statement
Keyboards Guidelines Design Criteria Human factors	This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	69	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Acknowledgements

The authors would like to thank the following people for giving their time and lending their expertise by reviewing this document: Alan Hedge, PhD of Cornell University, Ithaca, NY, Alex Chaparro, PhD at Wichita State University, Wichita, Kansas and Kenneth Allendoerfer, William J. Hughes Technical Center, Atlantic City, NJ

We would also like to thank Dave Hess and Carol Hewitt, who created clear and accurate graphics for the document.

Table of Contents

1. INTRODUCTION

The Human Factors Design Standard (HFDS) is a Federal Aviation Administration (FAA) reference document that brings human factors principles and design criteria to system designers. It facilitates the integration of human factors into the National Airspace System. The interactions with most systems in the Federal Aviation Administration (FAA) rely heavily on the use of keyboards. Thus, the human factors information on keyboards within the HFDS is an important chapter, frequently used in system acquisition and design.

Originally released in 1994 as the Human Factors Design Guide, the information within the keyboards chapter was due for an update in order to bring the information in line with current human factors knowledge. Current information on the various keyboards and keyboard characteristics, their advantages and differences, and appropriate applications was necessary for the safety and performance of those using the devices and to minimize cost to those programs involved in developing and procuring keyboards.

This document is divided into two sections. The first section summarizes the development of an updated and revised set of keyboard design criteria. It is a brief chapter intended to provide an overview of why the chapter on keyboards was updated and what process was used to achieve the update. The first section does not contain technical guidance or design criteria. It also provides information oat a high level on how to use the update chapter. The second section (the appendix) contains the design criteria.

1.1 Purpose

The purpose of this document is to revise the original Chapter 9 of the Human Factors Design Standard (HFDS). The new Chapter 9 provides an updated and consistent set of keyboard design criteria that meet the need of the FAA missions and systems.

1.2 Scope

The research team limited this document in scope to human factors guidance related to keyboards. Although other interaction devices, such as a mouse or a trackball, can generally perform some of the same functions as a keyboard, the team addressed alternative interaction devices in a different report. An informal review of reports used by acquisition programs indicated that these two topics are usually addressed separately. Having two individual chapters, each focusing on a specific topic, allows the users to be more specific in the requirements definition process.

1.3 Relationship to other chapters

This chapter was designed so that it could be used as a stand alone set of criteria if necessary, however, it is also meant to be used as a chapter within the HFDS. Additional supporting information on chapter organization and use beyond the scope of this first section is contained within the HFDS.

1.4 Shall and Should

Each standard specified is identified as a “shall” or “should” statement. A solid, black square (■) adjacent to the standard identifies the “shall” statements. These originate from, or are comparable to, statements from authoritative sources such as those associated with FAA orders, standards, military specifications, and peer-reviewed valid research.

Each "should" statement is identified by an open, white square (□). These represent best practices guidance that is applicable in most cases but may involve trade-offs or be influenced by domain or system-specific factors.

2. METHOD

Researchers organized the revision process in phases, which included the review and verification of information of the current HFDS chapter on input devices; identification of new source material; systematic evaluation of literature; reorganization, addition and revision of certain topic areas; and the addition of information to justify the design criteria and define tradeoffs associated with the design criteria.

2.1 Review of HFDS Chapter

In the first phase of this effort, the research team sought out guidelines and standards that pertained to keyboard acquisition and design. They compared these guidelines and standards against the current information from the HFDS and then updated the information as needed. The researchers then used the references from the guidelines and standards to identify the primary sources cited by the reference documents. They obtained the primary sources and verified the information within the guidelines and standards where possible. During the review of the current guidelines and standards, it became evident that the research team needed to obtain more current additional source materials.

The researchers then expanded their search to identify current research related to keyboards published in the literature. This literature search identified over 200 potentially relevant sources. The researchers obtained the relevant sources and reviewed them for information relevant to the design or acquisition of keyboards. Upon review of each source, researchers weighed the relevancy, adequacy, and validity of the material before including it in the document. When information in the new source document warranted new or updated standards, they created or updated a guideline. When new source material proved statements in the current document were outdated or invalid, they revised or deleted these statements as necessary. They then rewrote relevant information from the literature into should or shall statements that designers could use in requirements documents.

Although the HFDS contained design criteria on keyboards and input devices in a single chapter, the volume of information was not conducive to combining these two topics. Reports produced by program offices indicated that the program offices addressed these two topics separately. The organization of the information within the HFDS should reflect the needs of the users; thus, the researchers decided to publish the keyboards information separate from the information on non-keyboards interaction devices. Discussions with human factors practitioners currently working with FAA programs validated this decision.

2.2 Reorganization

With the addition, deletion, and revision of many of the design criteria and creation of specific standards, researchers had to reorganize the entire chapter. They performed card sorts with the design criteria and arranged the design criteria based on the results of the card sorts to facilitate easy access by users. They divided the chapter into 13 sections: General, Workplace characteristics for keyboard use, Workstation characteristics for keyboard use, Wrist/Palm rest, Keyboard physical characteristics, Keyboard functions, Numeric keypad, Key dimensions, Key labeling, Key activation, Key feedback, Ergonomic keyboards, Reduced alphanumeric keyboards for one-handed input, Membrane keyboards, Backlit keyboards, and Accommodating people with disabilities. Some of these sections have necessary sub-sections.

2.3 Additional Information

Based on feedback from FAA users, there are instances when users are faced with budget constraints, time constraints, or other concerns. For these instances, users are able to implement some of the design criteria, but not all of them. These users need to know the consequences of violating design criteria or under which conditions violation of design criteria might be acceptable. Throughout the document, the researchers added paragraphs of additional information that provide the grounds users need to make informed decisions when faced with design choices.

2.4 Expert Review

A draft of the newly created keyboard design criteria was circulated among a group of human factors professionals for review and comment. Reviewers included those both inside and outside the FAA. The reviewers provided feedback on the chapter organization, content, clarity, and relevance.

3. DOCUMENT OVERVIEW

The revision of Chapter 9 of the HFDS created notable changes. The search for current, updated information pertaining to input devices caused the realization that the chapter needed to be separated into two chapters. The chapter on Keyboards remains Chapter 9, which is addressed in this report. However, the researchers found that “input devices” was a somewhat outdated term, due to the advent of new technology. The second chapter that emerged from the initial “Input Devices” chapter is now referred to as “Non-Keyboard Interaction Devices.” We found it necessary to separate these two areas to fully address design criteria and standards that are continually evolving. The combination of the two separate chapters on Keyboards and Non-Keyboard Interaction Devices will replace the current Chapter 9 of the HFDS.

The reorganization of the information in this document involved regrouping, separating and removing certain redundant, obsolete, or unverifiable design guidelines. Many of the remaining guidelines were transformed into design criteria.

The underlying purpose of creating a human factors design standard for keyboards is to ensure that the device will facilitate the goals of efficient interaction without harming the user. Achieving this goal is depends on multiple factors, both intrinsic to the design of the keyboard and the design broader workplace factors. Research indicates that force, frequency of repetition, duration, compression and awkward positions contribute to workplace musculoskeletal disorders (commonly referred to as Cumulative Trauma Disorders (CTDs). No single factor will allow an efficient, ergonomic workplace in isolation of the other factors. For example, a user that has a keyboard that reduces awkward positions, but still requires excessive force, is likely to still be at risk for CTDs.

The researchers created these standards to aid in uniformity and cohesion of the design, use, and acquisition of keyboards. However, as with any set of standards, common sense and advice from human factors professionals should be sought for use in a specific application.

The research team considers the revised Human Factors Standard for the Design and Acquisition of Keyboards as a living document. We will update it as necessary to keep abreast of emerging technology, additional research, technological advances, and user feedback.

The researchers attempted to create a useful, organized, comprehensive document. This is evidenced throughout the document where the user will find that each standard has at least one valid source, if not more. The inclusion of sources allow the users a place to go to find additional information if necessary. The effort to provide the user with an organized, easy-to-use reference document is evident in the arrangement of the report, the glossary, and extensive list of references.

The team understands that there is always room for improvement and encourage comments and feedback. Please send comments and feedback Vicki Ahlstrom at the Research Development and Human Factors Laboratory, William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

Appendix A presents the full set of keyboards design criteria. A table of contents precedes the document. A glossary containing key terms and a list of references follow the standards.

<table>
<tr><td colspan="3">DOCUMENT IMPROVEMENT PROPOSAL</td></tr>
<tr><td colspan="3">INSTRUCTIONS 1. Please complete blocks 1-7 and send to the address in block 8. 2. The responsible party will provide a reply 30 days from receipt of the form if you provide the contact information.

NOTE: This form may is not intended as a way to request copies of documents, nor to request waivers, or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements.</td></tr>
<tr><td>RECOMMEND A CHANGE:</td><td>1. DOCUMENT NUMBER</td><td>2. DOCUMENT DATE</td></tr>
<tr><td colspan="3">3. DOCUMENT TITLE</td></tr>
<tr><td colspan="3">4. NATURE OF CHANGE (Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)</td></tr>
<tr><td colspan="3">5. REASON FOR RECOMMENDATION</td></tr>
<tr><td colspan="3">6. SUBMITTER</td></tr>
<tr><td>a. NAME (Last, First, Middle Initial)</td><td colspan="2">b. ORGANIZATION</td></tr>
<tr><td>c. ADDRESS (Include ZIP Code)</td><td>d. TELEPHONE (Include Area Code)</td><td>e. E-MAIL ADDRESS</td></tr>
<tr><td colspan="3">7. DATE SUBMITTED (MMDDYYYY)</td></tr>
<tr><td colspan="3">8. RESPONSIBLE PARTY</td></tr>
<tr><td>NAME:
Vicki Ahlstrom</td><td colspan="2">E-MAIL:
Vicki.ahlstrom@faa.gov</td></tr>
<tr><td>ADDRESS:
FAA, William J. Hughes Technical Center
Human Factors Group, Bldg 28
Atlantic City International Airport, NJ 08405</td><td colspan="2"></td></tr>
</table>

Table of Contents

List of exhibits

9.0 Keyboards

This chapter presents criteria for the design and acquisition of keyboards.

Considerations when designing or choosing a keyboard include the specific user task, ergonomics, performance, user comfort, and user abilities. Although improving keyboard design can help to reduce risks for cumulative trauma disorders, workplace factors such as duration of use also contribute to the development of cumulative trauma disorders.

The additional information provided in conjunction with each paragraph are meant to provide some insight on the underlying rationale so that program managers may better understand what the possible implications could be if they stray from the stated design criteria.

9.1 General

■ 9.1.1 **When to use.** When applicable, keyboards shall be provided for the entry of alphabetic, numeric, and other special characters into the system. [Source: MIL-STD-1472F, 1999]

❑ 9.1.2 **The nature of the task.** The frequency of key activation, the duration of use, and relative importance of accuracy and speed should be considered when choosing the keyboard type. [Source: Kodak, 1983]

❑ 9.1.3 **Repetitive data entry.** If the task is highly repetitive and has a high keystroke frequency, traditional keyboards should be used instead of membrane keyboards, touch pads, or touch-screens. [Source: Cohen, 1982; Kodak, 1983; Loeb, 1983]

Additional information. Membrane keyboards yield worse performance in speed than traditional keyboards. Although there is some evidence that this effect is reduced with practice, traditional keyboards still outperform membrane keyboards for high frequency typing. [Source: Cohen, 1982; Kodak, 1983; Loeb, 1983]

- ❑ **9.1.4 Use in cold environments.** In extremely cold environments, a stylus should be used for data entry rather than a finger operated keyboard. [Source: Blomkvist & Gard, 2000]

  Additional information. In cold environments, users either input data while wearing gloves or expose a finger or fingers while entering the data, causing the finger to become cold. Both methods lead to errors in data entry. Inputting data without gloves may also lead to injuries due to exposure. [Source: Blomkvist & Gard, 2000]

- ■ **9.1.5 Multiple keyboards.** Systems that include more than one keyboard shall maintain the same configuration for alphanumeric, numeric, and special function keys throughout the system. [Source: MIL-STD 1472F]

- ❑ **9.1.6 Keyboard equivalents to pointing device operations.** If an application provides both a keyboard and a pointing device, critical operations that can be performed with the pointing device should also be performable with the keyboard. [Source: EITAAC, 1999]

  Additional information. This guideline serves two purposes. If a pointing device is not working, the user can still interact with the system through the keyboard. Additionally, if the user has trouble using an interaction device due to disability, there are alternative means for interacting with the system.

- ❑ **9.1.7 Switching between devices.** Frequent switching between keyboards and interaction devices should be avoided due to the time and effort it takes to switch modes and the possibility of hand positioning errors. [Source: Douglas & Mithal, 1997; Myers, Lie & Yang, 2000]

9.2 Workplace characteristics for keyboard use

- ■ **9.2.1 Duration of keyboard work.** Keyboards shall not be used continuously for long periods of time without rest breaks, especially if typing quickly and under time pressure. [Source: Bergqvist, Wolgast, Nilsson & Voss 1995a, Bergqvist, Wolgast, Nilsson,& Voss,1995b; Fagarasanu & Kumar, 2003; Matias, Salvendy, & Kuczek, 1998]

Additional information. Proper keyboard design can minimize the potential for cumulative trauma disorder; however, some research implies that even with proper keyboard design, cumulative trauma disorders can occur if too much time is spent typing, particularly if typing at a high rate and/or under time pressure. There is no definitive amount specifying exactly what constitutes safe keyboard usage, although some research has found increases in repetitive stress injuries with 4-6 hours of typing a day or 6-8 hours of numeric pad use and with more than 20 hours of typing a week. Keyboard use for less than 8 hours a week is not associated with an increased risk of carpal tunnel syndrome. [Source: Andersen, Thomsen, Oergaard, Lassen, Brandt, Vilstrup, Kryger & Mikkelsen, 2003; Gerr, Marcus, & Monteilh, 2004; Moore, Garg, Roberts, & Root, 1997; Palmer, Cooper, Walker-Bone, Syddall & Coggon, 2001]

- 9.2.2 **Pace of keyboarding work.** Users should be allowed to pace themselves when performing extensive keyboarding tasks. [Source: Gerard, Armstrong, Martin & Rempel, 2002]

Additional information. Forcing users to keep a particular pace leads to increased muscle activity and fatigue. [Source: Gerard et al., 2002]

- 9.2.3 **Limits of keyboard work duration.** At minimum, users should be given a 30-second break from typing every 15-20 minutes and a 3-minute break from typing every hour. [Source: Galinsky, Swanson, Sauter, Hurrell & Schleifer, 2000; Henning, Jacques, Kissel, Sullivan & Alteras-Webb, 1997; Kopardekar & Mithal, 1994; McLean, Tingley, Scott & Rickards, 2001]

Additional information. Research shows that productivity may increase and errors decrease when breaks are taken. For example, Kopardekar & Mithal (1994) showed that users committed 80% more errors when working for 2 hours without a break than if they were given a 5-minute break for every 30 minutes of work. Risk for discomfort and cumulative trauma disorder increases after 1 hour of continuous typing. In general, short, frequent breaks in work are more desirable than long, infrequent breaks. However, breaks needed depend on work intensity, speed, and repetition of tasks. [Source: Henning et al., 1997; Kopardekar & Mithal, 1994; Matias et al., 1998]

- **9.2.4 Activity during breaks.** During breaks from keyboarding activity, users should perform stretching and/or exercise activities rather than sitting and resting. [Source: Henning et al., 1997; Lee, Swanson, Sauter, Wickstrom, Waikar & Mangum, 1992]

- **9.2.5 Indication of break times.** Users should be informed that it is time to take a break in a way that does not interrupt or disrupt their task. [Source: McLean et al, 2001]

  Additional information. Software programs are available that indicate rest-break intervals based on the intensity of the work being performed. Breaks are more effective when scheduled than when allowing users discretion over when to take the breaks. [Source: McLean et al, 2001]

9.3 Workstation characteristics for keyboard use

- **9.3.1 Location for frequent keyboarding tasks.** The main keyboard for frequent keyboarding tasks should be located directly in front of the user so as to allow the user to adopt and maintain the following body angles:

  a. Elbows at an angle of greater than 90 degrees.

