Improving the quality of office environments through user-centered design can provide enormous health, social, and economic benefits. This chapter from the 2008 Reviews of Human Factors and Ergonomics, Volume 4, reveals the results of scientific research on office workspaces published between 1997 and 2007. Shifts occurred from primarily health and safety considerations (e.g., preventing injuries) to strategic investment in human factors and ergonomics design guidelines to improve organizational effectiveness and other positive outcomes. For example, design standards and guidelines relevant to office ergonomics have increasingly taken a user-centered, rather than a product-centered, approach to ensure that musculoskeletal loadings, awkward postures, and the negative aspects of workload have been optimized for office occupants. The importance of group and organizational contexts in the design and successful implementation of ergonomics products, programs, and interventions are outlined. Organizational cultures that embrace occupant-centered needs and intelligent buildings that truly respond to dynamic worker requirements will likely be at the center of improving quality of life for office workers.

Office Ergonomics

A Review of Pertinent Research

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CHAPTER 7

Office Ergonomics: A Review of Pertinent Research and Recent Developments

By Jay L. Brand

Office ergonomics provides an arbitrary framework for integrating a large body of research that is relevant to the design of office work environments to optimize the health, safety, comfort, and effectiveness of their human occupants. In this chapter, I organize this vast literature by focusing on important empirical and practical developments over the last decade. In particular, a systems perspective is maintained in order to more fully interpret the salient psychosocial (subjective) variables that mediate the influence of physical-environment characteristics on relevant human outcomes. I suggest that this approach is important for capturing current trends as well as moving the discipline forward. Included are reviews of research related to seating and other furniture considerations (e.g., the update of HFS 100 to HFES 100), pertinent information technologies (e.g., input devices and laptops), lighting, thermal comfort, and other general ambient conditions (e.g., private [cellular] offices vs. open-plan offices).

Office ergonomics is an applied branch of human factors/ergonomics (HF/E). Although, from a scientific perspective, this topic provides a somewhat arbitrary theoretical framework for exploring and interpreting many different lines of original and applied investigation, there may not be a more important applied research area to review. After all, at least 50% of the world's population currently works in some form of office (Brounen, & Eichholtz, 2004; cf. Charles et al., 2004; Veitch, Charles, Farley, & Newsham, 2007), so HF/E research conducted on any topic relevant to office workplaces can potentially benefit millions of people around the world.

To illustrate this potential, at least 2% of the American workforce suffers from a work-related musculoskeletal disorder (WRMSD) annually, and the costs of medical intervention and lost wages for these represent, disproportionately, one third of national worker compensation costs (see Faucett, Garry, Nadler, & Ettare, 2002); the overall, annual costs of such injuries/illnesses range between \$45 and \$54 billion (Drury et al., 2006). Within the European Union (EU), "economic costs of all work-related ill health range from 2.6 to 3.8% of the gross national product and work-related musculoskeletal disorders (or cumulative trauma disorders) constitute 40-50% of this" (Drury et al., 2006, p. 1471). If we include job stress and the cost(s) of its effects, these estimates would double or perhaps triple.

Estimates from the American Institute of Stress and the European Agency for Safety and Health at Work suggest that 1 million workers miss work each day in the United States

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because of job stress. Finally, even within the relatively artificial conceptual perspective of "office ergonomics," a lot of pertinent work has been conducted over the last few years. In this review, I attempt to synthesize and integrate this considerable body of research, focusing on its practice implications while including several promising emerging developments.

Several basic research areas inform office ergonomics' body of knowledge and guide its practice, including anthropometry, biomechanics, work physiology, environmental science (e.g., indoor air quality, personal space/territoriality; Sommer, 1969), individual differences, visual and auditory perception, mental workload, information processing, and human motivation. A number of applied areas of interest also enrich office ergonomics research and practice, including macroergonomics, participative ergonomics, usability, job and task analysis, human-computer interaction, displays and controls, organizational design and behavior, and organizational development.

It might seem too ambitious to organize such broad areas of investigation to provide a focused, coherent account of the derivation and application of ergonomics principles within office work environments; nonetheless, in this chapter, I offer just such an attempt. In some cases, somewhat arbitrary contrasts between previous and current research will be explored in an effort to illustrate how this very broad area of research and practice has changed since the late 1990s. After some historical and theoretical considerations, I review basic and applied research on aspects of human-computer workstations, then follow with a summary of some recent developments that situate human-workspace interactions within their broader, organizational work contexts. The chapter ends with some tentative conclusions and several practical implications.

