

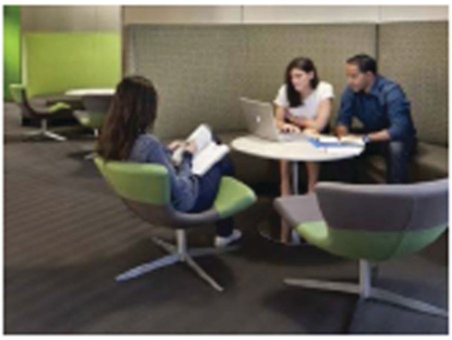

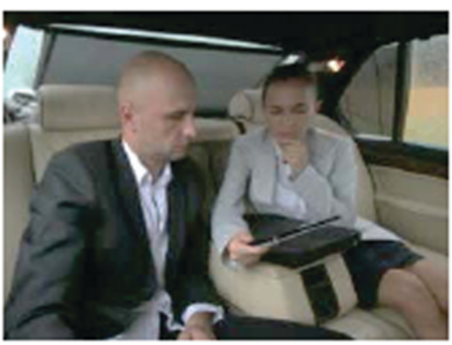


ERGONOMIC WORKPLACE DESIGN FOR HEALTH, WELLNESS, AND PRODUCTIVITY

edited by

Alan Hedge

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ERGONOMIC WORKPLACE DESIGN FOR HEALTH, WELLNESS, AND PRODUCTIVITY

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Preface

Every day billions of people around the world go to work. Work is fundamental to human societies. Work partly defines us as individuals, and certain professions can serve as status symbols. Many people spend years in education systems training for a work career. Losing one's job can be a significant stressor, as can retirement from work. Anything that improves the conditions of work has an enormous impact on the well-being of vast numbers of people. Ergonomics is the science of work, and it is a valuable discipline that focuses on improving the ability of people to perform work. Ergonomics adopts a systems approach to designing effective work, and that requires consideration of relevant cognitive, physical, and organizational factors. Indeed, in the International Ergonomics Association's description of ergonomics, it describes these three sets of factors. Yet there is also a crucial fourth factor, namely, the environment. As this book will demonstrate, the ergonomic design of the environment is an essential, yet all too often overlooked, component of the work systems design process.

All human work, whether physical, mental, or both, occurs somewhere, and the design of the work environment obviously plays a critical role in the ability of a person to perform their work. Work performance can suffer if the environmental conditions are suboptimal, such as workplaces that are too cold or too hot, where the lighting is too bright or too dim, where it is too noisy, where the air is polluted, or where the work setting is vibrating or in motion. Also, a suboptimal spatial layout of a workplace can detrimentally affect work postures, which in turn impacts health, wellness, and task performance.

Although early humans were most likely nomadic, where possible they inhabited places and natural structures such as caves, which offered protection against elements and predators, and which served as congregation places. Eventually, some 5000 years ago, developments in agriculture allowed communities to settle in specific locations starting the processes of urbanization and civilization as we now know it. At that time, it is likely that a majority of workers did most of their work outdoors, with activities such as hunting and fishing, agriculture, road building, construction, and fighting battles.

The industrial revolution that began around 1750 marked the acceleration in the movement of work from outdoors in fields to indoors in factories. In developed countries today, a majority of workers perform their work inside some kind of designed structure, such as a building or a vehicle. How well the designed environment supports their work plays a significant role in factors such as the risks of work-related injuries, accidents, and productivity.

Although the designed environment plays an obvious role in impacting human behavior, this often gets overlooked, even in the ergonomic analysis of work. For example, task analysis methods typically focus on the work content and the physical actions involved in performing work, and cognitive task analysis, workload measurement, and error analysis methods focus on the mental processes involved in completing the tasks, yet such methods typically neglect the consideration of the physical environment design changes that either positively or negatively impact the work processes. We all know from personal experience how critical the design of the environment is to the successful performance of work. If you use an iPad, you may have struggled to read the screen in bright sunlight because the ambient lighting overwhelms the luminance of the screen, or, conversely, you may have struggled to read a printed menu in a dimly lit restaurant where the lighting is insufficient for easy legibility of the text. You may be an adroit typist, but if you are using a laptop while riding on a bus that is driving along a bumpy highway, you will have experienced how difficult it is to maintain adequate performance and to minimize errors because the environment is not supporting your ability to do work. You may have experienced feelings of drowsiness when sitting in a crowded meeting in an inadequately ventilated room, and this occurs because of an accumulation of carbon dioxide. Your manual dexterity and cognitive abilities are substantially impaired by exposure to very cold conditions, and your energy levels may be set by hot and humid conditions. Environmental conditions, such as the thermal environment, the luminous environment, the acoustic environment, and the vibration, all impact our comfort, health, and performance. Quite simply, we are animals with biological systems that are adapted to a relatively narrow range of environmental conditions, and if we are to be successful when inside human-designed enclosures, ranging from submarines to spacecraft, from cars to buildings, then we must pay close attention to optimizing these environmental conditions to maximize our ability to perform work efficiently and effectively.

This book provides a good overview of these environmental requirements. But just knowing the environmental conditions by itself is not sufficient to ensure that our performance is optimized. Our capabilities are limited by our chronobiology—there are times of the day when we expect to be able to sleep and other times when we are alert. Unfortunately, in our 24/7 societies, there are many jobs that require people to work at those times of the day when our bodies are least prepared for this. In addition, our capabilities are also limited by factors such as our size, reach distances, and strength, and so the physical arrangement of tools and other work artifacts is critical if we are to demonstrate maximum performance ability while minimizing the risks of errors, accidents, and injuries. To illustrate these issues and other related considerations, this book also presents workplace design considerations for a wide variety of workplace settings. In most of the settings that are described, the ergonomics considerations focus on physical design issues, and one fact that remains invariant is that whenever we can position a person so that they can perform their work while in a neutral posture, whether sitting or standing, then we will maximize their physical capabilities and their endurance and minimize the possibilities of developing work-related injuries.

This book contains the latest information from internationally recognized ergonomics experts. In Section I, the first seven chapters of the book, the physical environmental conditions necessary for optimal health, wellness, and productivity are presented. In Chapter 1, Hedge describes the basic computer workstation design requirements for a healthy posture. We are homiotherms, and in Chapter 2, Parsons presents the thermal environment requirements for comfort, health, and performance. In many indoor settings, the thermal conditions are linked with ventilation, and in Chapter 3, Wargocki provides a comprehensive review of the optimal indoor air quality requirements. Noise can be stressful and can interfere with work performance, and in Chapter 4, Oseland and Hodsman tell us the requirements for the design of a successful acoustic environment. In many work settings, the worker is in motion or using tools that vibrate, and in Chapter 5, Burgess-Limerick describes what is acceptable and what will interfere with our ability to work as well our health and well-being. In Chapter 6, Figueiro and Rea summarize the lighting conditions essential for optimal visual performance in indoor workplaces. For optimal health, our bodies need to be synchronized with the environment, yet in our 24/7 world many people have to work at times when our body is not at its best, and Puttonen discusses this important topic of shift work in Chapter 7.

In Section II, there are eight chapters that present the application of ergonomics in different workplaces. Perhaps one of the commonest workplaces in the modern world, the office looks innocuous, but in Chapter 8, Vink et al. discuss a range of ergonomic issues with various types of office designs. Especially in the United States, healthcare is provided 24 hours each day, every day, and it is a sector that now is in transition as new healthcare information technologies permeate many aspects of medical care, and in Chapter 9, Springer describes a selection of these issues. Likewise, many control center operations involve 24/7 working, and their heavy emphasis on computing technology presents unique challenges, as shown by Papic in Chapter 10. Our education systems are critical in providing a future workforce with the necessary knowledge and skills for success, and in Chapter 11, Straker and Howie review the important contributions that ergonomics makes to the design of school settings. Universities are the pinnacle of many education systems, and in addition to teaching students, they are typically large institutions that fulfill a variety of research and other functions. In Chapter 12, Nou shows the importance of ergonomics in a variety of these settings. In Chapter 13, Burt describes the value of ergonomics in the design of laboratories and laboratory equipment that is used many research settings, from universities to biotechnology and pharmaceutical companies.

For many people, hotels provide temporary vacation accommodation and/or a temporary workplace; hospitality settings are complex environments that present ergonomists with a variety of challenges, and in Chapter 14, Punnett et al. discuss a wide range of these issues. In Chapter 15, Robertson and Maynard systematically look at the ergonomic design challenges presented by the growth in teleworking, where the residence also becomes the workplace for at least part of the working week.