Exhibit 9.3.1.a Elbow angle

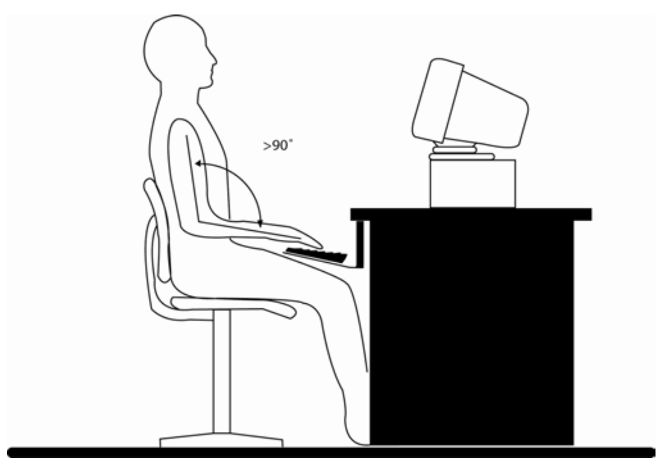
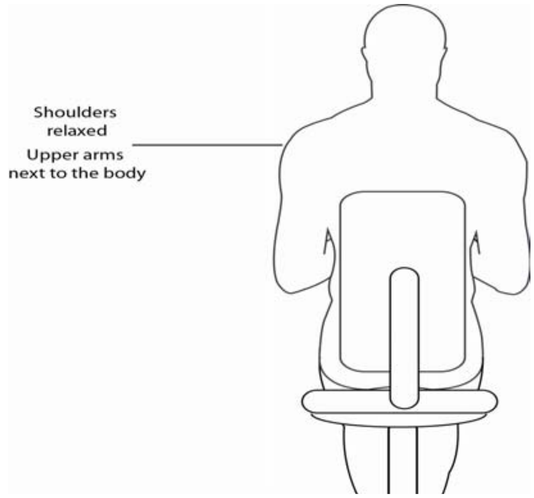


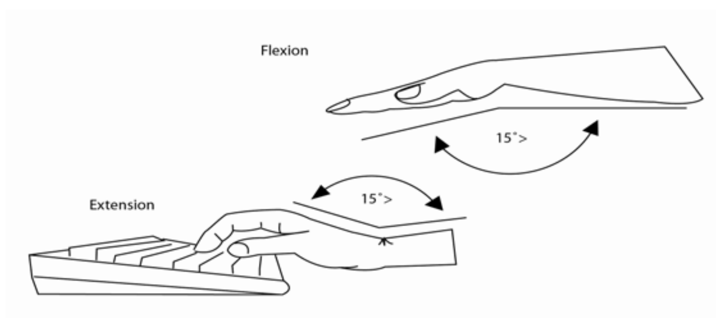
Exhibit 9.3.1.b Shoulder and upper arm position

b. Shoulders relaxed and upper arms next to the body



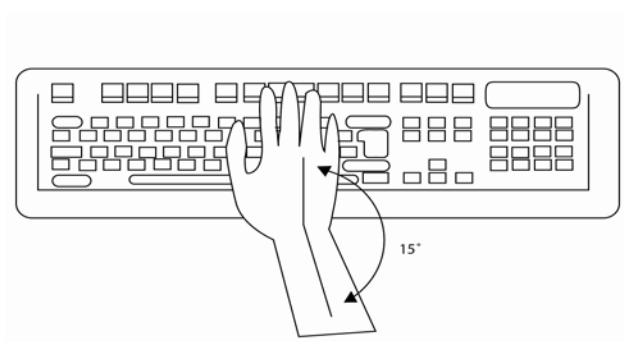
c. Wrist flexion/extension- less than 15 degrees

Exhibit 9.3.1.c Wrist extension/flexion



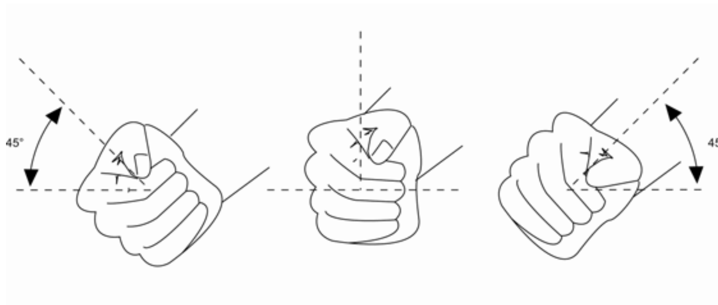
d. Ulnar/radial deviation-less than 15 degrees

Exhibit 9.3.1.d Ulnar/radial deviation



e. Pronation/supination – 0-60 degrees pronation, with closer to 45 degrees pronation preferred

Exhibit 9.3.1.e Pronation/Supination: Supination, Neutral wrist, Pronation

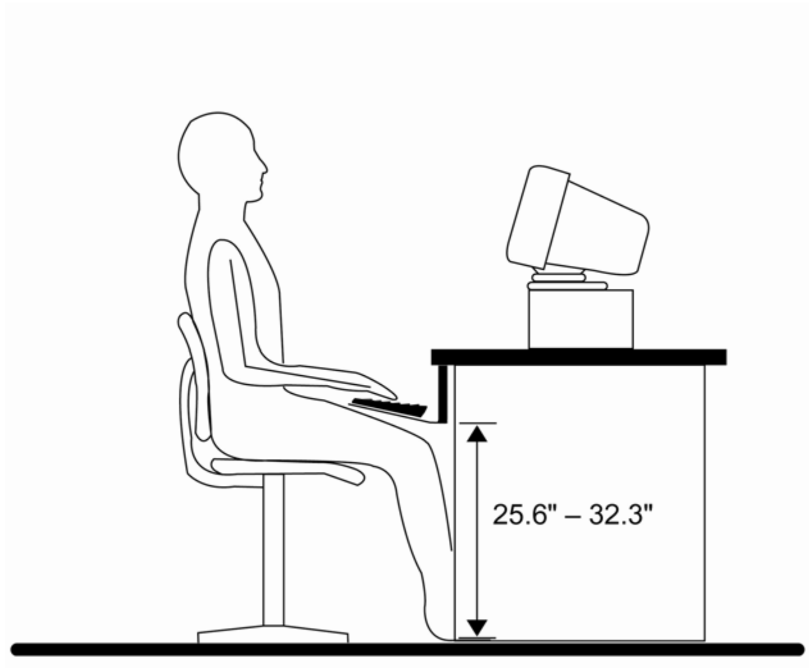


[Source: Armstrong & Chaffin, 1979; Bach, Honan, & Rempel, 1997; Cook & Kothiyal, 1998; Erdelyi, Sihoven, Helin & Hanninen, 1988; Grandjean, 1988; Grandjean, Hunting & Piderman, 1983; Hunting, Laubli & Grandjean, 1981; Keir, Bach & Rempel, 1999; Marcus, Gerr, Monteilh, Ortiz, Gentry, Cohen, Edwards, Ensor & Kleinbaum, 2002; OSHA, 1997; Rempel, 1995; Rempel, Bach, Gordon & So, 1998; Sauter, Schleifer & Knutson, 1991; Simoneau & Marklin, 2001; Weiss, Gordon, Bloom, So & Rempel, 1995;Werner, 1997; Zipp, Haider, Halpern, & Rohmert, 1983]

Additional information. The further postures deviate from neutral positions, the higher the probability of cumulative trauma disorders. [Source: Matias et al., 1998]

- ❑ 9.3.2 **Keyboard support surface height.** The keyboard support surface should be adjustable from 65 cm (25.6 inches) to 82 cm (32.3 inches) without the need for special tools. [Source: Grandjean, 1988; Miller & Suther, 1983; Nakaseko, 1985]

Exhibit 9.3.2 Keyboard surface height



Additional information. A range of keyboard heights is necessary to accommodate different user heights. Decreased keyboard height is associated with decreased wrist extension and increased musculoskeletal problems. Elevated keyboards are associated with increased discomfort, yet the keyboard must be high enough for sufficient knee clearance under the work surface. [Source: Bergqvist et al., 1995; Hunting et al., 1981; Sauter et al., 1991; Sommerich, 2000; Straker, Jones & Miller, 1997]

- ❑ **9.3.3 Repositionable on work surface.** Keyboards should be repositionable on the work surface to be placed according to the user needs. [Source: Nordic guidelines for computer accessibility, 1998]

Additional information. Users vary in anthropometric measurements. Easily repositionable keyboards allow users to move them in such a way as to achieve comfortable work postures. Ways to achieve this guideline are to use a wireless keyboard or to ensure that the keyboard has a sufficiently long cable.

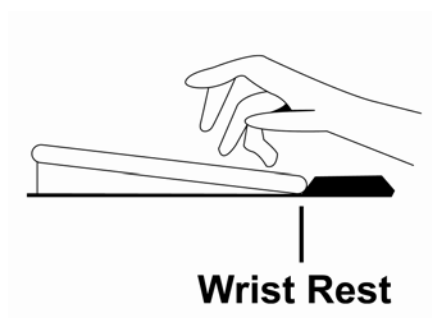
9.4 Wrist/Palm rest

The goals of a wrist/palm rest are to reduce shoulder muscle loads and promote a neutral wrist posture without negatively affecting productivity or introducing localized contact stress. Wrist/palm rests can help users avoid localized contact stress that may be caused by the edge of a workstation or keyboard. Wrist/palm rests are thought to promote more neutral wrist posture by reducing wrist extension. However, for some users, wrist/palm rests increase wrist discomfort, and they can potentially increase carpal tunnel pressure or cause awkward wrist positions.

Although the term "wrist rest" is used as an umbrella term in the general populace, properly designed wrist rests are intended to support the palm or heel of the hand rather than the actual wrist. [Source: Grandjean et al., 1983; Hagglund & Jacobs, 1996; Horie, Hargens & Rempel, 1993; Hunting et al., 1981; Parsons, 1991; Paul & Menon, 1994, Smith, Karsh, Conway, Cohen, James, Morgan, Sanders & Zehel, 1998]

- ❑ 9.4.1 **Shape of wrist rest.** When keyboards have integrated or attachable wrist rests or supports, the wrist rest or support should be matched to the width, height, and shape of the front edge of the keyboard. [Source: Paul & Menon, 1994]

Exhibit 9.4.1 Wrist rest



Additional Information. Broad flat wrist rests are preferable to narrow curved shapes because contoured wrist rests can cause more wrist deviation than flat pads. [Source: Paul & Menon, 1994]

- **9.4.2 Avoid soft tissue pressure.** Wrist rests should be designed so that the user rests the palm or heel of the hand on the wrist rest and not the soft tissue at the wrist crease. [Source: Horie et al., 1993, Ilg, 1987]

  Additional information. Resting the soft tissue of the wrist on a support, will raise intracarpal pressure on the median nerve.

- **9.4.3 Free movement.** Wrist rests should avoid restricting the user's ability to freely move their hands when typing. [Source: Paul & Menon, 1994]

- **9.4.4 Avoid localized pressure.** Wrist rests should not cause localized contact pressure that is uncomfortable to user. [Source: Paul & Menon, 1994]

- **9.4.5 Size of wrist rest.** Forearm and wrist support on a keyboard should have a depth of at least 150 mm (5.91 in). [Source: Grandjean, 1988]

- **9.4.6 Avoid moisture accumulation.** Wrist rests should not cause uncomfortable moisture accumulation on the skin. [Source: Parsons, 1991]

- **9.4.7 Forearm support.** Where palm support cannot be provided, workstations should allow the users to rest their forearms on a support surface while typing. [Source: Aaras & Ro, 1997; Barrero, Hedge & Muss, 1999; Feng, Grooten, Wretenberg & Arborelius, 1997; Hagglund & Jacobs, 1996; Hedge & Powers, 1995, Hunting et al., 1981; Schuldt, Ekholm, Harms-Ringdahl, Nemeth & Arborelius, 1987; Sihvonen, Baskin & Hanninen, 1989; Visser, deKorte, van der Kraan & Kuijer, 2000]

  Additional information. Forearm support is associated with decreased shoulder and neck muscle activity and decreased reported pain in neck, shoulders, and arms. However, resting the forearms on a support surface may cause the users to adopt awkward sitting positions with negative consequences or may result in contact pressure if the supporting surface is not sufficiently padded. [Source; Aaras & Ro, 1997; Hagglund & Jacobs, 1996; Hedge & Powers, 1995; Hunting et al., 1981; Powers, Hedge & Martin, 1992; Schuldt et al., 1987; Sihvonen et al., 1989; Visser et al., 2000]

- **9.4.8 Forearm support design.** Forearm support shall not cause compression of the flexor muscles, uncomfortable accumulation of moisture, or localized contact stress. [Source: Aaras & Ro, 1997; Barrero et al., 1999; Hagglund & Jacobs, 1996; Hedge & Powers, 1995, Hunting et al., 1981; Schuldt et al., 1987; Sihvonen et al., 1989; Visser et al., 2000]

- **9.4.9 Comfortable use of forearm support.** Forearm support shall not cause the users to adopt uncomfortable or awkward positions when used. [Source: Aaras & Ro, 1997; Barrero et al, 1999; Hagglund & Jacobs, 1996; Hedge & Powers, 1995, Hunting et al., 1981; Schuldt et al., 1987; Sihvonen et al., 1989; Visser et al., 2000]

9.5 Keyboard physical characteristics

9.5.1 General

- **9.5.1.1 Maintain neutral posture.** Keyboards used for frequent typing by two-handed typists shall allow the user to maintain wrist extension of less than 15 degrees and ulnar deviation of less than 15 degrees while typing. (See Exhibit 9.3.1c) [Source: Bach, Honan, & Rempel, 1997; Hedge, Morimoto & McCrobie, 1999]

  Additional information. Increasing the wrist extension and the ulnar deviation increases carpal tunnel pressure. [Source: Simoneau, Marklin & Monroe, 1999]

- **9.5.1.2 Stability.** The keyboard shall be stable during normal operations (e.g. it should not slip, slide, or rock). [Source: ANSI, 1988]

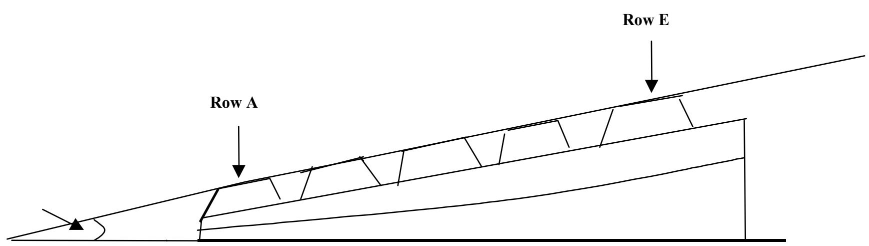
  Additional information. Ways to avoid slippage during normal operations are by providing friction-causing material on the undersurface of the interaction device (e.g., rubber feet) and by ensuring that the interaction device has sufficient weight to obtain good friction on the work surface.

- **9.5.1.3 Keyboard finish.** Keyboard surfaces shall have matte finish. [Source: Ilg, 1987; NUREG 0700, 2002]

  Additional information. The justification for a matte finish is that it minimizes reflections from ambient light sources.