HISTORICAL FOUNDATIONS AND EMERGING FRAMEWORKS

Because of their ubiquity as work environments, office workplaces have endured a great deal of scientific scrutiny almost from the inception of the human factors/ergonomics discipline. However, workplaces with any semblance to current instantiations of the "office" concept have existed for less than two centuries (Creighton, 2007). Human-centered scientific investigation of these "information work" environments began in earnest in the 1960s with the *Bürolandschäft* (landscaped office) idea, developed and exported by the Quickborner team, located just outside Hamburg, Germany (Voss, 1996). Although it featured a decidedly human focus on the quality of indoor environments and included many of the laudable goals of the contemporary "green building" movement (e.g., Pile, 1978), this approach introduced some challenges for occupant-centered design. Compromised privacy and personal control over social access and work processes were perhaps paramount among these concerns, and contemporary research continues to highlight problems such as inability to concentrate, increased perceived workload, and motivational effects (Banbury & Berry, 2005; De Croon, Sluiter, Kuijer, & Frings-Dresen, 2005; Evans & Johnson, 2000).

A number of comprehensive reviews of the HF/E literature have appeared in the decades following the spread of landscaped offices, from Germany to Europe, Canada, and then the United States (e.g., Grandjean, 1987; Helander, 1982; Human Factors and Ergonomics

Society, 1988; Smith & Cohen, 1997). These reviews explored human-computer interaction; applied investigations of attitudes and behaviors relative to a variety of furniture, equipment, and settings in office and other work environments; and the design of computer workstations. This latter, somewhat narrow, emphasis is in fact reasonable, because people who work in offices spend more than 50% of their time interacting with personal computers, laptops, or other similar information technology equipment using keyboards, mice, laser-light pens, trackballs, and various other input modalities—including voice recognition and specialized handheld computers (e.g., Brown, Albert, & Croll, 2007).

From an office ergonomics perspective, these reviews summarized both laboratory and field research that related the design of the physical environment and job tasks to predictable consequences for office employees. These outcomes notably included musculoskeletal problems but ranged from physiological conditions and symptoms to psychological results such as job satisfaction and motivation.

Interdependencies Among Ergonomics Principles

Consider Alphonse Chapanis's classical model of a human-machine system (e.g., McCormick & Sanders, 1982). This framework successfully models a human-computer interaction, or perhaps even a human-computer-workstation interaction. However, in predicting overall system performance, it would leave out many important, additional levels of the physical and psychosocial environments that relate in important ways to individual and group outcomes. Office ergonomics must not only provide design guidance to minimize or eliminate health and safety issues; increasingly, the discipline needs to deliver positive organizational outcomes such as enhancing employee recruitment, retention, and productivity (e.g., Lahiri, Gold, & Levenstein, 2005; Leaman & Bordass, 1999; Linhard, 2005). Even when implementing a health management system for documenting and treating health symptoms, a comprehensive, multicomponent approach will likely be more effective than independent, one-time interventions (Chapman & Pelletier, 2004).

In order to meet such ambitious demands, a broader, systems view for office ergonomics must be adopted (e.g., Bettendorf, 1998; cf. Malone, Savage-Knepshield, & Avery, 2007). Such a framework fully acknowledges the influence of additional psychosocial, sociotechnical, and organizational layers beyond individual human-workstation interactions. And it begins by embracing the interdependencies of the human body as a dynamic biomechanical system.

For example, wrist postures cannot be evaluated independently of elbow position, and therefore the design of keyboards or mice cannot be optimized without also considering the design and placement of forearm or wrist support(s). (This specific empirical comparison will be reviewed more thoroughly in a subsequent section.) Optimal desk surface or input device heights cannot be provided without knowledge of seat height and seat pan angle. Whether or not a foot rest should be recommended depends somewhat on seat height, seat back angle, and seat pan angle as well as on knee clearance considerations related to desk surface height, placement of input devices, and the relative position of these components to one another. After all, maintaining neutral body postures in any particular limb or body segment should not require that other limbs or body segments assume awkward postures. Maintaining neutral postures and neutral loadings for users requires simultaneous design of the physical components of the environment, their spatial relationships to one another, the user's behavioral interaction with each component, and task requirements.

Many empirical examples require this theoretical shift from considering the individual components of human-workstation design in isolation to the importance of evaluating their interactions. Marshall, Mozrall, and Shealy (1999) investigated the influence of complex wrist and forearm postures on wrist range of motion (ROM). Although their results relate more to human functionality constraints than to awkward postures per se, they still illustrate the necessity of an interactive systems framework for applying basic ergonomics research to practical office design problems.