The final six chapters in Section III address emerging ergonomic design issues. In Chapter 16, Peacock et al. examine some of the issues of transportation systems, including the role of vehicles as modern workplaces. Many organizations are experimenting with replacing more traditional office designs. In Chapter 17, Brand describes the drivers for these new ways of working (WOW) and presents alternative workplace design strategies, and in Chapter 18, McAtamney et al. summarize a range of ergonomic design considerations associated with new WOW settings. The green building movement has transformed the construction industry worldwide, and ergonomic designs can play a valuable role in the creation of sustainable buildings, as described by Dorsey in Chapter 19. Innovation is the lifeblood of most organizations, and in Chapter 20, Yoon and Chung outline a number of important elements for designing 3C workplaces that can foster connectedness, collaboration, and creativity, and present recent work on this topic using social sensing technology. Finally, in Chapter 21, Hedge and Pazell discuss the benefits of ergonomics and wellness programs, which are traditionally separated in organizations with ergonomics being a part of Health and Safety and wellness a part of the Human Resources, and they discuss the importance of new initiatives aimed at a total systems approach to the design of workplaces to promote employee health, wellness, and productivity.

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Acknowledgments

The topic of workplace design often gets little attention in the human factors and ergonomics world. This book will hopefully serve to raise the profile of workplace ergonomic design. But this book probably would not have materialized without the foresight of Gavriel Salvendy of Purdue University and Tsinghua University, for it is he who enthusiastically suggested that I compile this book. But also, I could not have completed this task without the willingness and dedication of all the contributors. I also acknowledge all of the ergonomics practitioners who help those who have been injured because of the inadequate design of their workplaces. I hope that this book will serve as a stimulus that triggers greater interest in the importance of workplace design in the human factors and ergonomics community, for every day what we do directly affects the health, wellness, and productivity of millions of workers around the world.

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Editor

Alan Hedge is a professor in the Department of Design and Environmental Analysis, Cornell University, where he also directs the Cornell Human Factors and Ergonomics laboratory. His research and teaching activities focus on ergonomic designs that promote health, comfort, and productivity, especially in healthcare and office workplaces.

He is a fellow of the Human Factors and Ergonomics Society (HFES), and he was awarded the 2003 Alexander Williams Jr. Design Award and the 2009 Oliver Hansen Outreach Award by the HFES. He is also a fellow of the International Ergonomics Association, a chartered ergonomist in the UK, and a certified professional ergonomist.

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Section I

The Physical Environment

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1 Introduction to Workplace Ergonomics and Issues of Health and Productivity in Computer Work Settings

Alan Hedge

CONTENTS

1.1 INTRODUCTION

In the United States, the number of white-collar or no-collar office workers has grown from ~18% of employees in 1900 to ~60% of employees in 2010 (Cenedella 2010). The microcomputer revolution of the 1970s and the 1980s has led to the vast majority of U.S. office workers using a computer for some part of their work activities. This is especially true for the office workplace, where the vast majority of these workers use a computer at their workplace and also likely use a computer elsewhere when away from their office, such as at home. The technology shift from paper to computer that began in the 1980s marked the beginning of a major change in the emphasis in the practice of ergonomics because a growing number of office workers using computers began to develop work-related musculoskeletal injuries, and the culprit was the poor design of their workspaces. The ergonomic redesign of office workspaces emerged as both a means of rehabilitating workers who had become injured and also a means of preventing workers from becoming injured. This focus on the physical design of workspaces also forms the basis of technical standards and, in 1998, saw the release of the first U.S. computer workstation design standard (American National Standards Institute [ANSI] Human Factors Society [HFS] 100 1988). Since that time, considerable research has been conducted to investigate how to optimize the design of different computer components, such as keyboards, mice, trackballs, touchpads, voice recognition systems, and computer screens. More recently, a revised standard was promulgated that gives designers greater guidance on how to optimize the physical layout of a computer workspace (ANSI HFES 100 2007). As technology continues to develop so does research continue to be conducted on the optimal arrangements of computer technologies to maximize worker productivity and comfort and minimize their risks of injuries. What we know is that the concept of *neutral posture working* has emerged as being of fundamental importance to much of this work, and it provides a basis for the physical ergonomics design of modern computer workplaces. The knowledge of neutral posture working is of such value because the capabilities of the human body change quite slowly, whereas the technologies that are used to perform work can change very rapidly. We also know that our ability to perform tasks is dependent on the level of comfort that we are experiencing. For example, if one has a toothache, a headache, or a backache, then this impairs both physical and cognitive capabilities. In short, we know that "pain distracts the brain." Yet when we look at workers in many of our designed settings, we find a high prevalence of those who are experiencing frequent discomfort and often musculoskeletal pain, and for these individuals, it is impossible for them to perform their work at an optimum level. There is also abundant evidence that placing individuals in work settings that have been designed to promote a neutral posture while performing a task can eliminate pain and discomfort. Consequently, the principles of neutral posture working are summarized in the ANSI HFES 100 ergonomic standards (2007), and they serve as the goal of ergonomic interventions that focus on redesigning individual workspaces. The fundamental requirements for neutral posture working with a computer are summarized in the following sections.

1.2 NEUTRAL POSTURE WORKING

Every articulating joint of the body has a normal range of motion. Working with the body positioned in a neutral posture means that no parts of the body are bent, twisted, or otherwise contorted away from a normal, relaxed, and comfortable position. For specific body segments, this means that a neutral posture conforms to the following guidelines (note that these positions are not absolute and a task may require intermittent excursions beyond them, but sustained postures outside of the neutral posture can cause discomfort and injuries):

- Neck—The neck is balanced and aligned with the top of the spine with minimal forward flexion or backward extension (dorsiflexion), and not laterally bent or twisted.
- Back—The whole spine is erect in a normal S shape with no part of the spine being uncomfortably flexed or extended and with no segment being laterally bent or twisted. If the spine

is in an S shape but in a reclined posture, then this should be supported by a suitable back support, such as an ergonomic chair back.

- Shoulders—The shoulders are relaxed and symmetrical; neither shoulder should be elevated, hunched or twisted.
- Upper arms—The upper arms are relaxed by the side of the body with minimal abduction or no adduction, as close to vertical as possible with minimal forward extension or backward flexion.
- Elbows/Forearms—The elbows/forearms are close to horizontal, not flexed, and forearms, not twisted into the extremes of pronation or supination.
- Wrists/Hands—The wrists/hands are straight and level, not laterally bent, extended upward or flexed downward, or twisted into the extremes of pronation or supination.
- Thighs—When seated, the thighs should be close to horizontal or slightly declined, well supported without uncomfortable compression, and when standing, these should be vertically aligned and not twisted.
- Knees—The popliteal angle behind the knee should be 90° or greater; otherwise, the blood flow to the lower legs is impeded. When standing, these should not be uncomfortably bent.
- Lower legs—When seated, the lower legs should be close to vertical or slightly angled so that the feet lie ahead of the knees. They must be free from uncomfortable compression. When standing, these should be vertically aligned and not twisted.
- Ankles/Feet—The feet can be flat on the floor beneath the lower legs or if the flower legs are outstretched then the feet should be on an inclined foot support.

These neutral posture guidelines also form the basis for posture targeting methods, such as the rapid upper limb assessment method (McAtamney and Corlett 1993) and the rapid entire body assessment method (Hignett and McAtamney 2000). Several field studies have confirmed the importance of neutral posture working for computer workers in offices and demonstrated how this results in a very substantial decrease in the prevalence of work-related upper body musculoskeletal symptoms (Rudakewych et al. 2001; Hedge et al. 2002, 2011; Hedge 2013; Hedge and Puleio 2014).

Figures 1.1 and 1.2 show the examples of a person in a neutral posture for sitting and standing computer use. Note that in these figures, the keyboard is placed on a height-adjustable downward-tilting platform that can also accommodate a mouse (not shown) and that has been adjusted so the hands are relatively leveled with the fingertips resting on the keytops, but the computer screen has limited height adjustability and ideally should be placed a little higher than shown to minimize any forward neck flexion. The person is positioned centered on their input devices and computer screen.

1.3 ERGONOMIC GUIDELINES FOR ARRANGING A COMPUTER WORKSTATION

Today many workers sit or stand to use a computer to perform their work tasks. Creating a good ergonomic working arrangement for safe computer use is important to maximize worker performance and minimize the risks of musculoskeletal injury. There is a wide variety of workplace settings in which computers are used, but for office workplaces, the following ergonomic considerations are important.