- ❑ **9.5.1.4 Maximum keyboard slope.** Keyboard slope should not exceed 15 degrees. [Source: Bach, Honan, & Rempel, 1997; Hedge, McCrobie, Land, Morimoto & Rodriguez, 1995; Ilg, 1987; Miller & Suther, 1983; NUREG 0700, 2002; Suther, 1982]

Exhibit 9.5.1.4 Maximum keyboard slope



Additional information. The goal of this guideline is to promote neutral wrist position, reducing carpal tunnel pressure. Lower (even negative) keyboard slopes have been shown to reduce carpal tunnel pressure, thus reducing potential harmful effects on the wrist. [Source: Bach, Honan, & Rempel, 1997; Hedge et al, 1995; Ilg, 1987; Miller & Suther, 1981, 1983; NUREG 0700, 2002; Simoneau & Marklin, 2001; Simoneau, Marklin & Berman, 2003; Suther & McTyre, 1982; Treaster & Marras, 2000]

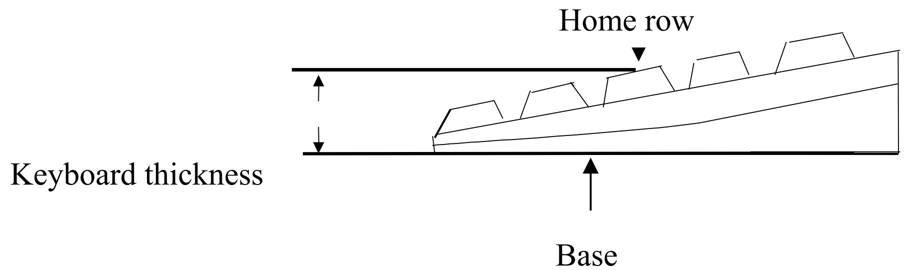
Exception to the rule. Slopes in excess of 15 degrees may be considered, if the device is used infrequently.

- **9.5.1.5 Adjustable slope.** Keyboard slope shall be adjustable by the user as necessary to keep the wrist in a neutral wrist posture without the need for tools. [Source: Hagglund & Jacobs, 1996; Hedge & Powers, 1995; Miller & Suther, 1983; Rempel, 1995; Simoneau & Marklin, 2001]

  Additional information. The goal of adjustable keyboard slope is to keep the wrist in a neutral position. Keyboard slope must be adjustable to accommodate users of different heights. [Source: Hagglund & Jacobs, 1996; Hedge & Powers, 1995; Miller & Suther, 1983; Rempel, 1995; Simoneau & Marklin, 2001]

- **9.5.1.6 Keyboard thickness.** The thickness of a keyboard (base to home row of keys) should be between 38 mm (1.50 in) and 70 mm (2.76 in) as long as the overall keyboard, plus work surface, height is adequate for the user to maintain proper posture and there is adequate knee clearance under the work surface. See Exhibit 9.5.1.6. [Source: Burke, Muto & Guzman, 1984; Emmons & Hirsch, 1982; Miller & Suther, 1981].

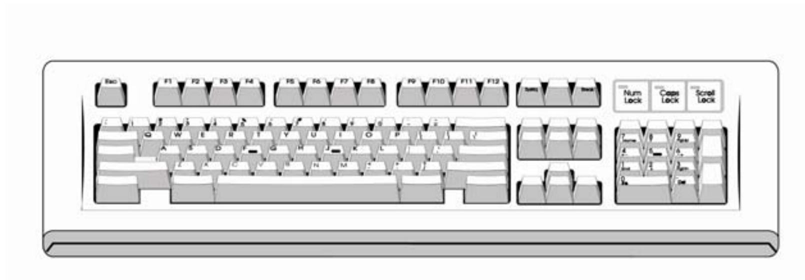
Exhibit 9.5.1.6 Keyboard thickness



Additional information. The height of the home row of keys (thickness of the keyboard) itself is mainly based on preference rather than performance. However, the overall height of the keyboard in relation to the floor (inclusive of the keyboard support) can have ergonomic implications. Preferred keyboard thickness tends to be interrelated with keyboard slope and the overall height of the keyboard plus work surface in relation to the floor. [Source: Burke et al., 1984; Emmons & Hirsch, 1982; Hunting et al., 1981; Miller & Suther, 1981]

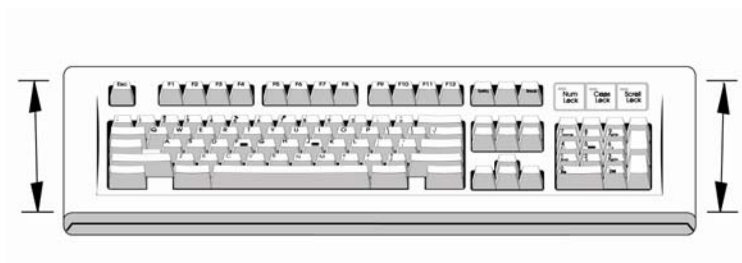
- **9.5.1.7 Home row locator.** The F and J keys on the alphanumeric keyboard and the number 5 key on the numeric keypad shall have a tactile feature to assist the users in positioning their fingers on the home row of the keyboard, preferably a small raised bar or spot on the key cap. [Source: Scadden & Vanderheiden, 1988]

Exhibit 9.5.1.7 Home row locators



- ❑ **9.5.1.8 Keyboard depth.** Keyboard size should be appropriate for the hand size of the user with the maximum depth from the first row to the last row of keys not exceeding 149.1 mm(5.8 in). [Source: Czaja, 1983]

Exhibit 9.5.1.8 Keyboard depth



Additional information. The length of the tip of the second digit (pointer finger) to the wrist crease for the 5th percentile female is 149.1 mm (5.87 in). If the keyboard is too deep, it becomes difficult for users with smaller hands to reach the keys without repositioning the hands or stretching.

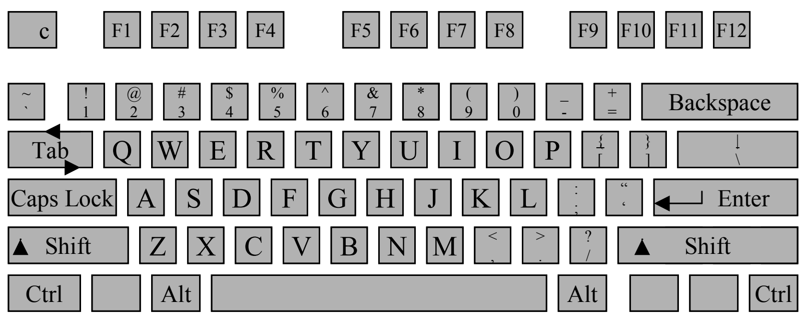
- ▪ **9.5.1.9 Smooth edges.** Keyboards shall have no sharp edges where the user may come into contact with them. [Source: NUREG-0700, 2002]

9.5.2 Keyboard layout

Description. Although other alternative layouts have been proposed, to date, the three most common alternatives for keyboard layout are the QWERTY (Sholes), Dvorak, and ABC (Alphabetical) layouts.

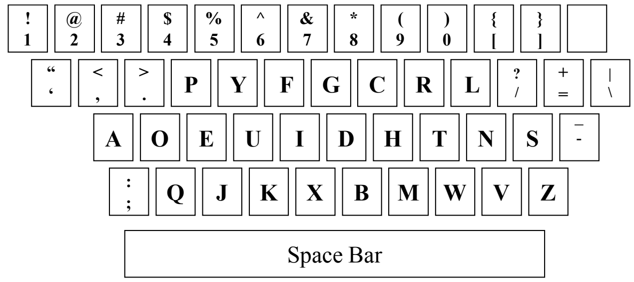
- **9.5.2.1 QWERTY layout.** Keyboards intended for the entry of both alphabetic and numeric information shall conform to the standard "QWERTY" arrangement unless the alternate arrangement shows sufficient enough improvement over the standard layout to justify the training time and other costs associated with the new arrangement. [Source: Alden, Daniels & Kanarick, 1972; ANSI, 1988; Ilinski, 2003; Kinkead & Gonzalez, 1969; Klemmer, 1971; Kodak, 1983; Lewis, LaLomia & Kennedy, 1999; Norman & Fisher, 1982; Sears, Jacko, Chu & Moro, 2001]

Exhibit 9.5.2.1.a QWERTY or Sholes layout



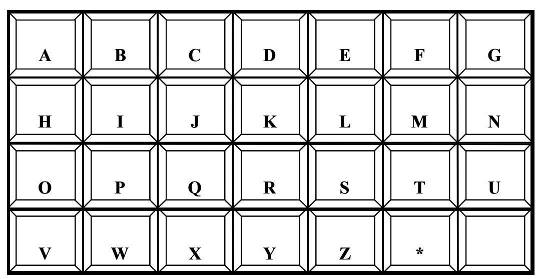
Additional information. The de facto industry standard is the QWERTY (also known as the Sholes) layout. Research indicates that keyboard arrangement is not necessarily the primary indicator of typing speed and there is no clear link between keyboard layout and user cumulative trauma disorders, therefore it is difficult to justify alternative keyboard layouts. Additionally, some researchers have found that visual search time to locate keys is faster for QWERTY than for other arrangements.

Exhibit 9.5.2.1.b. Dvorak layout



The Dvorak layout is intended to distribute the keys so that the workload among the fingers is evenly distributed. Research on the Dvorak is inconclusive. Some research has found advantages to using the Dvorak layout on efficiency. However, other research failed to show any advantage to switching from QWERTY to Dvorak. Research has found that it takes approximately 28 days for users familiar with a QWERTY keyboard to obtain the same keying rates on a Dvorak keyboard.

Exhibit 9.2.5.1 c. Alphabetic (ABC) layout



Arranging the keyboard alphabetically was proposed as a means of making it easier for novice typists to find the keys. However, the research studies found no advantage in accuracy or speed for the alphabetic layout even for low skilled typists. [Source: Alden, Daniels & Kanarick, 1972; Capobianco, Lee & Cohen, 1999; Hirsch, 1970; Ilinski, 2003; Kinkead & Gonzalez, 1969; Klemmer, 1971; Kodak, 1983; Lewis et al., 1999; Michaels, 1971; Norman & Fisher, 1982; Sears et al., 2001]

❑ 9.5.2.2 **Grouping by function.** Keys with similar functions should be grouped together. [Source: MIL-STD 1472F, 1999]

❑ 9.5.2.3 **Arrange to facilitate task.** The keyboard arrangement should provide ease of operation, minimize user training and retraining, and minimize ergonomic stress on the user. [Source: Kodak, 1983]

❑ 9.5.2.4 **Arranged for ease of use.** Keyboards should be arranged so that the most frequently used keys are within easy reach without requiring the user to reposition the hands (within the primary keying area). [Source: Douglas & Mithal, 1997]

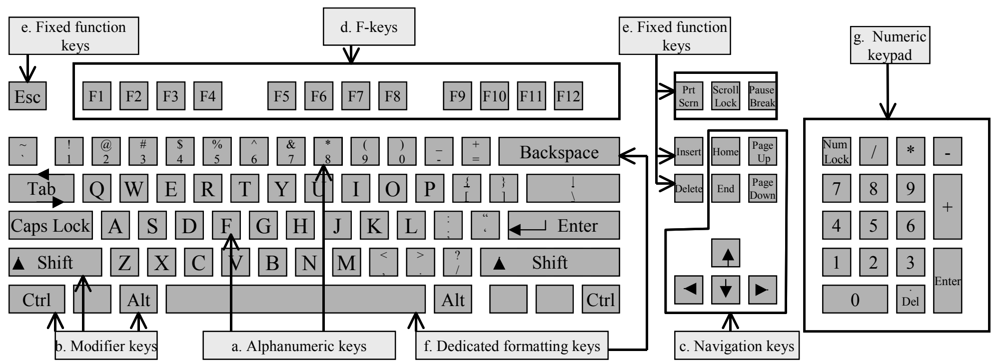
Additional information. Locating the most frequently used keys within the primary keying area allows the user to make the most of the keystrokes needed without moving his or her hands and losing speed. Each time a touch typist moves his or her hands from the home location, it takes time to correctly reposition the hands before typing begins again (homing time).

❑ 9.5.2.5 **Destructive keys.** Keys with negative or irreversible effects should be located so that inadvertent operation is unlikely. [Source: NUREG 0700, 2002]

Additional information. One way to minimize the chance of inadvertent operation is to locate potentially destructive keys out of the primary keying area so that the user must move his or her hand to reach the key.

9.6 Keyboard functions

Exhibit 9.6 Keyboard functions



Description. Keyboards vary greatly in the number and arrangement of keys. Most keyboards have approximately 100 keys and include the following:

a. *Alphanumeric keys* – Keys that consist of letters of the alphabet, numerals, and punctuation symbols.

b. *Modifier keys* - Keys that modify or qualify the effects of other keys, for example, Shift, Ctrl, Alt, and Caps Lock. These keys only have an effect when used in conjunction with another key.

c. *Navigation keys* - Keys that move a cursor, for example, Arrow keys, Home, End, Page Up, and Page Down.

d. *F keys (function keys)*- Keys provided for extra or general functions, typically labeled F1, F2, and so on.

e. *Fixed-function keys*- Keys that have a dedicated function such as Escape, Home, End, Page Up. Modifier keys, Navigation keys, and Dedicated formatting keys are all examples of fixed-function keys.

f. *Dedicated formatting keys*- Keys for text formatting operations such as the space bar, Tab key, and Backspace key.

g. *Numeric keypad*- Number keys used for frequent numeric input.

9.6.1 Toggle keys/ Dual state keys

▪ 9.6.1.1 **Indication of state.** Dual state (toggle) keys shall clearly indicate their operational (functional) status to the user. [Source: ISO 9241-4, 1998]

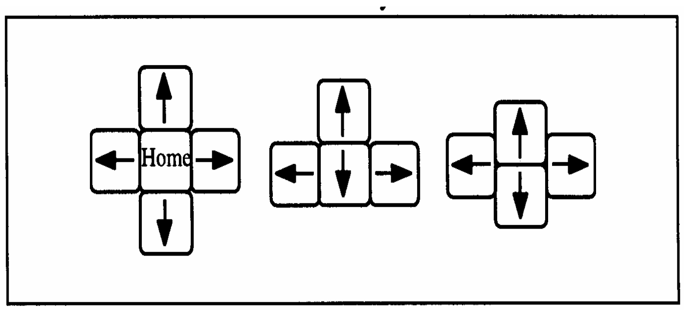
❑ 9.6.1.2 **Location of status indicator.** If indicator lights are used to indicate the status of dual state keys, they should be clearly labeled or close to the associated keys. [Source: ISO 9241-4, 1998]

9.6.2 Arrow keys

▪ 9.6.2.1 **Two-dimensional cursor control.** Keyboards shall provide for movement of the cursor in two dimensions by including a set of arrow keys. [Source: ANSI, 1988; DOE-HFAC1, 1992; NUREG 0700, 2002]

▪ 9.6.2.2 **Arrow key layout.** Arrow keys shall be arranged in a two dimensional spatial configuration reflecting the direction of actual cursor movement. Acceptable arrangements are a T shape, inverted T, diamond, or imbedded diamond shape. [Source: Reger, Snyder & Epps, 1987]

Exhibit 9.6.2.2 Arrow key layout



Additional information. Most users prefer arrow keys to be located on the right side of the keyboard rather than the left side. [Source: Reger et al., 1987]

▪ 9.6.2.3 **Cursor movement over long distances.** A cursor control device other than the arrow keys shall be provided if the user task requires moving the cursor frequently over distances greater than 1 cm (.40 in). [Source: Albert, 1982; Card, English & Burr, 1978; Casali, 1992]

Additional information. Arrow keys are primarily for short, discrete movements of the cursor and are usually not effective for precise positioning of cursors over distances greater than 1 cm (0.40 in). Arrow keys are significantly slower and more error prone than other methods for text selection and cursor positioning. [Source: Albert, 1982; Card et al., 1978; Casali, 1992]

9.6.3 Fixed-function keys

Description. A fixed-function key is a keyboard key with a predefined, unchanging function. Generally, these keys are labeled with their function.