Using electrogoniometry and manual measurement, Marshall et al. found that forearm and wrist postures jointly determine wrist ROM. In particular, they found that forearm postures and secondary wrist postures interacted to influence wrist ROM, and "radial deviation capacity was highest when performed with wrist extension and lowest when performed with wrist flexion" (Marshall et al., 1999, p. 211).

A second, although indirect, example results from research that used psychophysical methods to evaluate seating comfort. Helander, Little, and Drury (2000) found that difference thresholds were a function of seat height, seat pan angle, and seat back angle. However, secondary findings suggested that seat height and seat pan angle in particular were interdependent, even when participants adjusted a single chair in isolation—that is, adjustments of one influenced adjustments of the other. The authors represented this result as methodologically problematic because seat pan angle and seat height are confounded for typical task chairs given that the pneumatic support cylinder acts as a symmetrical fulcrum under the center of the seat pan rather than on one of its edges. Nonetheless, it could also be argued that human proprioceptive and kinesiological experience may be fundamentally interactive.

An applied example of this foundational interdependence among ergonomics principles given in Smith and Cohen (1997) involves the need for a headrest if people use a reclined posture, either to decrease spinal loading or to increase hip angle (Corlett, 2007; Gscheidle & Reed, 2004). Thus, whether or not ergonomics principles for neutral loading of the head and neck (balanced over the spine in upright postures) require a headrest depends critically on the seat back angle and associated user postures. Likewise, recommendations for wrist rests, palm rests, forearm rests, lumbar support adjustment, footrests, placement of the keyboard and/or other input device(s), seat height, seat pan angle, seat back angle, and placement of the VDT or other display device(s) depend on simultaneous consideration of many, if not most, of the others.

Another example from two investigations of the design of support for the upper extremities during office tasks illustrates the necessity of a systems perspective for framing practical recommendations. In a study of 4 male and 6 female experienced typists, Woods and Babski-Reeves (2005) obtained mixed results for forearm muscle activation but found wrist posture improvements for negative keyboard slopes up to –30° with no differences in key-strike force or performance measures. Males reported greater discomfort than did females, but this difference decreased as slopes became more negative up to –30°. However, using an experimental setup limited to single-finger, single-key measurement, Balakrishnan, Jindrich, and Dennerlein (2006) showed that finger joint torques and key-strike force are reduced for users typing on positively tilted keys. Applying these results (to reduce the risk of developing MSDs in the fingers) would require that keyboards be placed in positive tilt—the configuration shown to reduce neutral wrist postures.

In the absence of an experiment that simultaneously evaluates finger and wrist movements and postures, as well as muscle activation in the forearms, shoulders, neck, and upper back, savvy practitioners need a systems framework within which to weigh such competing results—perhaps including task requirements (Dennerlein & Johnson, 2006a; Dowell, Yuan, & Green, 2001), individual differences, and equipment characteristics. In this regard, Bufton, Marklin, Nagurka, and Simoneau (2006) showed that lower force activation is required for notebook (laptop) computers. However, subjects actually used *excessive* force with such keyboards; auditory feedback (clicks) and/or slightly greater key travel distances were suggested as possible remedies.

The impact of thermally valent seating on acceptable ambient temperature ranges provides still another example of the necessity of the systems perspective advocated in this chapter for optimal office ergonomics design and assessment. Although Zhang, Wyon, Fang, and Melikov (2007) conducted their research to guide user-centered vehicle design, their results apply equally well to office environments. Using laboratory experiments involving 11 climate chambers with air temperature ranges of 15° to 45° C and four seat temperatures ranging from cool to warm, Zhang et al. evaluated 24 participants dressed appropriately for these ambient conditions. In a "simulated summer series," subjects were adapted to be too warm and in another series, to be thermally neutral. Subjects' thermal sensations, overall acceptability of thermal conditions, and thermal comfort were regularly captured on visual analogue scales. Objective seat conditions were assessed by continuously measuring instantaneous heat flow. A second-order polynomial function of this local heat flow described the percentage of participants who were dissatisfied at each of the ambient room temperatures.

Zhang et al. found that at an air temperature of 22° C, subjects preferred a seat heat flow of zero, whereas the heat flow that minimized the percentage of dissatisfied participants was a simple linear function of air temperature under all conditions. These results suggest that optimal seat temperatures could extend traditional air temperature ranges (of 80% acceptable) 9.3° C lower and 6.4° higher. Thus, seat design interacts with the design of ambient conditions in determining subjective environmental quality.