1.3.1 How Will the Computer Be Used?

To answer the question, how will the computer be used? requires knowledge about the characteristics of the user or the users and also the daily duration of their computer use. If only one person is using the computer, then the workspace arrangement can be optimized for that person's size and shape, and the features such as a height-adjustable chair may be unnecessary if the person has

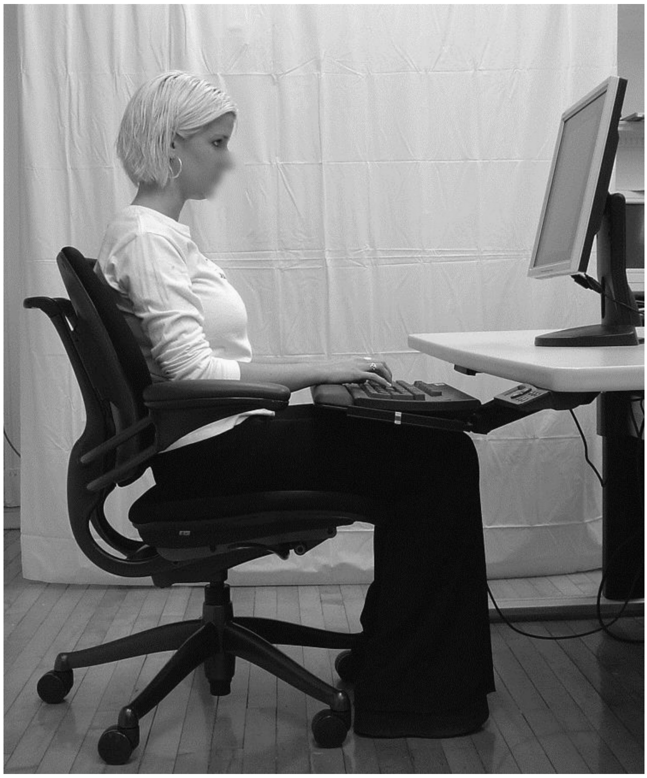

FIGURE 1.1 Seated neutral posture for a computer worker.

a chair that fits their body dimensions. However, in many situations where the furniture is being bought for large numbers of workers, it is advisable to buy ergonomic products that provide adjustability to fit any worker from the dimensions of a 5th percentile woman to a 95th percentile man. Providing products with a suitable range of adjustability and easy and quick adjustments is essential if the same product is going to be used by several people, such as with shift work in say a hospital. If the workspace arrangement does not fit the anthropometrics of the worker to support neutral posture working, then s/he will adjust their body to the work tools and most likely end up in a deviated, non-neutral work posture that impedes their productivity and increases injury risks.

Consideration of how long each person will be using the computer is important. If it is a few minutes in total each day, then the ergonomic issues may not be a high priority. If it is for a few minutes at a time but there is a high frequency of use, as with say computer cart use by a hospital nurse, then quick and easy adjustments are a priority. If it is to be used by a person for more than one hour per day, then it is advisable that an ergonomic workspace arrangement be created. If it is more than four hours each day, then this definitely requires an ergonomic workspace arrangement.

1.3.2 What Kind of Computer Will Be Used?

There are at least three different types of computers that a worker could use, a desktop, a laptop, and a tablet, and each has different needs for the design of the workspace.

1.3.2.1 Desktop Computer

Most ergonomic guidelines for computer workstation arrangements assume that the worker will be using a desktop system where the computer screen is separate from the keyboard/mouse and the central processing unit (CPU). The critical considerations for desktop computer use are the

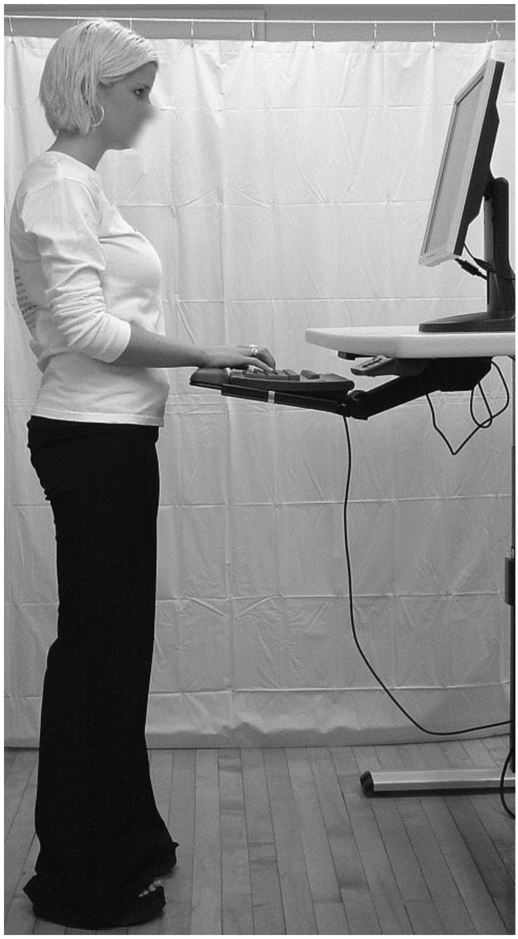

FIGURE 1.2 Standing neutral posture for a computer worker.

positioning of the keyboard and the mouse, the position of the computer screen, and whether the worker will be sitting or standing. If the worker also has to frequently access the CPU, then placing this close so that the worker can reach the CPU while still in a neutral posture is important.

1. Keyboard—If most of the work being done involves typing text, then the worker should be centered on the alphanumeric keyboard. Hedge (2004) summarizes the ergonomic considerations with computer keyboards and Kroemer (2001) provides an excellent annotated bibliography of the keyboard literature from 1878 to 1999. Rempel et al. (2008) have shown that the wrist extension during typing can elevate carpal tunnel pressure. Most modern keyboards are fairly flat and asymmetrical—the alphanumeric keyboard is to the left and a numeric keypad, to the right. If the outer edges of such a keyboard are used as landmarks for centering the keyboard and the monitor, the worker's hands, especially the right hand, will be ulnar-deviated because the alphanumeric keys will be to the left of the user's midline. Positioning such a keyboard so that the center of the alphanumeric keys, the H key, is centered on the midline of the user will reduce the hand deviation. However, if most of the entry work that is being done involves using the number pad, then aligning this with the right hand with the arm relaxed by the side of the body will reduce hand deviation. If the person is left-handed, then a left-handed keyboard or a separate number pad can be

used to align with their left hands. Placing the keyboard on an adjustable height and angle downward-tilting platform allows the keyboard to be positioned slightly below elbow level and the downward-tilting keytops can be used with the hands in a flat, neutral posture (Hedge et al. 1999; Simoneau and Marklin 2001).

2. Ergonomic and alternative keyboards—Many ergonomic keyboards are keyboards where the alphanumeric keys typically are split at an angle, split into two halves of the keyboard, dished, or otherwise arranged. The rationale for most split keyboards, whether they are fixed split angle or adjustable split angle, is to reduce ulnar deviation, and it can be traced back to the Crandall New Model typewriter of 1886. Contrary to expectations, even with a conventional flat keyboard, ulnar deviation is often not extreme and from studies of intracarpal tunnel pressure (Honan et al. 1995), ulnar deviation appears to be less important than wrist extension during typing. When typing, Baker et al. (2015) conducted a randomized crossover trial that tested fixed split-angle or standard flat keyboards for five months with 77 symptomatic computer operators in their workplace, and found no significant changes in discomfort with the fixed split-angle keyboard and a comfort preference for the flat keyboard. Some keyboards are completely split, and each half of the keyboard can even be mounted on chair arms. Hedge and Shaw (1996) studied a chair-mounted split keyboard and found that this design significantly reduced ulnar deviation, but did not reduce wrist extension and typing speed was slower, although the accuracy was unaffected. Muss and Hedge (1999) studied a vertical split keyboard used with or without articulating forearm supports, and found that the vertical keyboard significantly improved the proportion of typing movements performed in a neutral zone of wrist motion (71% for flexion/extension; 78% for radial/ulnar movements) compared with the conventional keyboard (44% and 25%, respectively), but the typing performance was slightly slower for the vertical keyboard. For a nontouch typist, such alternative designs can significantly impair the typing performance. Split designs typically focus on reducing the ulnar deviation of the hand, but research studies suggest that vertical hand posture (wrist extension) is more important (Hedge et al. 1999). There is no consistent research evidence that most of the alternative keyboard designs currently available really produce any substantial postural, performance, and usability benefits. Other keyboard designs have been developed such as chordic keyboards, which reduce the number of keys so that different letters are generated by the combined pressing of keys, like playing chords on a piano. People can memorize around 59 different chords, but even after 10 hours of practice typing, the speed is only around 14 words per minute, which is much slower than an average typist who types around 40 words per minute (Kroemer 1992). Ting and Hedge (2001) found that the typing speed was only ~9 words per minute for a hybrid chordic keyboard and game controller. Typing on a flat multitouch keyboard is significantly slower than on a conventional keyboard, and, even though there was significantly less wrist extension, the multitouch keyboard is judged to be less comfortable (Thom-Santelli and Hedge 2005). Typing on a laser-projected keyboard is also slower; ~17 words per minute and 8.6% errors compared with a conventional keyboard where the typing speed was ~40 words per minute and the error rate was 5.3% (Wang and Hedge 2008). For most people, a conventional flat keyboard design will work without substantially increasing injury risks if it is positioned so that the hands are in a neutral posture.