❑ 9.6.3.1 **Use.** Fixed-function keys should be available for functions that are critical or frequently used. [Source: NUREG 0700, 2002]

Additional information. Examples of fixed-function keys that would be frequently used are the Enter key and the Shift key. [Source: Shneiderman, 1998]

❑ 9.6.3.2 **Non-active keys.** Blank keys should replace non-active fixed-function keys. [Source: MIL-STD 1472F 1999]

Additional information. The presence of non-relevant keys adds to keyboard complexity and induces user errors.

❑ 9.6.3.3 **Disabled keys.** Unneeded function keys should be disabled so that no other action occurs upon their depression except an advisory message. [Source: MIL-STD 1472F, 1999; NUREG 0700, 2002]

▪ 9.6.3.4 **Key function.** Key assignments shall be displayed at all times, preferably through direct marking. [Source: NUREG 0700, 2002]

- ❑ **9.6.3.5 Consistent use.** Fixed-function keys should be standardized throughout the system and where possible across related systems. [Source: DOE-HFAC1, 1992; MIL-STD-1472F, 1999; NUREG 0700, 2002]

- ▪ **9.6.3.6 Single activation.** Fixed-function keys shall require only a single actuation to accomplish their function. [Source: NUREG 0700, 2002]

- ❑ **9.6.3.7 Return to default.** If the functions assigned to a set of function keys change as a result of user selection, the user should be given an easy means to return to the default functions. [Source: NUREG 0700, 2002]

- ❑ **9.6.3.8 Availability.** Fixed-function keys should be selected to control functions that are continuously available; that is, the lock out of fixed-function keys should be minimized. [Source: DOE-HFAC1, 1992, 1999; MIL-STD-1472F]

- ❑ **9.6.3.9 Mechanical overlays.** Mechanical overlays should not be used to lock out function keys. [Source: DOE-HFAC1, 1992; MIL-STD-1472F, 1999]

- ▪ **9.6.3.10 Grouping.** Fixed-function keys shall be grouped logically and shall be placed in distinctive locations. [Source: DOE-HFAC1, 1992; MIL-STD-1472F, 1999; NUREG 0700, 2002]

- ▪ **9.6.3.11 Spatial relationships.** Spatial relationships among the functions of the keys shall be reflected in the geometric relationship of the keys. [Source: DOE-HFAC1, 1992; MIL-STD-1472F, 1999]

  Additional information. For example, a key that causes left movements should be located to the left of a key that causes right movement and a key that causes up movement should be located above a key that causes down movement.

- ❑ **9.6.3.12 Keyboard equivalents to function keys.** If an application assigns operations to function keys, the operations that can be performed with a function key should also be performable with alphanumeric keys. [Source: Keane (DISA HCISG V1.0), 1992]

9.6.4 F Keys

Description. F keys refer to the set of function keys generally located across the top of the keyboard. These keys are different than the fixed-function keys in that they can be assigned to different functions depending on the program or system. The disadvantage to F key assignment is that they can impact user memory load in remembering and finding the appropriate key, particularly when they are not labeled.

- **9.6.4.1 Use.** F keys should not be assigned to trivial or seldom used functions. [Source: Brown, 1988]

  Additional information. F keys can be justified because they reduce transaction time by having a single key perform a common function.

- **9.6.4.2 Assignment of destructive commands.** Potentially destructive commands should not be assigned to F keys. [Source: Ahlstrom & Muldoon, 2003]

- **9.6.4.3 Execution of destructive commands.** If destructive commands must be assigned to an F key, an additional pop up window should appear before command execution allowing the user to confirm or cancel the command. [Source: Ahlstrom & Muldoon, 2003]

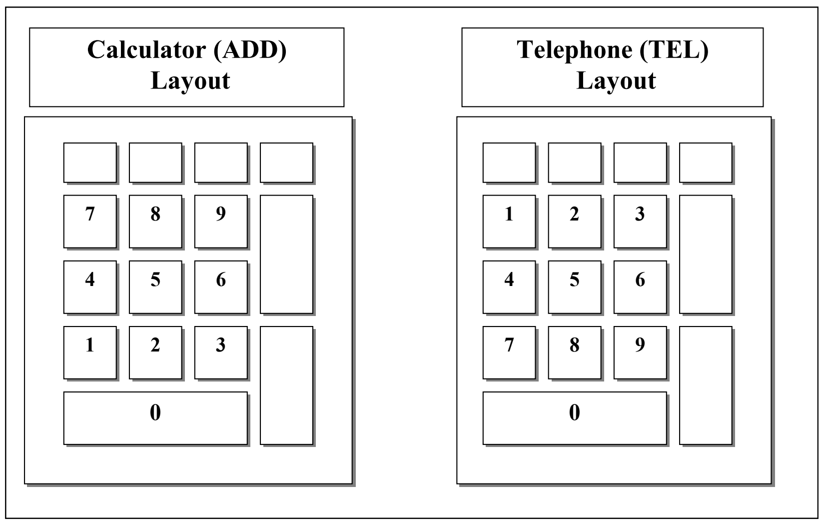
- **9.6.4.4 Frequently accessed functions.** Keys on the edge of a row (F1, F12) should be used for frequently accessed functions (such as F1 for Help), so long as these functions do not violate other rules on consistency. [Source: Ahlstrom & Muldoon, 2003]

  Additional information. Keys on the edge of a row are likely to be quicker and easier to locate than keys in the middle of a row. F1 is commonly assigned the Help function.

9.7 Numeric keypad

Description. Numeric keypads are a separate grouping of numbered keys from 1 to 9, generally arranged in 3 X 3 array, with zero on a separate bottom row. They are intended for high volumes of numeric input.

Exhibit 9.7 Numeric keypads



- **9.7.1 Include a numeric keypad for entering numeric data.** If an application requires substantial and repetitive input of numeric data, a numeric keypad shall be provided. [Source: Card, et al., 1978; MIL-STD-1472F, 1999]

- ❑ **9.7.2 Separate numeric keypad.** When numeric entry is infrequent and the keyboard is used together with other input devices, the numeric keypad should be separate from the keyboard. [Source: Ilg, 1987; Morelli, Johnson, Reddell & Lau, 1995]

Additional information. A separate numeric keypad allows a shorter keyboard footprint, allowing better positioning and more room for pointing devices, such as a mouse, within easy reach. It also allows for right- or left-handed usage, which can be matched to hand dominance and preference of the user.

- ❑ 9.7.3 **Location of numeric keypad.** If numeric keypads are integrated into a keyboard, the keypad should be located to the side or above the primary keying area. [Source: Def-Stan-00-25, 1992]

- ■ 9.7.4 **Arrangement of keys.** Keyboards intended solely for the entry of numbers shall have the numerals "1" through "9" arranged in a three by three array, with "0" centered below the bottom row. [Source: Conrad & Hull, 1968; Loricchio & Lewis, 1991; Lutz & Chapanis, 1955; Marteniuk, Ivens & Brown, 1996]

- ❑ 9.7.5 **Layout of keys.** Numeric keypads should use either the calculator or telephone arrangement of keys, preferably the telephone layout. [Source: Conrad & Hull, 1968; Klemmer, 1971; Lutz & Chapanis, 1955; Marteniuk et al., 1996]

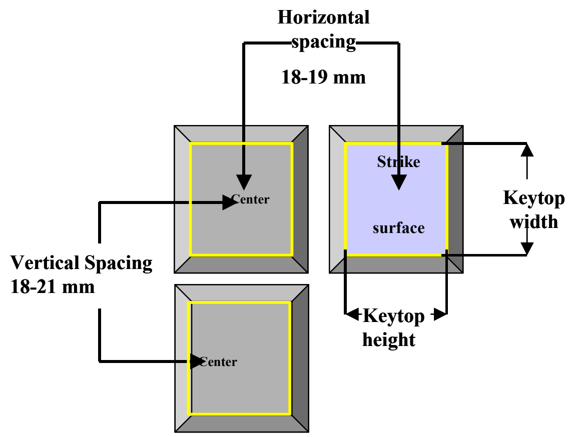
Additional information. Although the telephone layout (with numbers 1, 2, and 3 in the top row of keys) yields performance advantages, (higher speeds and lower errors), the calculator layout (with numbers 7, 8, and 9 in the top row of keys) is commonly found on computers. As performance is likely to be affected by cognitive factors like familiarity, either could be justified. [Source: Conrad & Hull, 1968; Klemmer, 1971; Lutz & Chapanis, 1955; Marteniuk et al., 1996]

- ■ 9.7.6 **Consistency between keypads.** When more than one numeric keypad is used, the layouts between the keypads shall be consistent. [Source: Conrad & Hull, 1968]

Additional information. Switching between telephone and calculator layouts for numeric keypads causes significant performance decrements. [Source: Conrad & Hull, 1968]

9.8 Key dimensions

Exhibit 9.8 Key dimensions



- **9.8.1 Key size.** Horizontal key strike surfaces in the primary alphanumeric keying area should be 12-15 mm (.47 in -.59 in) wide. [Source: Alden, Daniels & Kanarick, 1972; Hufford & Coburn, 1961 cited in Kodak, 1983; Ilg, 1987; Lorrichio & Lewis, 1991; NUREG 0700, 2002]

  Additional information. Fastest keying speeds and lower error rates were found with keys 12.7 mm (.5 in) square. [Source: Deininger, 1960]

  Exception. Although larger key sizes are preferred, the horizontal strike surface for keys used for one finger input can be 10 mm (.39 in) if a minimum of 16 mm (.63 in) center line inter key distance is maintained without significantly impacting performance. [Source: Lorrichio & Lewis, 1991]

- **9.8.2 Horizontal spacing of keys.** Centerline distances between alphanumeric keys should be between 16-19 mm (.63 and .75 inch) horizontally. [Source: Alden, et al., 1972; Ilg, 1987; NUREG 0700, 2002; Yoshitake, 1995]

  Additional information. Key spacing of less than 17.78 mm (.7 in) vertical and horizontal significantly reduces typing speed. [Source: Ilg, 1987]

- ❑ 9.8.3 **Vertical spacing of keys.** Centerline distances between keys should be between 18-21 mm (.71 and .82 in) vertically. [Source: ANSI, 1988; Ilg, 1987]

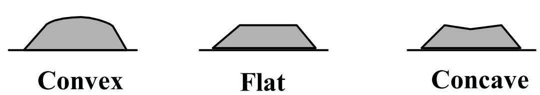
- ❑ 9.8.4 **Key spacing for non-alphanumeric keys.** Inter-key spacing for non-alphanumeric keys should be between 4 and 7 mm (.16 and .28 in). [Source: Alden et al., 1972; Deininger, 1960; Lorrichio & Lewis, 1991]

- ❑ 9.8.5 **Key shape.** Key strike surfaces should be square or rectangular (preferably square). [Source: Cakir, Hard & Stewart, 1980; Clare, 1976; Ilg, 1987; Monty, Snyder & Birdwell, 1983]

  Additional information. Square strike surfaces provide larger strike areas than circular strike surfaces for a given area. Square strike surfaces are also preferred by users over oval strike surfaces.

- ❑ 9.8.6 **Key tops.** Key top strike surfaces for alphanumeric keys should be concave. [Source: Clare, 1976; Ilg, 1987; Radwin & Jeng, 1997]

Exhibit 9.8.6 Key tops



*Additional information***.** The raised flanks of a concave key help to prevent the fingers from slipping off of the key and allow the user to feel the key edges.

9.8.7 **Key top shape for keys closest to user.** Key top strike surfaces for the space bar and keys in the row of the keyboard closest to the user or other keys that may be operated by the side of the thumb rather than the fingertip should be convex rather than concave. [Source: Clare, 1976; Ilg, 1987; Radwin & Jeng, 1997]

Additional information. Users often use the side of their thumb rather than the fingertips to activate the space bar and a concave shape could induce contact stress for the thumb.

9.9 Key labeling

- ▪ 9.9.1 **Easily legible.** Keyboards shall be free from reflection and have easily legible characters under the lighting conditions of the intended operational environment. [Source: Ilg, 1987; NUREG 0700, 2002]

- ❑ 9.9.2 **Font for keyboard labels.** Keyboard labels should be in a sans serif font. [Source: Nolan, 1991]

- ❑ 9.9.3 **Single letter font.** Single letters on keyboard keys should be upper case. [Source: Nolan, 1991]

- ▪ 9.9.4 **Durability of key labels.** The labels on the keys shall be durable enough to withstand normal wear and tear (including routine cleaning) for the life of the keyboard. [Source: NUREG 0700; 2002]

- ▪ 9.9.5 **Contrast of labels.** Key labels may be darker or lighter than the background but shall maintain a luminance contrast ratio of at minimum 3:1 or a contrast modulation of 0.5. [Source: ANSI, 1988; NUREG 0700, 2002]

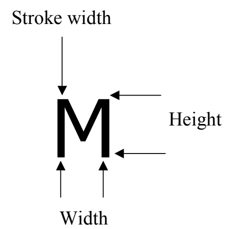
  Additional information. In general, higher luminance contrasts support better legibility, which can improve performance. The recommendations above are minimums, applicable to tasks with no time constraint and low risks. Tasks that require rapid and accurate perception of the symbols may require much higher contrast ratios. A correction formula requiring higher luminance contrasts must be applied to characters smaller than 20 min of arc to offset the effects of blur in the eye's optics.