As an applied science, ergonomics should never ignore relevant basic research, but a pragmatic perspective that recognizes the conceptual interdependence among practical ergonomics recommendations can help in translating and integrating isolated findings such as those of Lengsfeld, Frank, van Deursen, and Griss (2000). These researchers investigated the relationship between type of seat back recline and extent of lumbar spinal curvature (*lordosis*). Based on solid body–segment modeling, the simulated results were interpreted as arguing against synchro-tilt, whereby the seat pan and seat back do not recline as a unit. However, this conjoint recline was confounded with the shape of the seat back—at least based on the illustrations provided. In addition, without simultaneous evaluation of the other components—in addition to seating—of an office or computer workstation, interpreting these results regarding synchro-tilt remains ambiguous for practical applications.

Furthermore, building on the arguments of Allie, Purvis, and Kokot (2005), the following factors must be considered and balanced in arriving at applied recommendations: human-machine system outputs (e.g., performance/productivity), user symptoms (e.g., pain, comfort, and discomfort ratings; workload) user preferences and expectations (e.g., spontaneously adjusted settings/positions of office furniture and equipment), biomechanical/musculoskeletal factors (e.g., awkward postures; muscle tension—often referred to collectively as exposure to risk factors for WRMSDs), sensory/perceptual conditions (e.g., visual acuity; visual accommodation responses; color responses; e.g., Agahian & Amirshahi, 2006), individual differences (e.g., Fischer, Tarquinio, & Vischer, 2004; Kupritz, 2003), and task requirements (e.g., Dennerlein & Johnson, 2006a).

Sometimes these different categories of outcome measures lead to different design suggestions, depending on the system priorities that inform the design criteria (see Table 7.1). Ideally, research approaches such as response surface methodology (a research design approach that allows investigation of higher-order interactions without the number of conditions and subjects required by full, factorial designs; e.g., Mason, Gunst, & Hess, 1989) can perhaps eventually demonstrate for which design(s) and under what condition(s) these possible assessments overlap in terms of their practical implications.

The Work Compatibility Improvement Framework (WCIF), developed by Genaidy, Salem, Karwowski, Paez, and Tuncel (2007), provides a much-needed interpretive context within which office ergonomics could be usefully included. The WCIF relates the individual-workspace interaction to its broader, more meaningful layers within work groups and organizations, suggesting useful areas for integration among existing theory, practice, and empirical investigation. Specifically, Genaidy et al. recommended an assessment of the alignment among the current state of the system (actuality), what the current system design allows (capability), and ideal conditions (potential). Using quantitative assessments within each of these areas that integrate across organizational levels, their

Table 7.1. System-Level Goals That Imply Research-Based “Measures of Success” to Guide Ergonomic Design Recommendations for Human-Environment Interfaces Within Office Work Environments

“Success” Measures for Office Ergonomics

- Biomechanical/Musculoskeletal Risk Factors
    - Eliminate or minimize
- User Symptoms/Ratings
    - Minimize negative (e.g., stress; discomfort); optimize positive (e.g., comfort)
- User Preferences and Expectations
    - Match as far as possible
- User/System Performance/Productivity
    - Optimize speed, accuracy, and quality (e.g., creativity and innovation)
- Sensory/Perceptual Conditions
    - Leverage human potential and capabilities; augment for human limitations
- Individual Differences
    - Optimize with respect to user demographics and other characteristics
- Task Demands/Requirements
    - Optimize with respect to job requirements and needs

model seeks "to combine mechanistic, motivational, perceptual and biological" (p. 14) elements of human-at-work systems, thus ensuring that ergonomics research and recommendations will reflect the evolving, organic realities that influence people within contemporary organizations.

Recognizing Psychosocial and Organizational Contexts

A related development since Smith and Cohen's (1997) masterful review of the office ergonomics literature involves the importance of placing ergonomics findings within their larger psychosocial and organizational contexts. One pertinent aspect of this higher-order context relates to the quality of education and training about the elements and importance of ergonomics design guidelines and other interventions (e.g., Smith & Bayehi, 2003). The value of basic ergonomics information within applied settings often depends on the effectiveness of such training/orientation programs, as well as on individual differences (Levitt & Hedge, 2006). Recent reviews have affirmed the well-known risk factors in the development of musculoskeletal difficulties among office workers: frequency/repetition, awkward or static postures, excessive muscle loads (above 5% maximum voluntary contraction, or MVC; e.g., Graves, Way, Riley, Lawton, & Morris, 2004), inadequate recovery/rest periods (e.g., Nordander et al., 2000), and cool temperatures. However, field research has shown that individual differences, group-level factors, and organizational context(s) moderate the direct effect of aspects of workstation design on important outcomes such as comfort, productivity, and even musculoskeletal problems (Hughes, Babski-Reeves, & Smith-Jackson, 2007; cf. Galinsky, Swanson, Sauter, Hurrell, & Schleifer, 2000). Hughes et al. found increased muscle activation, key-strike force, and postural deviations of the wrist (risk factors in the development of WRMSDs) with increased time pressure, and increased key-strike force with increased mental workload.