3. Mouse—Computer mice are available in many different shapes and sizes. Whatever the design of the mouse, it is important that it is used with the hand in a neutral posture as much as possible. Research suggests that 15° of wrist extension is a limit above which there is a rapid rise in intracarpal pressure that can cause median nerve compression (Honan et al. 1995). A study of 100 mouse users showed that 97% of mouse users use this with their hand in more than 15° of wrist extension (Lee et al. 2008). When sitting, the optimal position for a convex mouse is when this is on a keyboard platform 1–2″ (25–50 mm)

above the thighs that is movable over the numeric keypad so that it is in line with the right hand (if the person is left-handed, then the same vertical position to the left side of the alphanumeric keyboard works well). In this position the hand will be in a more neutral posture (Damann and Kroemer 1995). Compared with a more conventional convex mouse design, the use of vertical mouse designs can actually increase wrist extension deviation, which is undesirable (Hedge et al. 2010; Feathers et al. 2013), and can slow performance (Gustafsson and Hagberg 2003). Although a slanted mouse design can put the hand into a neutral posture, this also can slow performance (Hedge et al. 2010). Other cursor control input devices are available that typically center their control location on the keyboard, which is a position that has been shown to allow right- or left-hand use and to reduce wrist deviation (Dennerlein and Johnson 2006). One such device, the Rollermouse, has been shown to yield performance comparable to a conventional computer mouse (Bohan et al. 2003). However, a disadvantage of this central location for a cursor control device is that the worker has to reach over this input device to access the keyboard keys for typing.

4. Phone—Keeping the phone in close proximity is recommended for anyone who frequently uses it. If the person is right-handed, then positioning the phone to the right side of the user and within the zone of comfortable reach for the work surface is recommended, and vice versa if the user is left-handed. For very frequent phone, use a wireless/Bluetooth headset or speakerphone, or a shoulder cradle to reduce the lateral bending of the neck, if the phone is a landline.

1.3.2.2 Laptop/Notebook Computer

Originally designed as mobile computers to be frequently used for short periods of computer work, laptops/notebook computers typically have a keyboard with an integrated pointing device, usually a touchpad that is connected to the computer screen. The guidelines for laptop use are more difficult because often the laptop design is inherently problematic—when the screen is at a comfortable height and the distance from the user the keyboard is not, and vice versa. If a laptop has a separate screen and a keyboard, then that can be arranged as described in the following section for a tablet computer. If the keyboard and the screen are connected as one unit, then for sustained laptop use, or where the laptop is replacing a desktop, it is recommended that the worker be provided with the following:

1. Laptop riser—A laptop riser is used to elevate the screen to a comfortable viewing height and then provide a wireless keyboard and mouse so that the position of the display can be adjusted independent of the position of the input devices, and placing these on a height-adjustable downward tilting keyboard/mouse platform is preferable. This reduces neck flexion and also improves typing performance (Berkhout et al. 2004; Asundi et al. 2012).
2. External screen—If a laptop riser is not available, then an external computer screen or a docking station that connects to an external computer screen can be used.

1.3.3.3 Tablet Computer

Originally called slate computers, tablets are mobile computers designed to be frequently used for short periods of information consumption, compared with information creation work on desktops and laptops. Typically, a tablet has a capacitive screen design that can display a virtual touch screen keyboard, although tablets also typically support third-party external physical keyboards and mice. Compared with larger, heavier tablets, the performance seems to be comparable for smaller to medium tablets, and these are rated as more usable and less fatiguing, especially tablet designs with a ledge or handle-shape on the back and a rubberized textured surface (Pereira et al. 2013). Holding a tablet in one hand for more than 10 min can result in a high level of fatigue (Chau and Wells 2015). Intensive use of a poorly positioned tablet typically results in extreme neck flexion, and this can increase injury risks, and the resulting neck discomfort has been called *iPad neck* (Young et al. 2012).

There are now numerous products that allow a tablet to be supported on a work surface in a position that minimizes neck flexion so that an external keyboard and mouse can be used while the person is sitting in a more neutral posture.

1.3.3 What Chair Will Be Used?

Although sitting for prolonged periods in static postures can be detrimental to health (Buckley et al. 2015), the chair is an antigravity device that reduces the workload on the body, and it is important that a worker has the ability to sit in a comfortable chair for at least a part of their workday. If only one person is using this chair, it can be at a fixed height provided that it is comfortable to sit on and has a good backrest that provides lumbar support. If, however, more than one person will be using the chair or a single chair model is being purchased for many different workers, then the chair must have certain ergonomic features. Table 1.1 summarizes the requirements for an ergonomic chair from the ANSI HFES 100 standard (2007).

In addition to the list of requirements, the ANSI HFES 100 (2007) standard also lists a number of recommendations for the design of ergonomic chairs, and these are summarized in Table 1.2.

As Helander (2003) notes, users cannot easily perceive many of the ergonomics chair features that are designed to relieve sitting discomfort because the differences in pressure due to different body postures cannot be sensed by the spine; small changes in angle cannot be sensed by the joints; and many of the chair controls are hidden from view beneath the seat pan. However, users can perceive esthetic features, and their ratings of chair comfort and choice of chair tend to be based on esthetics rather than on ergonomic features.

Even if a chair has all of the required and recommended features, there is no guarantee that the worker will use these and correctly adjust the chair for themselves (Vink et al. 2007). Helander et al. (1995) investigated how people adjusted their chair for 26 chairs with a total of 24 different types of control arrangements and found that, although the chair with the greatest number of adjustability controls was judged to be the most comfortable, it took significantly greater time to adjust and this requires more training. This issue of control complexity is further discussed by Vink in Chapter 8, where he also reports that a majority of office workers may not know how to correctly adjust their chairs. Simple controls and, where possible, automated controls improve usability.

When sitting in the chair, the seat pan should be at least 1″ wider than a user's hips and thighs on either side. The seat pan should not be too long for a user's legs; otherwise, it may either compress behind the knees or prevent the user from fully leaning back against the lumbar support. Most ergonomic chairs have a seat pan with a waterfall front that prevents the seat from compression behind the knees. The seat pan should also be contoured to allow even weight distribution, and it should be comfortable to sit on. If there is insufficient hip room, this can encourage a forward-flexed posture on the seat pan, and this posture may create thigh compression problems. If the seat pan is made from low-density foam, then continuous use may cause it to become permanently deformed and then it will not provide adequate-cushioned support. Insufficient cushioning and inappropriate contouring can cause discomfort, imbalance, and hip and back fatigues. For preference, the seat pan height should be easily adjustable while sitting on the chair. Some chairs have a mechanical height-adjustment (spinning) mechanism that may also be acceptable. The height of the seat pan should be aligned level with the front of their knees or be slightly below the level when feet are stable on the ground.

Chairs can be covered in a variety of upholstery materials, each of which has benefits and concerns. Vinyl and vinyl-like coverings are easy to clean and spill resistant, but they do not breathe and if the chair begins to heat up under the thighs, uncomfortable amounts of moisture can accumulate. Cloth upholstery is the most common covering, but this is less resistant to spills and more difficult to clean. A cloth-covered seat pan can also become warm and moisture laden, and cloth-covered foam seat pans can be a significant source of dust mite allergen (O'Reilly et al. 1998). Mesh chair seats can focus compressive forces under the hips and the thighs, and curved mesh chair backs can

TABLE 1.1
Chair Requirements Summarized from ANSI HFES 100

Item	Requirements	Yes/No
Chair	Shall have a lumbar support	
	Shall have a backrest that reclines	
	Shall have a seat pan that adjusts for height and tilt	
	Shall support at least one of the two other seated reference postures in addition to the upright sitting posture	
	Shall provide support to the user's back and thighs in the chosen reference postures	
Seat pan and backrest adjustments	Shall be height adjustable	
	Shall have a user adjustment for tilt	
Backrest	Shall not constrain the user's torso to a position forward of vertical	
	Shall not force a torso–thigh angle less than 90°	
	Shall allow adjusting the angle between the backrest and the seat pan to an angle of 90° or greater	
	Shall allow the user to recline to at least 15° from the vertical	
Armrests	Shall provide sufficient clearance to allow the user to sit or stand without interference	
	Shall not cause the user to violate any of the following postural guidelines: • Elbow angles between 70° and 135° • Shoulder abduction angles less than 20° • Shoulder flexion angles less than 25° • Wrist flexion angles less than 30° • Wrist extension angles less than 30° • Torso-to-thigh angles equal to or greater than 90°	
Seat height	Shall be adjustable by the user over a minimum range of 11.4 cm (4.5″) within the recommended range of 38–56 cm (15–22″)	
	Manufacturer shall provide information to show which of the three seated postures the chair will accommodate	
Depth and front edge of the seat pan	Shall, if nonadjustable, be no greater than 43 cm (16.9″)	
	Shall include 43 cm (16.9″) if adjustable	
Seat pan width	Shall be at least 45 cm (17.7″) wide	
Seat pan angle	Shall have a user-adjustable range of at least 4°, which includes a reclined position of 3°	
Seat pan–backrest angle	Shall be able to achieve a position that is vertical or to the rear of vertical	
	Shall have an adjustment range of 15° or more within the range of 90° and 120° relative to horizontal if the backrest is adjustable	

Source: Human Factors and Ergonomics Society, ANSI HFES 100, Human Factors Engineering of Computer Workstations, Santa Monica, California, 2007. With permission.

give better support than flat mesh designs (Agarwal and Hedge 2006). Some chair mesh materials can stretch with time, and mesh can accumulate dust and then become abrasive for clothing. When selecting a chair covering, think about cleaning and maintenance issues and plan appropriately.