  In most situations, (based on research done on printed text) black letters on a light background will be more legible than white letters on a black background. Research has found that white isolated capital letters on a black background are 23.6 % less legible than black on white. [Source: Tinker, 1963, 1965]

- ❑ 9.9.6 **Primary symbol height.** The size of the primary symbols on the keys should be a minimum of 2.5 mm (.1 in) in height. [Source: Grandjean, 1969; NUREG 0700, 2002]

❑ 9.9.7 **Primary symbol width.** The width of the single letters and numerals should be 60-90% of the height for all letters except the letters M, W, J and I. [Source: Grandjean, 1969; McCormick, 1964; NUREG 0700, 2002]

Exhibit 9.9.7 Symbol height/width and stroke width



❑ 9.9.8 **Stroke width for dark letters.** The stroke width for black letters on a light background should be between 1:6 and 1:8. [Source: McCormick, 1964]

❑ 9.9.9 **Stroke width for light letters**. The stroke width for white letters on a dark background should be between 1:8 and 1:10. [Source: McCormick, 1964]

❑ 9.9.10 **Abbreviation on key labels.** If abbreviations are necessary to label keys, standard abbreviations should be used that are well known to the users. [Source: NUREG 0700, 2002]

❑ 9.9.11 **Words and abbreviations on keys.** When a full word or well-known abbreviation is used on a key, it should have the first letter capitalized and the remaining letters lowercase. [Source: Nolan, 1991]

9.10 Key activation

- ▪ **9.10.1 Force to depress keys.** The maximum force needed to depress keys shall measure between 0.25N and 1.5N (0.9 and 5.3 ounce-force) with a preferred range between 0.5N and 0.6N (1.8 and 2.2 ounce-force) for normal data entry tasks. [Source: ANSI, 1988; Armstrong, Foulke, Martin, Gerson & Rempel, 1994; Kinkead & Gonzalez, 1969; NUREG 0700, 2002; Radwin & Jeng, 1997; Radwin & Ruffalo, 1999; Rempel, Serina, Klinenberg, Martin, Armstrong, Foulke & Nataraja, 1997; Rose, 1991]

  Additional information. Excessive force can cause fatigue and user discomfort and can increase carpal tunnel pressure. As the force needed to activate a key increases, finger force increases. Too high of a key force can lead to user fatigue and make it difficult to type. Too low of a key force can lead to inadvertent key activation. [Source: Armstrong et al., 1994; Radwin & Jeng, 1997; Radwin & Ruffalo, 1999; Rempel et al., 1997; Rose, 1991]

- ❑ **9.10.2 Key force**. Key force requirements should be uniform across the surface of the key. [Source: Armstrong et al., 1994; Radwin & Jeng, 1997; Radwin & Ruffalo, 1999; Rempel et al., 1997; Rose, 1991]

- ❑ **9.10.3 Initial key resistance.** Keys should have a high initial increase in resistance to depress, with resistance disappearing after closure and increasing with overshoot. [Source: Baber, 1997; Brunner & Richardson, 1984]

Exhibit 9.10.3.a High initial increase to actuation point

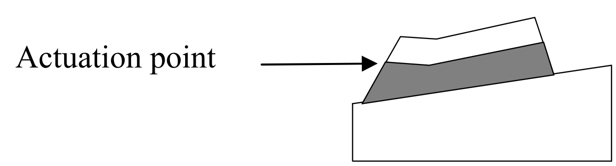
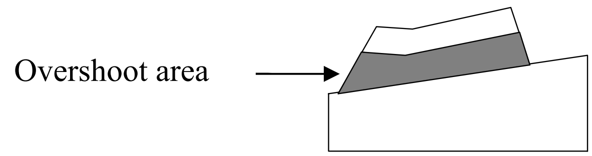


Exhibit 9.10.3.b Overshoot area



- ❑ **9.10.4 Key action.** Keys should use an elastomer action instead of a linear spring or snap action. [Source: Akagi, 1992; Brunner & Richardson, 1984]

  Additional information. Performance is higher with an elastomer action than a linear spring or snap action key mechanism. Although keys with linear spring action lead to lower errors and higher speed than snap action, elastomer action outperforms both linear spring and snap action in performance and preference. [Source: Akagi, 1992; Brunner & Richardson, 1984]

- ▪ **9.10.5 Key displacement.** Vertical displacement of the keys shall be between 1.3 to 6.4 mm (0.05 to 0.25 in), with preferred displacement of 2.0 to 4.0 mm (0.08 to 0.15 in) for normal data entry tasks. [Source: ANSI, 1988; Ilg, 1987; Kinkead & Gonzalez, 1969; NUREG 0700, 2002; Radwin & Jeng, 1997; Radwin & Ruffalo, 1999]

  Additional information. Displacements of between 2.0 and 4.0 mm (.08 and .16 in) produce the highest text entry rates with the lowest errors. Increasing key travel decreases key force, which is associated with higher carpal tunnel pressure. However, displacements of .7 to 1.6 mm (.03 to .06 in) are acceptable for data entry that is not continuous. [Source: ANSI, 1988; Ilg, 1987; Kinkead & Gonzalez, 1969; NUREG 0700, 2002; Radwin & Jeng, 1997; Radwin & Ruffalo, 1999]

- ❑ **9.10.6 Key rollover.** Keyboards should have n-key rollover. [Source: Kallage, 1972; NUREG 0700; 1981]

  Additional information. N-key rollover stores the keys pressed and allows them to be processed in the order that they were activated after the other key is released. N-key rollover can minimize errors and slow downs for high-speed data entry. [Source: Kallage, 1972]

- ❑ **9.10.7 Key repeat capability.** Alphanumeric, symbol, and cursor keys on a keyboard should have a repeat capability. [Source: NUREG 0700, 2002]

- ❑ **9.10.8 Key repeat rate.** The default character repeat rate should be approximately 10 characters per second after an initial delay of 500 ms following key activation. [Source: NUREG 0700, 2002]

- ▪ **9.10.9 Terminating key repeat.** The release of the key shall terminate the repeat. [Source: NUREG 0700, 2002]

- ❑ **9.10.10 Key stability**. Key tops should not wobble or stick during normal operations. [Source: Ahlstrom, 1998]

9.11 Key feedback

- ▪ **9.11.1 Positive feedback.** Feedback shall be provided to inform the operator that the key was pressed and that the next operation may be initiated. [Source: MIL-STD-1472F, 1999]

- ❑ **9.11.2 Type of feedback.** Tactile and auditory feedback should accompany the actuation of a key. [Source: Alden et al., 1972; Clare, 1976; Gerard et al., 2002; Klemmer, 1971; Monty et al., 1983; Roe, Muto & Blake, 1984; Rosinski, Chiesei & Debons, 1980]

  *Additional information***.** Although visual feedback may be helpful when users are initially learning to type and for correcting errors, research has found that visual feedback has no impact on typing speed. Some research has found that auditory feedback (in the form of an impulse sound such as a click) and tactile feedback (usually through changing resistance over the distance of key travel) is faster and less error prone, more preferred by users, and leads to reduced typing force. [Source: Alden et al., 1972; Clare, 1976; Gerard et al., 2002; Klemmer, 1971; Monty et al., 1983; Rempel, Jacobsen, Brewer & Martin, 2000; Roe et al., 1984; Rosinski, 1980]

- ❑ **9.11.3 Type of auditory feedback.** Auditory feedback should be in the form of an impulse sound such as a click or tone. [Source: Monty et al., 1983]

9.12 Ergonomic keyboards

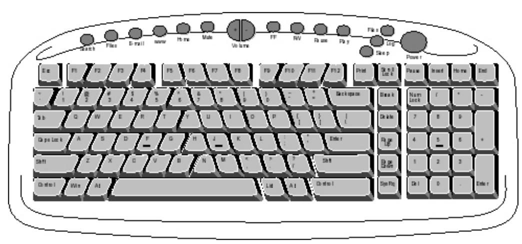
The objective in the design of ergonomic keyboards is to place the forearm, fingers, hands, and wrists of the typists in a more neutral position to prevent or decrease musculoskeletal discomfort or injury. Any keyboard manufacturer can apply the name "ergonomic" to a keyboard. Just because a keyboard is called an "ergonomic" keyboard, it does not mean that it reduces or prevents musculoskeletal discomfort. There is currently insufficient research to make specific recommendations for most "ergonomic" keyboard designs.

There are a variety of alternative keyboard features that have been developed to promote better user posture. Alternative keyboards may incorporate more than one of these features in the design.

Some of the alterations of conventional keyboard design intended to promote neutral wrist positions include:

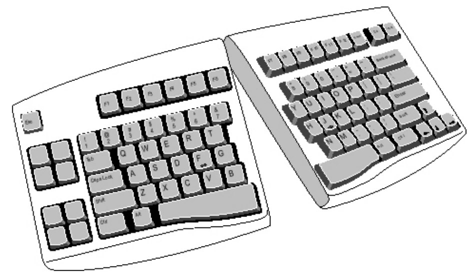
Angled keys – these keyboards seek to help the user type with a straight wrist by angling the keys diagonally inward toward the center.

Exhibit 9.12.a Angled keys



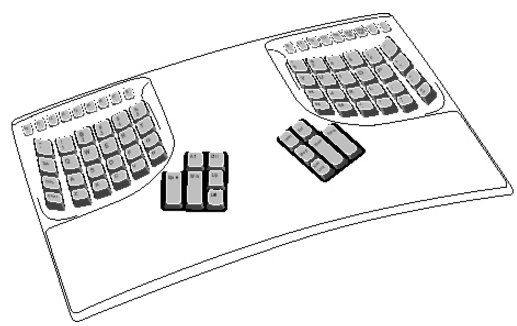
Adjustable-angle split keyboards - The adjustable split keyboard has a user adjustable keyboard angle and rotates the two halves of the keyboard. Generally, these keyboards are adjusted to have additional lateral inclination at an angle more extreme than fixed angle keyboards. An adjustable split keyboard is intended to allow the user to place the wrist and forearm into a more neutral position, specifically decreasing ulnar abduction. [Source: Nakaseko, Grandjean, Hunting & Gierer, 1985; Simoneau, Marklin, Monroe & Zabors, 1996; Swanson, Galinsky, Cole, Pan & Sauter, 1997; Tittiranonda, Burastero, Wei & Rempel, 1996; Zecevic, Miller & Harburn, 2000]

Exhibit 9.12.b Adjustable-angle split keyboard



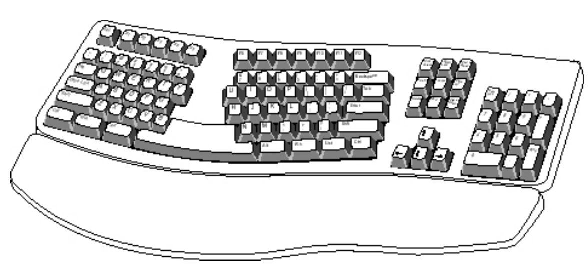
Contoured or curved keys – The rows of keys on these keyboards are curved or contoured to more closely follow the shape of the hand with the intent of reducing the workload on the fingers.

Exhibit 9.12.c Contoured or curved key keyboard



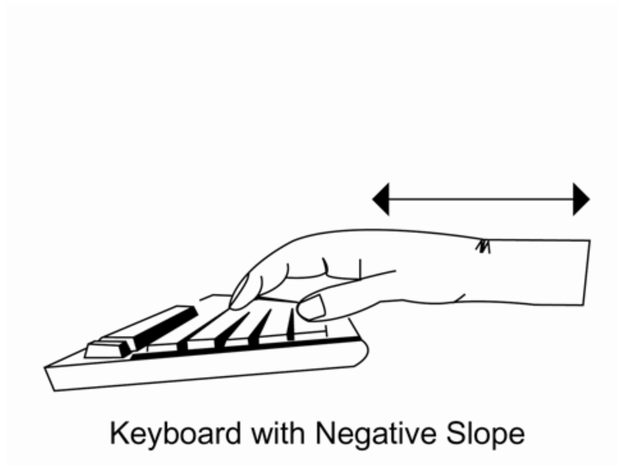
Fixed-angle, separated keyboards – These keyboards have a split in the middle of the keyboard with the keys rotated, similar to the angled key keyboards but with a fixed space between the two halves of the keyboard.

Exhibit 9.12.d Fixed-angle separated keyboard



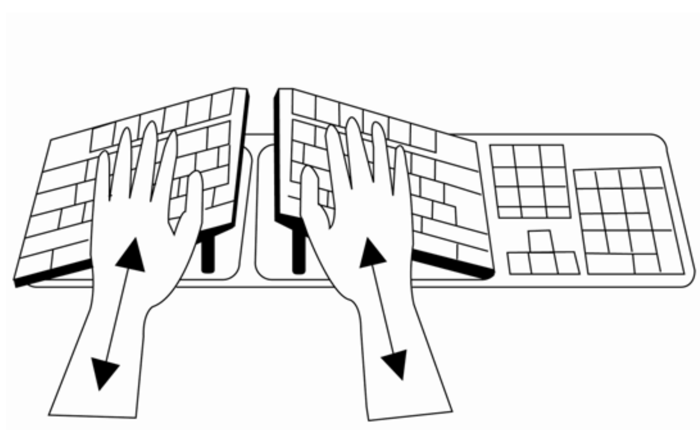
Negative slope keyboards - These keyboards raise the front edge of the keyboard with the intention of reducing wrist extension.

Exhibit 9.12.e Negative slope keyboard



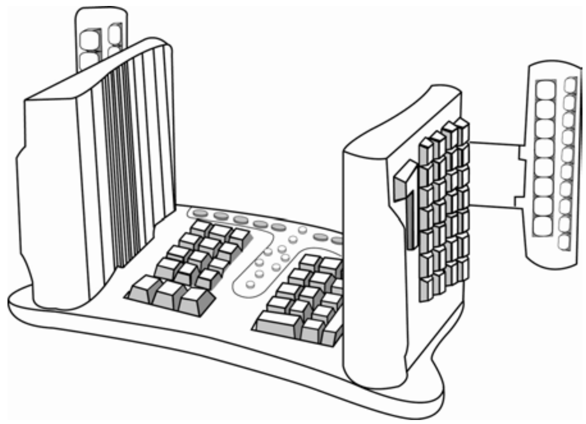
Tented keyboards - These keyboards feature two halves of a keyboard that are rotated up like a tent. The purpose of this feature is to minimize wrist pronation.

Exhibit 9.12.f Tented keyboard



Vertical split keyboard – These keyboards take the two halves of a conventional keyboard and rotate them so that they are perpendicular to the worksurface.

Exhibit 9.12.g Vertical Split keyboard

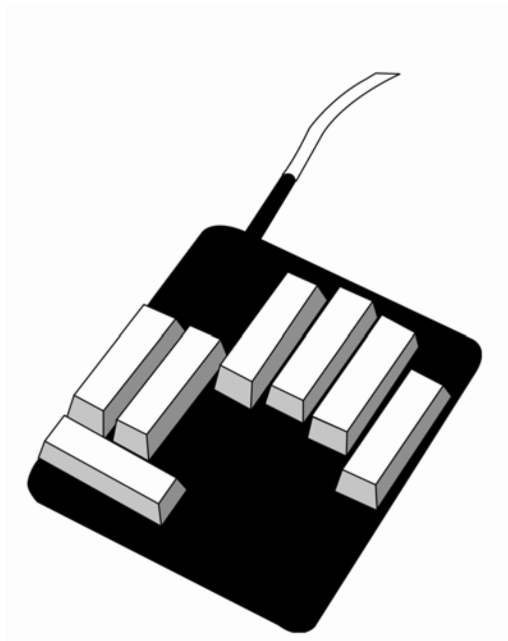


Non-keyboard alternatives:

Chord keyboards –Chord keyboards are smaller, generally one-handed keyboards, that require the user to activate two or more keys simultaneously to produce a single input unit. Common uses for chord keyboards are for stenographers, some mail sorting machines, and for people with disabilities. Advantages to the chord keyboards are that trained users can reach data entry rates even higher than with traditional keyboards; they are small; and most can be used by one hand. There are also potential ergonomic advantages of assigning the most frequently used keys to the strongest, least fatigue-prone fingers.

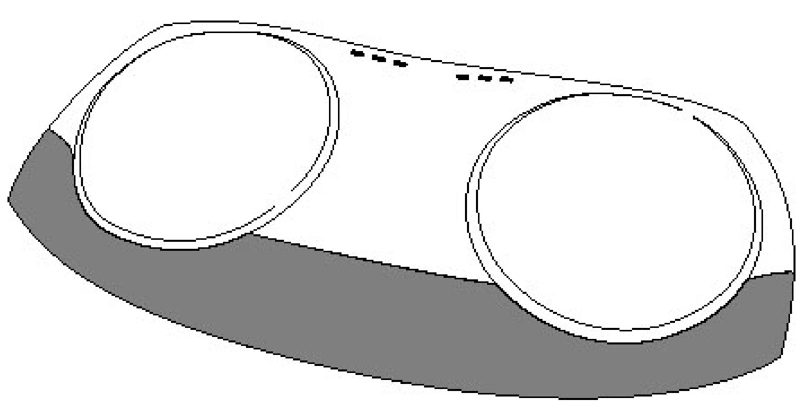
Chord keyboards were found to be superior to traditional keyboards for mail sorting tasks; however, chords can be difficult to learn and execute. Additionally, chord keyboards often require a means of interpreting the data entry. As the need for data entry is currently being filled by traditional keyboards, it is not likely that chord keyboards will be widely adopted for Federal Aviation Administration use. [Source: Conrad & Longman, 1965; Gopher et al., 1985; Greenstein & Muto, 1988; Lu & Aghazadeh, 1992; McAlindon, 1994; McCormick, 1976 cited in Baber, 1997; Noyes, 1983; Siebel, 1962]

Exhibit 9.12.h. Chord Keyboard



Keyless keyboards –Some keyboards have been designed that do not use keys at all, but instead accept movements of the hand and arm rather than movements of the fingers on keys. Although these devices show promise for users with severe disabilities, the typing times with these devices are significantly slower than with a conventional keyboard. Thus, it is unlikely that these devices will be adopted in the FAA.

Exhibit 9.12.i Keyless keyboard



9.12.1 Split keyboards

The most common alternative keyboard is the fixed split keyboard. Split keyboards have been shown to reduce muscular strain and tension, reduce fatigue, and promote a more neutral wrist position, reducing pronation and ulnar deviation. Some researchers have also found split keyboards to be associated with significant pain reduction for users suffering from carpal tunnel syndrome. [Source: Cakir, 1995; Chen, Burastero, Tittiranonda, Hollerbach, Shih & Denhoy, 1994; Gerard, Jones, Smith, Thomas & Wang, 1994; Grandjean, 1988; Marek et al., 1992; Marklin & Simoneau, 1996; Ro & Jacobs, 1997; Sommerich, 1994; Strasser, Keller & Fleischer, 2000; Tittiranonda et al., 1996; Zecevic et al., 2000]

- ❑ **9.12.1.1 Use.** Fixed split keyboards should be considered for touch typists who type frequently as an alternative to conventional keyboards. [Source: Cakir, 1995; Chen et al., 1994; Gerard et al., 1994; Grandjean, 1988; Marek et al., 1992; Marklin & Simoneau, 1996; Ro & Jacobs, 1997; Sommerich, 1994; Strasser et al., 2000; Tittiranonda et al., 1996; Zecevic et al., 2000]

  Additional information. Although conclusive evidence does not exist that split keyboards prevent wrist injury, split keyboards have been shown to promote neutral wrist posture. Carpal tunnel pressures, which are associated with negative physiological changes in the wrist, are lower when the wrist is in neutral positions. Although there may be slight declines in initial performance with split keyboards, typists regain performance within 30 minutes to 2 days of use. [Source: Marklin et al., 1998; Sommerich, 1994; Swanson et al., 1997; Tittiranonda et al., 1997]

- ❑ **9.12.1.2 Location of split.** Split keyboards should be split between the YHN keys and the TGB keys. [Source: Grandjean, 1988]

- ❑ **9.12.1.3 Horizontal angle of split.** The horizontal split angle between 2 halves of the split keyboard should be from 10 to 25 degrees. [Source: Fernstrom, Ericson & Malker, 1994; Grandjean, 1988; Keller, Fleischer & Strasser, 2000; Marklin & Simoneau, 1996; Nakaseko et al., 1985; Ro & Jacobs, 1997; Zecevic et al., 2000]

- ❑ **9.12.1.4 Lateral inclination.** The lateral inclination of a fixed split keyboard should be 8-12 degrees. [Source: Ilg, 1987; Nakaseko et al., 1985; Swanson et al., 1997; Zecevic et al., 2000]

- **9.12.1.5 Positive lateral inclination.** The lateral inclination of a keyboard shall be positive (the center must be higher than the outer edges of the keyboard). [Source: Nakaseko et al., 1985; Zecevic et al., 2000]

  Additional information. A negative lateral inclination would lead to increased wrist pronation.

9.13 Reduced alphanumeric keyboards for one-handed input

As technology continues to evolve, there has been a trend toward the use of miniaturized keyboards and handheld devices to allow portable, one-handed data input. Some of these devices are designed for single finger input, whereas other devices are designed for thumb input. Although additional research is being conducted on keyboards for thumb input, there is currently insufficient research to give clear guidelines on designing reduced keyboards specifically for thumb input.

- ❑ **9.13.1 Letters per key.** Where size permits, keys should be assigned only one letter per key. [Source: Hornsby, 1981]

  Additional information. Keyboard entries are significantly faster if only one letter is assigned per key because only one stroke is necessary per letter.

- **9.13.2 Use.** Miniaturized keysets shall not be used if the task requires the user to enter large amounts of continuous data. [Source: Goldstein, Book, Alsio & Tessa, 1999]

- ❑ **9.13.3 Constrained keyboards.** If size requires a constrained keyboard such that more than one letter must be assigned to each key, a phone type layout should be used with a 3 x 4 array of buttons. [Source: Butterbaugh & Rockwell, 1982]

- ❑ **9.13.4 Miniaturized keys.** Keypads designed for one finger input should have keys no smaller than 6-8 mm (.24 in-.31 in) with 16-19 mm (.63- .75 in) interkey spacing. [Source: Drury & Hoffman, 1992]

  Additional information. Smaller key size has been associated with decreased response time for one-handed input. [Source: Hansen, 1983]

9.14 Membrane keyboard

Description. Membrane keyboards are thin, flat, pressure sensitive devices with areas marked to indicate specific keys. They are different from traditional keyboards in that they have little or no key travel. They are also different from touch-screens both in technology and use. Touch-screens have broader applications than membrane keyboards in that they are used not only for keying in data but often for point and click type applications. Pressure sensitive keys, such as in touch pads and poke boards, are suitable for occasional keying tasks, but are not recommended for more repetitive operations. [Source: Hashimoto & Togasi, 1995; Hunter, Zhai, & Smith, 2000; Kodak citing Klemmer, 1971; Zhai, Sue, & Accot, 2002]

- 9.14.1 **Use.** Membrane keyboards should be used for tasks when only occasional data entry is necessary. [Source: Cohen, 1982; Loeb, 1983]

  Additional information. Performance is worse on membrane keyboards than traditional keyboards. Text entry is slower. [Source: Cohen, 1982; Loeb, 1983]

- 9.14.2 **Force.** Force to operate a membrane keyboard should be about .6 N (2 ounce-force). [Source: Stevens, 1975, cited in Kodak]

  Additional information. Requiring a minimum activation force reduces the possibility of accidental activation.

- 9.14.3 **Feedback.** Membrane keyboards should have either a raised dome over the keys and/or auditory feedback. [Source: Roe et al., 1984]

  Additional information. The presence of a dome allows users to locate the keys by touch and provides tactile feedback. The combined use of raised domes and auditory feedback decreases errors and increases typing speed. [Source: Roe et al., 1984]

9.15 Backlit keyboards

Backlit keyboards are designed for low ambient light conditions where a standard keyboard cannot be used. The backlighting generally uses LED technology to illuminate the keys on the keyboard, to allow the user to operate the keyboard in varying ambient lighting conditions. Backlit keyboards are often found in public safety, mobile, and control room applications.

Due to the fact that backlit keyboards are not common in most office work environments, there is a lack of research on the design of backlit keyboards. The Federal Aviation Administration (FAA) does use backlit keyboards in several operational environments. The following guidelines are derived from a study conducted on backlit keyboards for the FAA.

- ❑ 9.15.1 **Leakage of light between keys.** Leakage of light between the keys of backlit keyboards should be minimized. [Source: Ahlstrom, 1998]

- ❑ 9.15.2 **Even illumination.** The entire character on backlit keyboards should be evenly illuminated to facilitate character identification. [Source: Ahlstrom, 1998]

- ❑ 9.15.3 **Location of brightness control.** The brightness control knob should be placed in a location that is easily accessible without getting in the way of operations, but will not be inadvertently activated. [Source: Ahlstrom, 1998]

- ❑ 9.15.4 **Activation of brightness control.** The brightness control knob or dial should increase brightness when rotated clockwise or to the right and decrease brightness when rotated counterclockwise or to the left. [Source: NUREG 0700, 2002]

- ❑ 9.15.5 **Location of on/off switch.** The on/off switch should be placed in a location that is easily accessible without getting in the way of operations, but will not be inadvertently activated. [Source: Ahlstrom, 1998]

- ❑ 9.15.6 **Color of backlighting.** Where possible, backlit keyboards should use white backlit characters on black keys. [Source: Ahlstrom, 1998]

- **9.15.7 Colored keys.** If backlit keyboards use colored keys or non-white characters, they should be tested in an environment representative of the operational environment to ensure legibility. [Source: Ahlstrom, 1998]

9.16 Accommodating people with disabilities

- **9.16.1 Avoiding inadvertent operation.** A computer or computer system intended to be operable by people with moderate motor disabilities should provide either a means for delaying the acceptance of a keystroke for a preset, adjustable amount of time or a keyguard or means for mounting a keyguard. [Source: Scadden & Vanderheiden, 1988]

  Additional information. Delaying the acceptance of a keystroke or providing keyguards helps some users who may otherwise bump and accidentally activate keys other than the intended key.

  Definition. A keyguard is a keyboard cover with holes over keys. [Source: Scadden & Vanderheiden, 1988]

- **9.16.2 Keyguard mounting.** Keyboards should be designed so that keyguards can be mounted easily. [Source: Scadden & Vanderheiden, 1988]

- **9.16.3 Keyset interlock.** Keyboards for users who have frequent overlap errors in their typing should allow a 100 msec keyset interlock to prevent simultaneous activation of two keys. [Source: Trewin, 2002]

  Additional information. Keyset interlocks keep the key from being triggered until 75 % of its downward displacement has occurred. Their use has been associated with an increase in productivity and decrease in errors. Users who have trouble typing without simultaneously pressing more keys than intended (overlap errors) can be helped by providing a 100 msec keyset interlock without slowing their typing time. [Source: Alden, et al., 1972; Klemmer, 1971; Trewin; 2002]

- **9.16.4 User selectable key repeat rate.** Users should be able to set the initial delay and repeat rate for keys. [Source: NUREG 0700, 2002]

  Additional information. Allowing the user to select the repeat rate accommodates users with disabilities who may require a longer delay.

- **9.16.5 Connection point for alternative input device.** A computer or computer system should provide a point at which an alternative input device can be connected if modifications cannot be made to make a standard input device accessible. [Source: Scadden & Vanderheiden, 1988]

- **9.16.6 Non-visual indication of state of toggle keys.** A computer or computer system should provide blind users with a non-visual indication of the state of toggle keys that is available automatically or upon the user's request. [Source: Scadden & Vanderheiden, 1988]

- **9.16.7 Key demarcation.** All keys should have edges that can be discerned by touch. [Source: Scadden & Vanderheiden, 1988]

  *Additional information***.** Flat, membrane keyboards without ridges outlining the keys can be particularly difficult for the visually impaired to use. [Source: Scadden & Vanderheiden, 1988]

- **9.16.8 Key labels.** Alternatives to visual key labeling should be made available for visually impaired users. [Source: Scadden & Vanderheiden, 1988]

- **9.16.9 Distinguishing macro input from typed input.** Computers and computing systems should be able to keep up with assistive software input. [Source: Scadden & Vanderheiden, 1988]

  Additional information. Keystrokes generated by assistive devices or assistive software may be sent faster than the application software can recognize them, in which case, they may be ignored, thus preventing use of the assistive device or software. [Source: Scadden & Vanderheiden, 1988]

Glossary

ABC keyboard A keyboard layout based on the alphabet starting with the letter A in the upper left part of the keyboard.

Abduction A movement of a body segment in a lateral plane away from the midline of the body, such as raising the arm sideways.

Alphanumeric keys The letters of the alphabet, numerals, and punctuation symbols (numeric keypads may be separate on portable computers).

Arrow keys A set of keys dedicated to controlling the movement of the cursor labeled with arrows indicating the direction of movement (also known as cursor keys).

Assistive technology Any item, piece of equipment, or system, whether acquired commercially, modified, or customized, that is commonly used to increase, maintain, or improve functional capabilities of individuals with disabilities.

Backlit keyboard Backlit keyboards are designed for low ambient light conditions where a standard keyboard cannot be used. The backlighting generally uses LED technology to illuminate the keys on the keyboard, to allow the user to operate the keyboard in varying ambient lighting conditions.

Chord keyboard A keyboard that uses multiple simultaneous key combinations to create characters, instead of having one character per key. One advantage to a chord keyboard is that it can take up less space than traditional keyboards. A disadvantage is that it generally requires significant training time to learn the chords.

Carpal Tunnel Syndrome (CTS) A disorder of the wrist due to compression of the nerve often associated with keyboard or input device use.

Contrast modulation An equation derived to represent the higher contrasts needed by characters less than 20 min of arc to make them equally perceptible as a larger character.

Contrast ratio The luminance of the symbol (or text) divided by the luminance of the immediate background. It is sometimes called luminance ratio.

Cursor	The visual indicator of input focus on a computer screen.
Cursor keys	*see Arrow keys*
Dedicated formatting keys	Keys for text formatting operations such as a Space bar, a Tab key, and a Return or Enter key.
Dished profile	A concave arrangement of keys.
Dvorak keyboard	An alternative keyboard layout to the QWERTY, the Dvorak was purposely designed to decrease awkward finger movements and distribute the finger movement workload by skill and strength.
Elastomer Action	Movement of a key that produces an intermediate amount of key actuation feedback.
Extension	A movement in the opposite direction of flexion which causes an increase in the angle at the joint, such as straightening the wrist or raising the hand at the wrist joint.
F keys	Also called function keys. Special keys on the keyboard that have different functions depending on the program that is currently running. They are generally labeled F1 through F10, F12 or F15 and are generally located across the top of the keyboard. Advantages to the “F” keys are that they allow quick access to frequently used functions; disadvantages are that because they are not labeled, they require the user to remember what those functions are.
Flat profile	A keyboard with the keys arranged all at a single level.
Flexion	A movement of a segment of the body causing a decrease in the angle as the joint, such as bending at the wrist.
Function keys	Keys provided for extra or general functions, typically labeled F1, F2, and so on. (See F Keys)
Home row	The row of keys on a keyboard where all typing/finger strokes begin and end. The home row on a QWERTY keyboard contains the keys ASDFGHJKL;’.
Home row locator	Tactile cues, generally bumps or dots on the F and J keys to aid the user in locating the correct position of their fingers on the home row keys.

Homing time	The time needed to position the hands in the home position on a keyboard or interaction device.
Key force	The effort required for a finger to actuate a key.
Key top	The strike surface of a key.
Keyboard slope	The angle of the key surfaces in relation to the work surface.
Keyguard	A keyboard cover with holes over keys used to prevent accidental activation of keys by those with physical disabilities.
Keyset interlock	A delay in character that prevents two or more simultaneously depressed keys from either jamming the print mechanism or outputting an invalid key code.
Linear spring action	Produces light initial resistance which doubles at the point of switch closure due to compression of foam-backed mylar contact pad.
Membrane keyboards	A keyboard where the "keys" are not actual keys but delineated areas on a flat surface.
Modifier keys	Keys that modify or qualify the effects of other keys for as long as they are held down, for example, Shift, Ctrl, and Alt.
N-key rollover	A type of electronic interlock that only allows one character at a time to be created, but in the case that the keys are pressed in rapid succession (such that more than one key is pressed down at once) allows n characters to be stored in memory and created in the order that they were pressed after the other keys are released.
Navigation keys	Keys that move a cursor, for example, Arrow keys, Home, End, Page Up, and Page Down.
Numeric keypad	A separate grouping of numbered keys from 1 to 9 in 3 X 3 array, with zero on a separate bottom row.
Overshoot	To go beyond or exceed the point in which the key activates.