Contrary to widely held belief, research shows that the best seated posture is a reclined posture of 100°–110° and not the erect 90° posture that is often portrayed as being an ergonomic sitting posture (Andersson and Ortengren 1974; Andersson et al. 1975; Grandjean and Kroemer 1997; Wilke et al. 1999; Gscheidle and Reed 2004). In a slightly reclined posture, the chair back begins to support some of the body weight, and this reduces the activity of the back muscles (Park et al. 2000) and reduces spinal compression (Leivseth and Drerup 1997). In this recommended posture, the chair starts to work for the body, and there are significant decreases in postural muscle activity and in

TABLE 1.2
Chair Recommendations from ANSI HFES 100

Item	Recommendations	Yes/No
Chair	Should be adjustable to provide clearance under the work surface	
	Should provide information to the user as to the recommended use and adjustment of the chair	
Casters	Should be appropriate for the type of flooring at the workstation	
Seat pan and backrest adjustments	Should be wide enough to accommodate the clothed hip width of a 95th percentile female	
	Should be of sufficient depth to allow the user's back to be supported by the backrest without contact between the back of the user's knee and the front edge of the seat pan	
	Should have a tilt lock or stop position that the user can select while seated, if a tilt lock is provided (a stop limits the motion in one direction, whereas a lock limits the movement in two directions)	
	Should have a rounded front edge	
Backrest	Should allow the user to control the resistance necessary to recline the backrest	
	Should provide support to the lumbar and thoracic regions of the back	
	Should have a means of adjusting the backrest tension	
Armrests	Should be adjustable in height	
	Should allow adjustment of the clearance width between the armrests	
	Should be detachable	
	Should adjust in height from 17 to 27 cm (6.7–10.6″) above the compressed seat pan height	
	Should be designed to evenly distribute forces over the contact area	
	Should not create excessive pressure points	
	Should not irritate or abrade the skin	
	Should be able to be detached from the chair, if necessary, to fit the workplace	
	Fixed-height armrests should be between 18 and 27 cm (7.1–10.6″) above the compressed seat pan height	
	The clearance between armrests should be at least 46 cm (18.1″)	
	The clearance between armrests should be adjustable by the user (for example, pivot or otherwise move)	
Seat pan–backrest angle	If the backrest recline angle exceeds 120° from the horizontal, the backrest should have a headrest, preferably user adjustable	
Backrest height and width	Should be at least 45 cm (17.7″) above the compressed seat height	
	If fixed, the lumbar support area of the backrest should be located between 15 and 25 cm (5.9 and 9.8″) above the compressed seat height	
	The position of the center of the lumbar support should be user adjustable between 15 and 25 cm (5.9 and 9.8″) above the compressed seat height	
	The width of the backrest should be at least 36 cm (14.2″)	

Source: Human Factors and Ergonomics Society, ANSI HFES 100, Human Factors Engineering of Computer Workstations, Santa Monica, California, 2007. With permission.

intervertebral disk pressure in the lumbar spine. Erect sitting is not relaxed sitting or a sustainable posture over a long duration, whereas reclined sitting is. Moreover, many ergonomic chairs also incorporate a dynamic chair back whereby the back of the chair moves to stay in contact with the worker's back as s/he moves. The use of a dynamic chair back results in less spinal compression that occurs in a fixed back chair (van Dieën et al. 2001).

Many chairs have cushioned lumbar supports that can be height and depth adjusted to best fit a user's shape. If the chair will be used by multiple users, then this level of adjustment can be beneficial. If the chair has a fixed height lumbar support and it feels comfortable when a user sits back against this, and that user will be the primary user of the chair, then a fixed lumbar support may be acceptable. Many chairs also have back supports that are large enough to provide midback and upper-back support, in addition to good lumbar support. As described earlier, the movement of the back while sitting helps to maintain a healthy spine. Chairs that allow for easy reclining that provide good back support in different recline postures and that have a back that tracks where the user's back is are preferable. Locking the chair backrest in one position is not generally recommended or beneficial to users.

Other useful chair features include height- and position-adjustable chair armrests, which can be helpful to aid ingress and egress from the chair. Also, the armrests can be useful for the occasional resting of the arms (e.g., when on the phone, sitting back relaxing). However, the use of chair armrests does not necessarily improve hand/wrist posture when typing or mousing (Barrero et al. 1999). It is not a good idea to permanently rest the forearms on armrests while you are typing or mousing because this can compress the flexor muscles, and some armrest designs, especially narrow and hard armrests, can create ulnar nerve compression at the elbow, and consequently broader, flatter, padded armrest designs are preferable. Ideally, it should be easy to move the armrests out of the way when the worker needs unimpeded access to their keyboard and mouse. Chairs with headrests can be beneficial (Monroe et al. 2001).

If chair mobility is important to help with work then the chair should have at least a five pedestal bases with casters that freely glide over the floor surface, and choosing a chair that easily swivels can also be of benefit.

1.3.4 What Work Surface Furniture Will Be Used?

For any sustained period of work, the computer must be placed on a stable working surface (nothing that bounces) with adequate room for proper arrangement of the task tools (e.g., keyboard, mouse, documents).

1.3.4.1 Fixed-Height Work Surface

Ideally, for neutral posture working, a work surface should be at a height that is around the worker's seated or standing elbow height. Table 1.3 shows these heights for a 5th and 50th percentile woman and for a 50th and 95 percentile man (note that the distributions overlap so that the standing elbow height of a 95th percentile U.S. woman is equivalent to that of a 41st percentile U.S. man, and the standing elbow height of a 5th percentile U.S. man is equivalent to that of a 54th percentile U.S. woman). Many office workers sit at work surfaces that are 30″ (762 mm) high, and Table 1.3 shows that this is higher than the seated elbow heights of all woman and almost all men. However, when a keyboard, mouse, laptop, or tablet is placed on that work surface, it is too high for sustained use in a neutral posture. Ideally, the work surface should be adjustable over a range of 5.3″ (136 mm) for seated workers, 10″ (267 mm) for standing workers, or 23.7″ (603 mm) for sit–stand working desks.

TABLE 1.3
Elbow Heights for 5th and 50th Percentile U.S. Women and 50th and 95th Percentile U.S. Men either Standing or Sitting

Posture	U.S. Women (5th Percentile)	U.S. Women (50th Percentile)	U.S. Men (50th Percentile)	U.S. Men (95th Percentile)
Sitting	23.1″ (587 mm)	23.3″ (631 mm)	25″ (635 mm)	28.4″ (723 mm)
Standing	36.3″ (923 mm)	39.6″ (1005 mm)	43.3″ (1100 mm)	46.8″ (1190 mm)

If the work surface is not height adjustable and is too high for the worker to adopt a neutral arm/wrist/hand posture, then a height- and angle-adjustable keyboard platform can be used to lower the keyboard surface to an appropriate height (see Table 1.3). It is also preferable that any such platform allows for angle adjustability so that the keyboard can decline away from the worker so that the hands can be in a neutral posture (Hedge et al. 1999).

The ANSI HFES 100 ergonomics standard (2007) provides a series of requirements for office work surfaces, and these are summarized in Table 1.4.

In addition to the list of requirements, the ANSI HFES 100 standard (2007) also lists a number of recommendations for the design of ergonomic work surfaces, and these are summarized in Table 1.5.

1.3.4.2 Height-Adjustable Sit–Stand Workstation

An average person makes 66 sit-to-stand changes per workday (Dall and Kerr 2010). To help combat the potential perils of prolonged sitting (Dunstan et al. 2011; Hamilton et al. 2007; Buckley et al. 2015), the use of a height-adjustable work surface for sitting and standing work is becoming more popular. However, there is limited evidence that sit–stand furniture has cost-effective benefits, unless other changes in work practices are also made. The evidence suggests that there may be a reduction in back discomfort (Hedge and Ray 2004), but the research for this has not used adequate comparison groups (e.g., testing people who stand for the same time at the same frequency without doing keyboard/mouse work). There is no evidence that sit–stand improves wrist posture when typing or mousing on a flat surface, but the addition of a downward-tilting keyboard platform can help (Hedge et al. 2005). Logically, the potential benefit of sit-to-stand is just the intermittent changes between sitting and standing. But standing in a static posture is even more tiring than sitting in a static posture, and prolonged standing can result in greater risks of varicose veins (Tüchsen et al. 2000, 2005), carotid artery disease (Krause et al. 2000), and back pain (Gallagher et al. 2014).

Recent research suggests that sit–stand workstations that can be quickly adjusted allow each worker to easily modify their work surface height throughout the day, and this may reduce musculoskeletal discomfort and improve work performance (Hedge and Ray 2004; Karakolis and Callaghan 2014). However, correctly adjusting the height of the work surface to support the keyboard and mouse, and the height of the computer screen is extremely important.

With posture, the need to keep the body in a neutral posture is the same for height-adjustable, split work surfaces and sit–stand work surfaces. If the surface is too low below the elbow height, the hands will be in greater wrist extension, and the neck will be in forward flexion. If the surface is too high above the elbow height, the elbow will be in sustained flexion, and the neck may be dorsiflexed. It is impossible to position a single flat work surface at an appropriate height for the five main tasks of office work—keyboarding, mousing, writing, viewing documents, and viewing the screen—because these all require different heights for an optimal arrangement. When the work surface is set for a comfortable writing height (28–30″; 71–76 cm), a negative-slope keyboard tray system serves as an effective solution that incorporates a platform for height and angle adjustment for the keyboard (Hedge et al. 1999) and a platform that places the mouse just above the level of the keytops to maintain a neutral hand posture when mousing (Damann and Kroemer 1995). Screen monitor height, distance, and tilt can be adjusted by a separate monitor arm, which reduces neck discomfort (Boothroyd and Hedge 2007). There are also split work surface designs that allow for the separate adjustment of the keyboard and mouse surface and the monitor surface.

1.3.5 Display Positioning

Aligning the body and the head with what needs to be seen in the environment is crucial to the ability to maintain a neutral posture. Just like a car driver is positioned to view the road directly ahead so a computer worker needs to be positioned so that s/he can directly view the relevant visual

TABLE 1.4
Work Surface Requirements from ANSI HFES 100

Item	Requirements	Yes/No
Controls	Shall not intrude into the leg and foot clearance spaces when not in use	
	Shall not interfere with users' typical work activities	
Adjustable surfaces	Shall use a fail-safe mechanism to prevent inadvertent movement	
	Shall use a control-locking mechanism to prevent inadvertent operation	
Pinch points	Shall be avoided by means of design or guarding	
Leg and foot clearance	Shall provide adequate leg and foot clearances in the chosen reference posture or postures	
Input device location	Shall adjust in height, or a combination of height and tilt, to allow placement of the input device within the recommended space	
Seated and standing work	Shall provide adequate leg and foot clearances	
	Shall provide adequate space for multiple input devices (e.g., keyboard and mouse)	
Sit–stand work	Shall accommodate at least one of the three seated reference postures in addition to the standing reference posture	
Monitor support surface	Shall allow users to adjust the line-of-sight (viewing) distance between their eye point and the front (first) surface of the viewable display area	
	Shall allow users to adjust the tilt and the rotation angle between their eye point and the front (first) surface of the viewable display area	
Workstation adjustments	Shall not interfere with users' work activities or pose hazards during use	
Finish of furniture and accessories	Shall have radii of at least 3 mm	
Operator clearances	Shall accommodate at least two of the three seated reference working postures (declined, upright, or reclined)	
	Shall be • 52 cm (20.5″) wide • 44 cm (17.3″) deep at the level of the knee • 60 cm (23.6″) deep at the level of the foot • Adjustable between 50 and 72 cm (19.7 and 28.3″) in height at the edge of the work surface closest to the operator • Adjustable between 50 and 64 cm (19.7 and 25.2″) in height at the horizontal position of the knee • At least 10 cm (3.9″) in height at the position of the foot	
Monitor support surface/device	Manufacturer shall specify the size and weight of monitor that can be accommodated by the support surface because monitor support surfaces may not be compatible with certain-sized monitors	
	Manufacturer shall specify the range of adjustment if the support surface is adjustable	
Input-device support surface	Shall adjust in height, or a combination of height and tilt	
	Manufacturer shall provide information regarding the range of height adjustment	
	Manufacturer shall provide information regarding the tilt adjustments	
Sit–stand working postures: height adjustable surface	Shall adjust in height between 56 and 118 cm (22 and 46.5″) as measured from the floor to the surface at the front edge of the support	
	Shall comply with the clearance requirements specified when used in the seated position	

(*Continued*)

TABLE 1.4 (CONTINUED)
Work Surface Requirements from ANSI HFES 100

Item	Requirements	Yes/No
Sit–stand working postures: height and tilt adjustable surface	Shall accommodate seated workers by adjusting in height in some portion of the range between 56 and 72 cm (22 and 28.3″) as measured from the floor to the surface at the front edge of the support	
	Shall accommodate standing workers by providing additional height adjustability (greater than 72 cm [28.3″]) when combined with tilt as described in the equation $A + \sin(B) \times C$ = input device height	
	Shall adjust in tilt in some portion of the range between +20° and −45°, to include 0	
	Shall comply with the clearance requirements specified in Section 8.3.2.1 when used in the seated position	

Source: Human Factors and Ergonomics Society, ANSI HFES 100, Human Factors Engineering of Computer Workstations, Santa Monica, California, 2007. With permission.

information from a sitting or a standing neutral posture. When the primary visual display is a computer screen, this means that it should be positioned as follows.

The computer screen should be placed directly in front of the worker and facing them, not angled to the left or the right so that they have to twist their neck or torso to view the screen. This helps to eliminate too much neck twisting. If someone is working with a large monitor or spends most of their time working with software, like MS Word, which defaults to creating left aligned new pages, then aligning the worker's head/body to a point about 1/3 of the distance across the monitor from their left side will help to minimize lateral head movements.

While such positioning addresses the lateral position of the visual field, it is also important to address the vertical position of information. Once a screen is well positioned, use the screen scroll bars to ensure that what is being viewed most is in the center of the monitor rather than at the top or the bottom of the screen. The screen should be positioned at a comfortable viewing height that does not require tilting the head up to see items or bending the neck down to see items. When comfortably seated, a worker's eyes should be approximately in line with a point on the screen about 2–3″ (50–74 mm) below the top of the screen so that most of the central region of the screen can be viewed without any head movement. As a rule of thumb, the worker should sit back in their chair in a slight recline, at an angle of around 100°–110°, then they should hold their right arm out horizontally at shoulder level, and their middle finger should almost touch the center of the screen (see Figure 1.3). From this starting position, a worker then can make minor changes to screen height and angle to suit their viewing needs.

We see more visual field below the horizon than above this (look down a corridor and you will see more of the floor than the ceiling), so at this position, the user should comfortably be able to see more of the screen. Research shows that the center of the monitor should be about 17°–18° below horizontal (Sommerich et al. 2001) for optimal viewing, and this is where it will be if the worker follows the simple arm extension/finger pointing tip. If a user has to crane their neck forward to see the screen, then it is positioned too low. If they have to tilt their head backward to see the screen then it is too high. In either situation, repeated exposure to this posture will increase the risks of neck/shoulder pain. If a user is wearing bifocals, trifocals, or progressive lens, then the screen position and the tilt angle can be fine adjusted when they are sitting back in their chair in a reclined posture (at around 11°), until they can see the screen with the head in a neutral posture. If the text looks too small, then the user should either use a larger font or magnify the screen image in the software program rather than sitting closer to the monitor.

TABLE 1.5
Work Surface Recommendations from ANSI HFES 100

Item	Recommendations	Yes/No
Device cabling	Should be placed to avoid interference with the operation of workstation components	
	Should be placed to avoid creating hazards for people or equipment in the workstation	
Leg and foot clearances	Should not hinder the foot, the leg, or the knee in alternative or auxiliary (non-video display terminal [VDT]) work positions	
Horizontal work envelope	Should accommodate the user postural design criteria: • Elbow angles between 70° and 135° • Shoulder abduction angles less than 20° • Shoulder flexion angles less than 25° • Wrist flexion angles less than 30° • Wrist extension angles less than 30° • Torso-to-thigh angles equal to or greater than 90°	
	Should be at least 70 cm (27.6″) wide	
	Should locate the most commonly used objects in the primary work zone	
Monitor support surface	Should allow users with normal visual capabilities to adjust the line-of-sight (viewing) distance between their eyes and the front (first) surface of the viewable display area within the range of 50–100 cm (19.7–39.4″)	
Workstation adjustments	Should be usable by users while in the relevant reference postures	
Finish of furniture and accessories	Secondary user contact edges should have radii of at least 2 mm	
Surface gloss	Should have a matte finish that provides a specular reflectance of no more than 45 gloss units at an angle of 60° as measured with instruments and procedures that conform to ASTM D523-89 (1999) Standard Test Method for Specular Gloss (American Society for Testing and Materials 1999)	
Work surface	Should be at least 70 cm (27.6″) wide	
	Depth should allow a viewing distance of at least 50 cm (19.7″)	
	Depth should allow positioning of the monitor so that the angle between the horizontal level of the eyes and the center of the screen ranges between 15° and 25°	
	Depth should allow positioning of the entire viewing area (e.g., including the keyboard) in an arc 60° below horizontal eye level	
Monitor support surface/ device	Should be designed so as to allow placement of the viewing area of the screen at a minimum viewing distance of 50 cm (19.7″)	
	Should be designed so as to allow placement of the monitor's viewing area below the user's horizontal eye height	
	Should be stable during use	
	Should not interfere with the user's ability to adjust the height, tilt, and rotation of the monitor	
Input-device support surface	Should adjust fore and aft in the horizontal plane	
	Should adjust in side-to-side placement within the optimal area for input devices	
	Should tilt	

Source: Human Factors and Ergonomics Society, ANSI HFES 100, Human Factors Engineering of Computer Workstations, Santa Monica, California, 2007. With permission.