Primary keying area	The area that is easily reachable from the home position with the fingers resting on the home row of keys.
Pronation	Rotation of the hand and forearm so that the palm faces downward.
QWERTY keyboard	A keyboard layout based starting with the letters QWERTY in the upper left part of the keyboard also known as the Sholes keyboard.
Snap action	A spring mechanism that produces a rapid buildup of resistance on the downstroke of a key with a sharp drop off in mid travel at the point of switch closure.
Split keyboard	A keyboard that has the primary keying area split into two portions (generally between the tgb and yhn keys) in an effort to promote a more neutral, more ergonomic wrist position.
Strike surface	The top surface of the key. The primary area where the finger touches the key.
Supination	Rotation of the forearm and hand so that the palm faces up.
Toggle keys	Keys that change their state when pressed once and change back to the original state when pressed a second time. Also known as dual state keys. An example is the Caps Lock key.

References

Aaras, A., & Ro, A. (1997). Supporting the Forearms on the TableTop when Doing VDU Work. A Laboratory and Field Study. *Proceedings of the Marconi Research Conference*, Ergonomics Laboratory, University of California-San Francisco and the Center for Ergonomics, University of Michigan.

Ahlstrom, V. (1998). Human factors evaluation for Flight Data Input/Output Keyboard Replacement. Internal report. Atlantic City International Airport, NJ: Federal Aviation Administration, William J. Hughes Technical Center.

Ahlstrom, V., & Muldoon, R. (2003). *Function key and shortcut key use in airway facilities* (DOT/FAA/CT-TN03/07). Atlantic City International Airport, NJ: Federal Aviation Administration, William J. Hughes Technical Center.

Akagi, K. (1992). A computer keyboard key feel study in performance and preference. *Proceedings of the Human Factors Society, 36th Annual Meeting*, 523-527.

Albert, A. E. (1982). The effect of graphic input devices on performance in a cursor positioning task. *Proceedings of the Human Factors Society 26th Annual meeting*, Santa Monica, CA, 54-58.

Alden, D. G., Daniels, R. W., & Kanarick, A. F. (1972). Keyboard design and operation: a review of the major issues. *Human Factors*, 14(4), 275-293.

Andersen, J. H., Thomsen, J. F., Oergaard, E., Lassen, C. F., Brandt, L. P., Vilstrup, I., Kryger, A., & Mikkelsen, S. (2003). Computer use and carpal tunnel syndrome: a 1-year follow-up study. *JAMA*, 289 (22) 2963-2969.

ANSI (American National Standards Institute). (1988). American national standard for human factors engineering of visual display terminal workstations (BSR/HFES100). Santa Monica, CA: The Human Factors Society, Inc. Available from http://www.ansi.org

Armstrong, T.J., & Chaffin, D.B. (1979). Some biomechanical aspects of the carpal tunnel. *Journal of Biomechanics*, 12, 567-570.

Armstrong, T. J., Foulke, J. A., Martin, B. J., Gerson, J., & Rempel, D. M. (1994). Investigation of applied forces in alphanumeric keyboard work. *American Industrial Hygiene Association Journal*, 55, 30-35.

Baber, C. (1997). *Beyond the Desktop*. San Diego, CA: Academic Press.

Bach, J.M., Honan, M., & Rempel, D.M. (1997). Carpal tunnel pressure while typing with the wrist at different postures. *Marconi Research Conference*, Marshall, CA, April 13-16.

Barrero, M., Hedge, A., & Muss, T. (1999). Effects of chair arm design on wrist posture. Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting, Vol. 1, pp. 584-588

Bergqvist, U. (1995). Visual display terminal work - A perspective on long-term changes and discomforts. *International Journal of Industrial Ergonomics*, 16, 201-209.

Bergqvist, U., Wolgast, E., Nilsson, B., & Voss, M. (1995a). The influence of VDT work on musculoskeletal disorders. *Ergonomics*, 38 (4), 754-762.

Bergquist, U., Wolgast, E., Nilsson, B., & Voss, M. (1995b). Musculoskeletal disorders among visual display terminal workers: individual, ergonomic and work organizational factors. *Ergonomics*, 38 (4), 763-776.

Blomkvist, A, & Gard, G. (2000). Computer use in cold environments. *Applied Ergonomics*. 31, 239-245.

Brown, C. M. (1988). *Human-computer interface design guidelines*. Chapter 8: Control and display devices. 135-155. Norwood, NJ: Ablex Publishing Corp

Brunner, H. & Richardson, R. M. (1984). Effects of keyboard design and typing skill on user keyboard preferences and throughput performance. *Proceedings of the Human Factors and Ergonomics Society 28th annual meeting*, 267-271.

Burke, T. M., Muto, W. H., & Gutmann, J. C. (1984). Effects of keyboard height on typist performance and preference. *Proceedings of the Human Factors Society 28th Annual Meeting*, 272-276.

Butterbaugh, L. C., & Rockwell, T. H. (1982). Evaluation of alternative alphanumeric keying logics. *Human Factors, 24* (5), 521-533.

Cakir, A., Hard, D. J., & Stewart, T. F. M. (1980). Video Display Terminals. New York: Wiley. In C. Baber, *Beyond the Desktop*. San Diego, CA: Academic Press.

Cakir, A. (1995). Acceptance of the adjustable keyboard. *Ergonomics, 38,* 1728-1744.

Capobianco, G., Lee, M. D., & Cohen, S. (1999). Alphabetic vs. QWERTY keyboard layouts for touch screens: Hasn't someone already done that? *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*, 452-456.

Card, S. K., English, W. K. & Burr, B. J. (1978). Evaluation of mouse, rate-controlled isometric joystick, step keys and text keys for text selection on a CRT, *Ergonomics*, 21, 601-613.

Casali, S. P. (1992). Cursor control device by persons with physical disabilities: Implications for hardware and software design. *Proceedings of the Human Factors Society 36th Annual Meeting*, 311-315.

Chen, C., Burastero, S., Tittiranonda, P., Hollerbach, K, Shih, M., & Denhoy, R. (1994). Quantitative evaluation of four computer keyboards: Wrist posture and typing performance. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*.

Clare, C. R. (1976). Human Factors: A most important ingredient in keyboard design. EDN, 21 (8), 99-102.

Cohen, K. (1982). Membrane keyboards and human performance. *Proceedings of the Human Factors and Ergonomics Society*. 26, 424.

Conrad, R. & Hull, A. J. (1968). The preferred layout for numerical data entry keysets. *Ergonomics*, 11, 165-173.

Conrad, R., & Longman, D. J. A. (1965). Standard typewriter versus chord keyboard: an experimental comparison. Ergonomics, 8, 77-88. In C. Baber*, Beyond the Desktop*. San Diego, CA: Academic Press.

Cook, C.J., & Kothiyal, K. (1998). Influence of mouse position on muscular activity in the neck, shoulder and arm in computer users. Applied Ergonomics, 29(6) 439-443.

Czaja, S. (1983). *Hand Anthropometrics*. Technical paper, U. S. Architectural and transportation barriers compliance board. Washington, DC.

Def-Stan-00-25. (Defence Standard. Ministry of Defence 00-25). (1992). Human factors for designers of equipment. Directorate of Standardization, Kentigern House, 65 Brown Street, GLASGOW G2 8EX.

Deininger, R. (1960). Human factors engineering studies of the design and use of pushbutton telephone sets. *The Bell System Technical Journal*, 39, 995-1012.

DOE HFAC1 (Department of Energy.) (1992). *Human factors engineering design criteria*. Washington, DC: United States Department of Energy.

Douglas, S.A. & Mithal, A.K. (1997). *The ergonomics of computer pointing devices*. Springer-Verlag London.

Drury, C., & Hoffman, E. (1992). A model for movement time on data-entry keyboards. *Ergonomics*, 33 (2), 129-147.

EITAAC (Electronic and Information Technology Access Advisory Committee Final Report). (1999) http://www.access-board.gov/sec508/commrept/eitaacrpt.htm. Retrieved from the internet 3/23/04.

Emmons W. H., & Hirsch, R. S. (1982). Thirty millimeter keyboards: How good are they? *Proceedings of the Human Factors Society 26th Annual Meeting* (425-429). Santa Monica, CA: Human Factors Society.

Erdelyi, A., Sihoven, T., Helin, P., & Hanninen, O. (1988). Shoulder strain in keyboard workers and its alleviation by arm supports. International Archives of Occupational and Environmental Health, 60, 119-124.

Fagarasanu, M. & Kumar S. (2003). Carpal tunnel syndrome due to keyboarding and mouse tasks: a review. *International Journal of Industrial Ergonomics*, February 2003, 31 (2), 119-136(18).

Feng, Y., Grooten, W., Wretenberg, P., & Arborelius, U. P. (1997). Effects of arm support on shoulder and arm muscle activity during sedentary work. Ergonomics, 40, (8).834-848.

Fernström, E., Ericson, M. O., & Malker, H. (1994). Electromyographic activity during typewriter and keyboard use. *Ergonomics*, 37(3), 477-484.

Galinsky, T. Swanson, N., Sauter, S., Hurrell, J., & Schleifer, L. (2000). A field study of supplementary rest breaks for data-entry operators. Ergonomics, 43, 622-638

Gerard, M. J., Armstrong, T. J., Martin, B. J., & Rempel, D. A. (2002). Effects of workplace on within-participant and between-participant keying force, electromyography, and fatigue. *Human Factors*, 44.

Gerard, M. J., Armstrong, T. J., Rempel, D. A., & Woolley, C. (2002). Short term and long term effects of enhanced auditory feedback on typing force, EMG, and comfort while typing. *Applied Ergonomics*, 33 (2), 129-138.

Gerard, M. J., Jones, S. K., Smith, L. A., Thomas, R. E., & Wang, T. (1994). An ergonomic evaluation of the Kinesis ergonomic computer keyboard. *Ergonomics,* 37, 1661-1668.

Gerr, F., Marcus, M., & Monteilh, C. (2004). Epidemiology of musculoskeletal disorders among computer users: lesson learned from the role of posture and keyboard use. *Journal of electromyography and kinesiology*, 14, 25-31.

Goldstein, M., Book, R., Alsio, G., & Tessa, S. (1999). Non-keyboard QWERTY touch typing: a portable input interface for the mobile user. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.*

Gopher, D., Hilsernath, H., & Raij, D., (1985). Steps in the development of a new data entry device based upon two-hand chord keyboard. *Proceedings of Human Factors and Ergonomics Society*. 29, 132.

Grandjean, E. (1969). *Fitting the task to the man*. Taylor & Francis, London.

Grandjean, E. (1988). The design of workstations. In *Fitting the task to the man*. 78-81. Taylor & Francis, London.

Grandjean, E., Hunting, W., & Piderman, M. (1983). VDT workstation design: Preferred settings and their effects. *Human Factors*, 25, 161-175.

Greenstein, J. S. & Muto, W. H. (1988). Keyboards. In A. Sherr (Ed.), *Input Devices*. Boston: Academic Press.

Hagglund, K. L., & Jacobs, K. (1996). Comparisons of wrist postures in VDT operators using wrist rests and forearm supports, *Work*, 7 (3), 145-162.

Hansen, M. (1983). Keyboard design variables evaluated during dual-task mode selection. *Proceedings of the Human Factors and Ergonomics Society*, 27, 924.

Hashimoto, M. & Togasi, M. (1995). CHI '95 Mosaic of Creativity. *CHI Companion 95*, Denver, Colorado.

Hedge, A., McCrobie, D., Land, B, Morimoto, S., & Rodriguez, S. (1995). Healthy keyboarding: Effects of wrist rests, keyboard trays, and a preset tilt-down system on wrist posture, seated posture, and musculoskeletal discomfort. *Proceedings of the Human Factors and Ergonomics Society,* 39, 630.

Hedge, A., Morimoto, S., McCrobie, D. (1999). Effects of tray geometry on upper body posture and comfort. Ergonomics, 42 (10), 1333-1349

Hedge, A., & Powers, I. R. (1995). Wrist postures while keyboarding: Effects of a negative slope keyboard system and full motion forearm supports. *Ergonomics*, 38, 508-517.

Henning, R., Jacques, P., Kissel, G., Sullivan, A. B., & Alteras-Webb, S. M. (1997). Frequent short rest breaks from computer work: effects on productivity and well-being at two field sites, *Ergonomics*. January, 40 (1), 78-91.

Hirsch, R. S. (1970). *Effects of standard versus alphabetical keyboard formats on typing performance.* Journal of applied psychology, 54, 484-490.

Horie, S., Hargens, A., & Rempel, D. (1993). Effects of keyboard wrist rest in preventing carpal tunnel syndrome. *Proceedings of the America Public Health Association Annual Meeting.* Published abstract

Hornsby, M. E. (1981). A comparison of full-and reduced-alpha keyboards for aircraft data entry. *Proceedings of the Human Factors Society 25th Annual Meeting*.159-161.

Hufford, L. & Coburn, R. (1961). *Operator performance on miniaturized decolmantery keysets*. NEL report No. 1083. San Diego: US Naval Electronics Laboratory.

Hunter, M., Zhai, S., & Smith, B. A. (2000). Physics-based graphical keyboard design. *CHI '00 extended abstracts on human factors in computer systems*.

Hunting, W., Laubli, T., & Grandjean, E. (1981). Postural and visual loads in a VDT workplaces. Constrained postures. *Ergonomics*, 24(12), 917-931.

Ilg, R. (1987). Ergonomic keyboard design. *Behavior and Information Technology*, 6, 303-309.

Ilinski, R. (2003). Fitt's law & text input: Interface with pre-typing visual feedback for touch-sensitive keyboard. *CHI '03 extended abstracts on human factors in computer systems.*

ISO (International Organization for Standardization) (1998). Ergonomic requirements for office work with visual display terminals (VDTs) - Part 4: Keyboard requirements. (9241-4) International Organization for standardization ISO/IEC Geneva, Switzerland.

Kallage, R. (1972). Electronic keyboard design with n-key rollover. *Computer design*, 57-61.

Keane, J. (1992). *Human computer interface style guide* (Version 1.0 / DISA HCISG).Washington, DC: Defense Information Systems Agency.

Keir, P., Bach, J. & Rempel, D. (1999). Effects of computer mouse design and task on Carpal tunnel pressure. *Ergonomics* 42(10), 1350-1360.

Keller, E., & Strasser, H. (1997). Assessment of the ergonomics quality of hand tools and computer input devices via electromyographic and subjective methods. *Marconi Research Conference,* Marshall, CA, April 13-16.

Keller, E., Fleischer & Strasser, H. (2000). Subjective assessment of the ergonomic quality of a Keyboard for VDU Workplaces. *Proceedings of the IEA 2000/HFES Congress,* 344-347.

Kinkead, R. & Gonzalez, B. (1969). *Human factors design recommendations for touch-operated keyboards- final report.* (Document No. 12091-FR). Minneapolis, MN: Honeywell, Inc.

Klemmer, E.T. (1971). Keyboard Entry. *Applied Ergonomics,* .2-6.

Kodak. (1983). *Ergonomic design for people at work*. Vol.1. S.H. Rodgers & E.M. Eggleton (Eds.), Eastman Kodak Company. New York: Van Nostrand Reinhold.

Kopardekar, P., & Mital, A. (1994). The effect of different work-rest schedules on fatigue and performance of a simulated directory assistance operator's task. Ergonomics, 37(10), 1697-1707.

Lee, K., Swanson, N., Sauter, S., Wickstrom, R., Waikar, A., & Mangum, M. (1992). A review of physical exercises recommended for VDT operators. Applied Ergonomics, 23(6), 387-408.