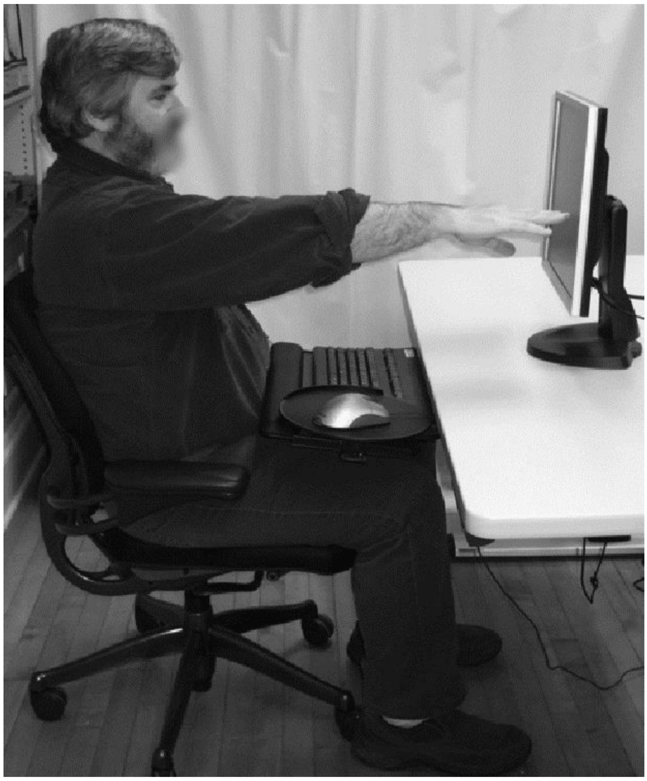

FIGURE 1.3 Ideal screen distance for a seated computer worker.

If the work being performed involves reading or transcribing any paper documents, then these should be placed as close to the computer screen as possible and a document holder can be used to position documents at a similar angle to the screen so that the eyes do not have to refocus when moving from the documents to the screen and vice versa. Three types of document holders can be used:

1. Screen-mounted document holder—If single sheets of a small number of sheets of paper are to be read, then a screen-mounted document holder positioned to the same side of the computer screen that is the worker's dominant eye can be used.
2. In-line document holder—This typically sits between the keyboard/keyboard tray and the computer screen and is aligned with the body midline so that all the worker has to do is look down to see the documents and raise their eyes to see the screen.
3. Freestanding document holder—This should be positioned adjacent to the same side of the screen as the dominant eye; it should be slightly tilted backward and/or curved so that it follows a curve from the side of the screen.

Finally, there are natural changes in vision that occur in most people during their early 40s, and these generally shorten the focal length of the eye and reduce its transparency so it is important to periodically have a visual health checkup by a qualified professional.

1.3.6 Where Will the Computer Be Used?

The environmental conditions where the computer will be used are important. This is especially relevant for residential use or for use in nonwork settings such as hotels, airports, etc.

1.3.6.1 Lighting

The ambient lighting where work is being done should not be too bright; otherwise, this will cause veiling glare on the screen, and also ensure that the screen is free from any bright light reflections (specular glare). If glare is a problem, then this can be addressed by moving the screen location (this mostly helps specular glare), lowering the light level (this mostly helps with veiling glare), and using a good quality antiglare screen. It is important to position the computer monitor screen so that it is not backed up to a bright window or facing a bright window so that the screen looks washed out (a shade or drapes will control the window brightness). Where possible, sitting sideways to a window is recommended.

1.3.6.2 Ventilation

The computer should be used somewhere that has adequate fresh air ventilation and that has adequate heating or cooling to provide thermally comfortable working conditions.

1.3.6.3 Noise

Noise can cause stress and that tenses muscles that in turn can increase injury risks. Find a quiet place for computer work. Listening to low-volume music, preferably light classical, such as Mozart, can boost productivity (Tayyari and Smith 1987; Smith et al. 2010) and mask office noises (Schlittmeier and Hellbruck 2009). Music can be played through earbuds/headphones or a noise-cancelling headset if it is a noisy environment such as an airplane.

1.3.7 Organizing an Optimal Work Pace

Taking frequent, brief rest breaks can improve the well-being by reducing musculoskeletal discomfort and can boost work productivity (Henning et al. 1996, 1997; Galinsky et al. 2000; McLean et al. 2001; Montie et al. 2004).

The following break schedules can be beneficial.

1.3.7.1 Eye Breaks

Looking at a computer screen for a while causes some changes in how the eyes work, slows the blink rate, and exposes more of the eye surface to the air. These effects can be mitigated by briefly looking away from the screen for a minute or two to a more distant scene, preferably something more than 20 ft (6 m) in the distance, every 20 min, which lets the ciliary muscles inside the eye relax, and by rapidly blinking the eyes for a few seconds to refresh the tear film and clear dust from the eye surface.

1.3.7.2 Microbreaks

Most typing is done in bursts of activity rather than continuously. Between these bursts of activity, the hands can be rested in a relaxed, flat, straight posture. During a microbreak, which typically lasts less than 2 min, brief stretching, standing up, moving around, or doing a different work task, e.g., making a phone call, can rest the muscles involved in typing and mousing. A microbreak is not necessarily a break from work, but it is a break from the use of a particular set of muscles that is doing most of the work (e.g., the finger flexors, if a lot of typing is being done).

1.3.7.3 Rest Breaks

Brief rest breaks around every 30 min in which a worker can stand up, move around, and do something else, such as going and getting a drink of water, tea, coffee, or whatever, will allow resting of the primary work muscles and exercising of different muscles that will also improve circulation and lessen feelings of tiredness and reduce reports of low back pain (Sheahan et al. 2015).

1.3.7.4 Exercise Breaks

There are many stretching and gentle exercises that can help relieve muscle fatigue. Doing these every 1–2 hours throughout the day can help to reduce overall fatigue.

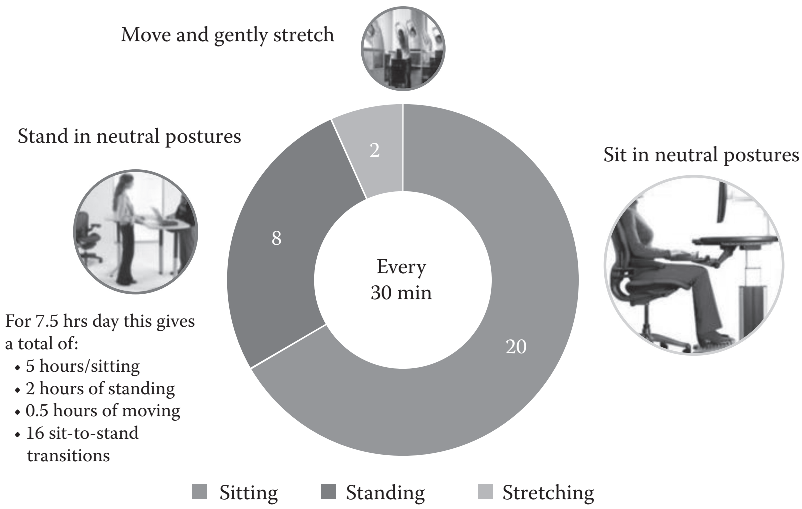

FIGURE 1.4 Optimal work pattern. (From Hedge, A., Sit-Stand Working Programs, http://ergo.human.cornell.edu/CUESitStandPrograms.html, 2015. With permission.)

Working at a computer can be hypnotic, and that often disrupts the sense of time resulting in longer duration of typing and mousing without a rest than is recommended. There are several ergonomic software programs that provide break reminders and can be installed on a computer. The best software will run in the background, and it will monitor how much typing and mousing have occurred and use this as the basis for triggering rest break reminders, and many programs also suggest simple exercises that can be done during breaks. Wearable activity trackers and a new generation of smart watches can also provide activity alerts for taking rest breaks.

With the current trend for using sit-to-stand workstations, Figure 1.4 shows a good break regime pattern to try and develop at work.

1.3.8 Other Ergonomic Office Products

Many kinds of products are labeled as being ergonomically designed, but this is often not true and some of these so-called ergonomic products can actually make matters worse in terms of injury risks and lowering productivity. There are many computer-related products that are marketed as being ergonomic, and in addition to those already discussed in this chapter, the most common ones are as follows.

1.3.8.1 "Ergonomic" Mice

Many of these mouse designs or alternative input device designs can work well to improve your hand/wrist posture. However, it is important to check that you can use these with your upper arm relaxed and as close to your body as possible and with your hand in a neutral posture. Overreaching to any ergonomic mouse defeats any benefits of this design.

1.3.8.2 Wrist Rests

Research studies have failed to demonstrate any substantial benefits with using wrist rests. Some wrist rest designs have no beneficial effects on wrist posture (Cook et al. 2004). A wrist rest, especially one that is narrow, curved/domed, and soft, may actually increase the pressure inside the carpal tunnel by compressing the undersurface of the wrist (Horie et al. 1993). The pressure applied to the underside of the carpal tunnel is transferred into the tunnel itself via the transverse carpal ligament and that intracarpal pressure can double when resting on a wrist rest compared with floating the hands over a keyboard. The best design for a wrist rest is one with a broad, flat, firm surface to support the heel of the palm on this and not compress the wrist. Resting in between bursts of typing is preferred to continuous resting while typing. Firmer rather than softer wrist rests are preferred because these will not contour to the wrist, restrict the freedom of movement of the hands, or encourage more lateral deviation during typing. The used pattern can often be seen in areas of erosion on the surface of a typical wrist rest, which shows the area of compressive forces on the wrist. The hands should be able to glide above the surface of any wrist rest during typing, rather than being in a fixed position on the rest while typing.

1.3.8.3 Wrist Support Braces/Gloves

There is no consistent research evidence that wearing wrist supports during computer use actually helps reduce the risk of hand/wrist injury. A wrist support should keep the hands flat and straight, not bent or extended. Wearing such a wrist support at night when sleeping may help relieve symptoms for those with carpal tunnel syndrome.

1.3.8.4 Forearm Supports/Resting Forearms on Chair Arms

Resting the forearms on any support while typing has the potential for restricting the circulation to the finger flexor muscles in the forearm and compressing the ulnar nerve in the elbow. Resting on chair arms while typing does not improve hand/wrist posture (Barrero et al. 1999). If the keyboard/mouse is appropriately arranged, they should be accessible with the user's arms in a neutral position (close to the body and with the upper arm hanging in a relaxed way) which does not pose any significant neck or shoulder load. If forearm supports are required, it is usually a sign of a poor ergonomic arrangement.

1.3.8.5 Footrest

If your feet cannot rest on the floor when your legs are in a comfortable position or if you want to stretch your feet out in front of you, like when driving a car, a freestanding floor-mounted support will allow you to rest your feet out in front of you in a comfortable manner. Look for a design that allows foot rocking movements to assist with the circulation to the lower legs.

Finally, before buying any ergonomic product, it is worthwhile asking the following four questions:

1. Do the product design and the manufacturer's claims make sense?
2. What research evidence can the manufacturer provide to support their claims? Be cautious with products that have not been studied by researchers.
3. Does it feel comfortable to use the product for a long period? Some ergonomic products may feel strange or slightly uncomfortable at first because they often produce a change in your posture but the changes can be beneficial in the long term. Think of some products as being like new shoes that initially may feel strange but then feel comfortable after being used for a while. If a product continues to feel uncomfortable after a reasonable trial period (say at least a week), then stop using it.
4. What do ergonomics experts say about the product? If they do not recommend it, do not use it.

1.4 CONCLUSIONS

This chapter has presented a brief summary of the recommendations for healthful ways of using computer technologies in the workplace, and it has given the supportive evidence where this is available. The following list summarizes the main recommendations from this chapter:

- Keep arms and elbows relaxed and close to body.
- Keep wrists flat and straight in relation to the forearms to use keyboard/mouse/input device.
- Use a negative-tilt keyboard tray with an upper mouse platform or downward-tilting platform adjacent to the keyboard.

- Use a stable work surface and a stable (no-bounce) keyboard tray.
- Use a good chair with a dynamic chair back and sit back on this.
- Sit at arm's length from the monitor screen.
- Position the top of the monitor casing 2–3″ (5–8 cm) above seated eye level.
- Center the monitor screen and the keyboard in front of you.
- Position the screen to be glare free or use an optical glass antiglare filter where needed.
- Use a document holder, preferably in line with the computer screen.
- Keep your feet on the floor or a stable footrest.
- Take frequent short breaks (microbreaks).

The other chapters in this book will provide more details on healthful and productive ways of working in specific workplaces.

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2 Designing Thermal Environments for Comfort, Health, and Performance

Ken Parsons

CONTENTS

2.1 INTRODUCTION

An objective for environmental design is to provide comfort, well-being, health, and performance to people who experience the environment, and maybe stimulation, inspiration, pleasure, and excitement. Implicit in that objective is the avoidance of discomfort and dissatisfaction; avoidance of conditions detrimental to health, which can lead to illness, injury, or even death; and enhancement of performance and productivity, which includes the avoidance of conditions that reduce motivation, physical capacity, including manual dexterity, and cognitive ability, or cause distraction and time off from work. This chapter provides principles and methods for the design and assessment of thermal environments. It describes how people respond to hot, moderate, and cold environments and presents principles, techniques, and tools for measuring thermal stress and its effects, and how they can be used in practical applications.

2.2 THE SIX BASIC PARAMETERS

Heat stress, cold stress, and thermal comfort are not defined by just one factor of the thermal environment such as air temperature, but by the interaction of six factors. These are often referred to as the *six basic parameters*, as representative values of continually changing variables are usually used in assessment. The six factors are air temperature, radiant temperature, air velocity, air humidity (the environmental factors), clothing of the person, and metabolic heat generated by the person (personal factors). A specification of instruments and how to measure the environmental factors is provided in International Standards Organization (ISO) 7726 (1998). The measurement or the estimation of all six variables to which people are exposed, and hence the six basic parameters, should always be a starting point for any design and assessment of the thermal environment.

2.3 HUMAN THERMOREGULATION

People are homeotherms and attempt to maintain an internal body temperature of around 37°C (98.6°F). Human thermoregulation could be considered to be the process by which they defend that position. Thermal stress can be defined as the environment made up of the six basic parameters. It is the interaction of the parameters that provides the thermal stress on the body. Thermal strain is the response of the person to thermal stress. If environmental or other conditions tend toward reducing (cold stress) or increasing (heat stress) internal body temperature, it will elicit both behavioral and physiological responses as the body attempts to defend and maintain an optimum condition. A system diagram is shown in Figure 2.1. This is adapted and modified from Parsons (2014).

The system is stimulated by both skin temperature and internal body temperature. Physiological responses are driven by the difference between the set point core temperature (which varies around 37°C [98.6°F]) and the actual core temperature of the body (e.g., brain temperature). If there is a tendency for the body to lose heat and hence for the body temperature to fall, the posterior hypothalamus promotes vasoconstriction where blood is withdrawn from the extremities (arms, legs, hands, and feet). This reduces skin temperature and hence heat loss from the skin (shell) in an attempt to maintain the internal body temperature (core). If this response is insufficient to reverse any fall in the internal body temperature, then the body generates heat by nonshivering thermogenesis, which is an increase in muscle tone, and then shivering which can provide significant additional metabolic heat production.

If the environmental conditions, the activity, and the clothing combine to provide a tendency for the body temperature to rise, the anterior hypothalamus initiates vasodilation, where blood flows to the skin and the extremities, hence raising the skin temperature and promoting heat loss. If that is insufficient, then sweating occurs which allows heat to be lost from the skin by evaporation. There is a connection between the anterior and the posterior hypothalamus to prevent instability and cold responses and heat responses working against each other.

A powerful form of human thermoregulation is behavioral. Not only does the body continuously, automatically, and unconsciously detect, process, and respond to its thermal state, but it also consciously recognizes or feels its thermal state (hot, cold, etc.). This is mainly by feeling the skin condition. This state is consciously compared with a desired state and so comfort, or something related to it, in addition to the internal body temperature, can be regarded as a controlled variable. When a person feels too cold, then s/he will move away from the environment that is causing discomfort, turn up the heating, close the windows, add clothing layers, reduce the exposed surface area by changing posture, and so on. When a person feels too hot, they may move away, lower the thermostat or the ventilation controls, take off clothing layers, increase the exposed surface area by changing posture, open the windows, and so on. In Figure 2.1, this is stimulated by skin temperature and how wet (W) the person feels. The effectiveness of behavioral thermoregulation and which behaviors are carried out will depend upon what is possible in the environmental context