Lewis, J. R., LaLomia, M. J., Kennedy, P. J. (1999). Evaluation of typing key layouts for stylus input. Proceedings of Human Factors and Ergonomics Society 43rd Meeting, pp. 420-424.

Loeb, K. (1983). Membrane keyboards and human performance. The Bell System Technical Journal, 62, 1733-1742. In C.Baber, *Beyond the Desktop*. San Diego, CA: Academic Press.

Loricchio, D. F. & Lewis, J. (1991). User assessment of standard and reduced-size numeric keypads. *Proceedings of the Human Factors Society 35th Annual Meeting*. 251-252, Santa Monica: The Human Factors Society.

Lu, H., & Aghazadeh, F. (1992). Infogrip chordic keyboard evaluation. *Proceedings of the Human Factors Society 36th Annual Meeting.* pp. 268-271.

Lutz, M. C., & Chapanis, A. (1955). Expected locations of digits and letters on ten-button keysets. *Journal of Applied Psychology*, 39, 314-317.

Marek, T., Noworol, C., Wos, H., Karwowski, W., & Hamiga, K. (1992). Muscular loading and subjective ratings of muscular tension by novices when typing with standard and split-design computer keyboards. *International Journal of Human-Computer Interaction,* 4(4), 387-394.

Marcus, M., Gerr, F., Monteilh, C., Ortiz, D., Gentry, E., Cohen, S., Edwards, A., Ensor, C., & Kleinbaum, D. (2002). A prospective study of computer users. II. Postural risk factors for musculoskeletal symptoms and disorders. American Journal of Industrial Medicine, 41, 236-249.

Marklin, R. & Simoneau, G. (1996). Upper extremity posture of typists using alternative keyboards. *Proceedings of the Silicon Valley Ergonomics Conference and Exposition,* ErgoCon '96, Palo Alto, CA, May 12-15, 126-132.

Marklin, R., Simoneau, G. & Hoffman, D. (1998). Effects of computer keyboard setup parameters and user's anthropometric characteristics on wrist deviation and typing efficiency. *Proceedings of the Human Factors and Ergonomics Society* 42, 876.

Marteniuk, R. G., Ivens, C. J., & Brown, B. E. (1996). Are there task specific performance effects for differently configured numeric keypads? *Applied Ergonomics*. 27(5), 321-325.

Matias, A., Salvendy, G., & Kuczek, T. (1998). Predictive models of carpal tunnel syndrome causation among VDT operators. *Ergonomics*, 41 (2), 213-226.

McAlindon, P. J. (1994). The development and evaluation of the keybowl: A study of an ergonomically designed alphanumeric input device. *Proceedings of the Human Factors and Ergonomics Society.* vol 38, 320.

McCormick, E. J. (1964). *Human Factors Engineering*. (2nd ed.) McGraw-Hill, NY.

McCormick, E. J. (1976). Human Factors in Engineering and Design. In C.Baber, *Beyond the Desktop*. San Diego, CA: Academic Press.

McLean, L., Tingley, M, Scott, R. N. & Rickards, J. (2001). Computer terminal work and the benefit of microbresks. Applied Ergonomics, 32, 225-237.

Michaels, S. E. (1971). QWERTY versus alphabetic keyboards as a function of typing skill. *Human Factors, 13*, 419-426.

Miller, I. & Suther, T. W. (1981). Preferred height and angle settings of CRT and keyboard for a display station input task. *Proceedings of the Human Factors Society 25th Annual Meeting,* 201-205. Santa Monica, CA: Human Factors Society.

Miller, W. & Suther, T. W. (1983). Display station anthropometrics: Preferred height and angle settings of CRT and keyboard. *Human Factors*, 25 (4), 401-408.

MIL-STD-1472F (Department of Defense). (1999). *Department of Defense design criteria standard human engineering*. Philadelphia, PA: Navy Publishing and Printing Office.

Monty, R. W., Snyder, H. L., & Birdwell, G. G. (1983). Keyboard Design: An investigation of user preference and performance. *Proceedings of the Human Factors and Ergonomics Society 27th Annual Meeting*. 201-205.

Moore, J., Garg, A., Roberts, M., & Root, D. (1997). Relationships between Workstation Attributes and the Use of Input Devices with the Prevalence of Distal Upper Extremity and Neck-Shoulder Symptoms. *Proceedings of the Marconi Research Conference,* Ergonomics Program, University of California, San Francisco and Center for Ergonomics, University of Michigan. Ann Arbor, April 13-16.

Morelli, D., Johnson, P., Reddell, C., & Lau, P. (1995). User preferences between keyboards while performing "real" work: A comparison of "alternative" and standard keyboards. *Proceedings of Human Factors and Ergonomics Soci*ety 39, 361.

Myers, B. A., Lie, K. P., Yang, B. (2000). Two-handed input using a PDA and a mouse. *CHI Letters*, 41-48.

Nakaseko, M., Grandjean, E., Hunting, W., & Gierer, R. (1985). Studies on ergonomically designed alphanumeric keyboards. *Human Factors,* 27 (2), 175-187.

Nelson, N. A., Silverstein, B. A. (1998). Workplace changes associated with a reduction in musculoskeletal symptoms in office workers, *Human Factors*, 40 (2), 337-350.

Nolan, P. R. (1991). The design of keyboard templates. *Proceedings of the Human Factors Society 35th Annual Meeting,* 486-490.

Nordic Guidelines for Computer Accessibility. (1998). 2nd ed. Claus Thoren, (Ed) Nordiska samarbetsorganet för handikappfrågor, Stockholm, Sweden.

Norman, D. A., & Fisher, D. (1982). Why alphabetic keyboards are not easy to use: keyboard layout doesn't much matter. *Human Factors*, 24 (5) 509-519.

Noyes, J. (1983). The QWERTY keyboard: A review. *International Journal of Man-machine studies*. 18, 265-281.

NUREG 0700 (Nuclear Regulatory Commission). (2002). *Human-system interface design review guidelines* (NUREG-0700 Rev. 2). Washington, DC: United States Nuclear Regulatory Commission.

OHSA (1997). Working safely with video display terminals. Revised (OSHA 3092) U.S. Department of Labor, Occupational Safety and Health Administration.

Palmer, K. T., Cooper, C., Walker-Bone, K., Syddall, H., Coggon, D. (2001). Use of keyboards and symptoms in the neck and arm: evidence from a national survey. *Occupational Medicine,* 1 September, 51 (6), 392-395.

Parsons, C. A. (1991). Use of wrist rests by data input VDU operators. E J Lovesey (ed) *Contemporary Ergonomics*, 1991, New York, Taylor and Francis, 319-321.

Paul, R. & Menon, K. K. (1994). Ergonomic evaluation of wrist pads. *Proceedings of the 12th Triennial Congress of the International Ergonomics Association.* Vol 2, Toronto, Canada, 204-207.

Powers, J. R., Hedge, A., & Martin, M. G. (1992). Effects of full motion forearm supports and a negative slope keyboard support system on hand-wrist posture while keyboarding. *Proceedings of the Human Factors Society 36th Annual Meeting*. 796-800.

Radwin, R., & O. Jeng, (1997). Activation Force and Travel Effects on Overexertion in Repetitive Key Tapping, *Human Factors*, Vol. 39, No. 1, 130-140.

Radwin, R. G., & Ruffalo, B. A. (1999). Computer key switch force-displacement characteristics and short term effort on localized fatigue. *Ergonomics*, 42 (1), 160-170.

Reger, J. J., Snyder, H. L., & Epps, B. W. (1987). Performance and preference for cursor-key control configurations in editing tasks. *Digest, society for information display.* 22-25. Playa Del Rey, CA: Society for Information Display.

Rempel, D. (1995). Position of the wrist associated with the lowest carpal tunnel pressure: Implications. Journal of Bone and Joint Surgery, 77, 1695-1699.

Rempel, D., Bach, I.M., Gordon, L., & So, Y. (1998). Effects of forearm pronation/supination on carpal tunnel pressure. The Journal of Hand Surgery, 23A(1), 38--42.

Rempel, D., Jacobsen, M., Brewer, R., & Martin, B. (2000). Finger Muscle Activity During Use of Different Pointing Devices. *Proceedings of the IEA2000/HFES 2000 Congress.*

Rempel, D., Kier, P. I., Smutz, W. R., & Hargen, A. (1997). Effects of static fingertip loading on carpal tunnel pressure. *Journal of Orthopaedic Research*, 15, 422-426.

Rempel, D., Serina, E., Klinenberg, E., Martin, B. J., Armstrong, T .J., Foulke, J. A., Nataraja, S. (1997). The effect of keyboard keyswitch make force on applied force and finger flexor muscle activity. *Ergonomics*, 40 (8), 800-808.

Ro, J., & Jacobs, K. (1997). Wrist postures in video display terminal operators (VDT) using different keyboards. *Work*, 9 (3), 255-266.

Roe, C. J., Muto, W. H., & Blake, T. (1984). Feedback and key discrimination on membrane keypads. *Proceedings of the Human Factors Society 28th Annual Meeting*. 277-281.

Rose, M. J. (1991). Keyboard operating posture and actuation force: Implications for muscle overuse. *Applied Ergonomics, 22(3),* 198-203.

Rosinski, R. R., Chiesi, H., & Debons, A. (1980). Effects of amount of visual feedback on typing performance. *Proceedings of the Human Factors Society 28th Annual Meeting,* 195-199.

Rudakewych, M., Valent-Weitz, L. & Hedge, A. (2001). Effects of an ergonomic intervention on musculoskeletal discomfort among office workers. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*. 791-795.

Sauter, S. L., Schleifer, L. M., & Knutson, S. I. (1991). Work posture, workstation design and musculoskeletal discomfort in a VDT data entry task. *Human Factors*, 33(3), 151-167.

Scadden, L. A., & Vanderheiden, G. C. (1988). *Considerations in the design of computers and operating systems to increase their accessibility to persons with disabilities* (Version 4.2). Madison, WI: Trace Research and Development Center.

Schuldt, K., Ekholm, J., Harms-Ringdahl, K., Nemeth, G., & Arborelius, A. (1987). Effects of arm support or suspension on neck and shoulder muscle activity during sedentary work. *Scandinavian Journal of Rehab. Medicine*, 19, 77-84.

Sears, A., Jacko, J. A., Chu, J. & Moro, F. (2001). The role of visual search in the design of effective soft keyboards. *Behaviour & Information Technology, 20, (3),* 159-166.

Shneiderman, B. (1998). *Designing the User Interface*. Third Edition. Massachusetts: Addison Wesley Longman, Inc.

Siebel, R. (1962). Performance on a five-finger chord keyboard. *Journal of Applied Psychology*, 46 (3), 165-169.

Sihvonen, T., Baskin, K, & Hanninen, O. (1989). Neck-shoulder loading in wordprocessor use: effect of learning, gymnastics, & arm supports. *International Arch. Occupational and environmental health*, 61, 229-233.

Simoneau, G. G., & Marklin, R. W. (2001). Effects of computer keyboard slope and height on wrist extension angle. *Human Factors*, 43 (2), 287-298.

Simoneau, G. G., Marklin, R. W., & Berman, J. E. (2003). Effects of computer keyboard slope on wrist position and forearm electromyography of typists without musculoskeletal disorders. *Physical therapy. 83(9),* 816-830.

Simoneau, G. G., Marklin, R. W., & Monroe, J.F. (1999). Wrist and forearm postures of users of convenetional computer keyboards. *Human Factors*, Sept. 41(3), 413.

Simoneau, G. G., Marklin, R. W., Monroe, J., & Zabors, J. (1996). Wrist and forearm position during a typing task using various keyboard models. *American Society of Biomechanics, 20th Annual Meeting.* Atlanta, GA.

Smith, M. J., Karsh, B, Conway, F., Cohen, W., James, C., Morgan, J., Sanders, K, & Zehel, D. (1998). Effects of a split keyboard design and wrist rest on performance, posture, and comfort, *Human Factors*, 40 (2), 324-336.

Smith, S. L., & Mosier, J. N. (1986). *Guidelines for designing user interface software*(ESD-TR-86-278). Hanscom AFB, MA: Electronic Systems Division.

Sommerich, C. M. (1994). Carpal tunnel pressure during typing: Effects of wrist posture and typing speed. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*. Santa Monica, CA: Human Factors and Ergonomics Society, 611

Sommerich, C.M. (2000). Inputting to a Notebook Computer. *Proceedings of the IEA2000/HFES 2000 Congress.* 671-674.

Stevens, S. S. (1975). Psychophysics-Introduction to its perceptual, neural and social prospects. In *Ergonomic Design for people at work. Vol.1 (1983*). S.H. Rodgers & E.M. Eggleton (Eds.), Eastman Kodak Company. New York: Van Nostrand Reinhold.

Straker L., Jones K. J., Miller J. A. (1997). Comparison of the postures assumed when using laptop computers and desktop computers. *Applied Ergon*omics, 28 (4), 263-268.

Strasser, H., Keller, E. & Fleischer, R. (2000). Electromyographic evaluation of muscle strain of the hand-arm-shoulder system during alternating typing at a conventional and ergonomic keyboard. *Proceedings of the Human Factors and Ergonomics Society*. 360-363.

Suther, T., & McTyre, J. (1982). Effect on operator performance at thin profile keyboard slopes of five, ten, fifteen, and twenty-five degrees. *Proceedings of the Human Factors and Ergonomics Society.* 26, 430.

Swanson, N. G., Galinsky, T. L., Cole, L. L., Pan, C. S., & Sauter, S. L. (1997). The impact of keyboard design on comfort and productivity on a text entry task. *Applied ergonomics*, 28 (1), 9-16.

Tinker, M. (1963). *Legibility of print.* Iowa State University Press, Ames, Iowa.

Tinker, M. (1965). *Bases for effective reading.* University of Minnesota Press, Minneapolis, Minnesota.

Tittiranonda, P., Burastero, S., Wei, E., & Rempel, D. (1996). Three month clinical prospective intervention study using four keyboards. *Marconi Computer Input Device Research Conference*, Marshall, CA, January 4-7.

Treaster, D. E, & Marras, W. S. (2000). A Biomechanical Assessment of Alternate Keyboards Using Tendon Travel. *Proceedings of the IEA 2000/HFES 2000 Congress.* 685-688.

Trewin, S. (2002). An invisible keyguard. *Proceedings of the 5th International Conference on Assistive Technologies.* 143-149.

Visser, B., de Korte, E., van der Kraan, I., & Kuijer, P. (2000). The effect of arm and wrist supports on the load of the upper extremity during VDU work. *Clinical Biomechanics*, 2000, 15 (1001), 34-38(5).

Weiss, N. D., Gordon. L., Bloon, T., So, Y., & Rempel, D. M. (1995). Position of the wrist associated with the lowest carpal tunnel pressure: Implications for splint design. *The Journal of Bone and Joint Surgery*, 77-A, 1695-1699.

Werner, R., Armstrong, T.J., Bir, C. & Aylard, M.K. (1997). Intracarpal canal pressures: the role of finger, hand, wrist and forearm position, Clinical Biomechanics, 12 (1), 44-51.

Yoshitake, R. (1995). Relationship between key space and user performance on reduced keyboards. Applied Human Science *Journal of Physiological Anthropology* 14(6), 287-292.

Zecevic, A., Miller, D. I., & Harburn, K. (2000). An evaluation of the ergonomics of three computer keyboards. *Ergonomics*, 43 (1), 55-72.

Zhai, S., Sue, A., & Accot, J. (2002). Movement model, hits distribution and learning in virtual keyboarding. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.*

Zipp, P., Haider, E., Halpern, N., & Rohmert, W. (1983). Keyboard design through physiological strain measurements. *Applied Ergonomics*, 14(2), 117-122.