However, at least one study remained skeptical of the importance of psychosocial risk factors in predicting WRMSDs—at least, these authors rejected the practicality of screening employees using psychosocial profiles (Bartys, Burton, & Main, 2005). Nonetheless, a sizable literature has developed that supports the critical role of psychosocial variables in predicting the development and severity of WRMSDs. For example, Bambra, Egan, Thomas, Petticrew, and Whitehead (2007), based on a review of 19 studies, found that decreased work autonomy and personal control over work tasks were associated with negative stress and health outcomes. Similarly, Wahlstrom, Hagberg, Toomingas, and Tornqvist (2004) found that the combination of physical exposure and job strain predicted neck pain among VDU users, but job strain seemed to be more important than physical exposure, evaluated singly.

To illustrate the importance of individual differences with another example from work environments, gender and weight have been shown to be important predictors of the development of musculoskeletal disorders (e.g., Shan & Bohn, 2003). It is thus at least theoretically possible for ergonomics practitioners to address employee problems proactively, although care must be exercised to prevent discrimination in hiring practices based on such information. The Americans with Disabilities Act (ADA) requires that reasonable accommodations be made in the design of the physical environment for particular employees, and savvy organizations recognize the value of preventing musculoskeletal discomfort in all workers to ensure a healthy and productive workforce. An important, emerging individual-difference factor that, based on current demographic trends, will continue at least through midcentury is an aging workforce. As far as possible, office ergonomics guidelines should be informed by the age group for which workplaces are being designed (e.g., Charness, & Dijkstra, 1999; Wilks, Mortimer, & Nylen, 2006).

In addition to individual differences (e.g., Madeleine, Lundager, Voigt, & Arendt-Nielsen, 2003), the effectiveness of ergonomics design guidelines can rest on the presence of available and easily accessible ergonomics training information. Faucett et al. (2002) found some initial benefits (at 6 and 32 weeks) in terms of sEMG-measured muscle tension for participants in two training interventions compared with a control group. However, mixed results were obtained for reported musculoskeletal symptoms at 32 and 72 weeks follow-up. This suggests the need for proximal, intermittent reinforcement of target behaviors to ensure the maintenance of risk avoidance by workers. More generally, we should consider the possibility that at least intermittent, immediate reinforcement may be necessary to prevent the development of WRMSDs, because the negative consequences following repetition of high-risk behaviors normally do not occur soon enough for users to associate them with their work activities.

As another example of the importance of education and training, consider the many ergonomic task chairs currently available. Without adequate instruction on the importance of ergonomics principles and chair adjustment strategies to fit specific anthropometries, postures, and task activities, users are unlikely to obtain the desired reduction in discomfort or enhancement in task performance. In this regard, some designers have advanced the design goal of so-called passive ergonomics to represent products or other ergonomics interventions that automatically adjust to fit important user dimensions or characteristics—without direct, intentional user input. Few, if any, scientific evaluations of chairs or other products designed on this premise have been published. However, it seems reasonable that users might benefit from these passive adjustments, because fully 80% of the time, office workers simply do not adjust their computer workstations.

Of course, all anticipated benefits from such passive ergonomics assume that the automatic adjustments are appropriate for users; to my knowledge, this assumption has not been scientifically demonstrated. However, preliminary tests of rotary dynamic seating systems support the potential efficacy of passive ergonomics. These seating systems have seat pans that slowly oscillate within an X-Y-Z coordinate system automatically, independent of intentional adjustment or movement on the part of the user. Tests have yielded positive results in terms of optimal spinal loading for osmosis and diffusion of nutrients within the intervertebral discs (Lengsfeld, van Deursen, Rohlmann, van Deursen, & Griss, 2000), lowered spinal shrinkage (van Deursen, Snijders, & van Deursen, 2000), and reduced subjective low back pain (van Deursen, Patijn, et al., 1999). In addition, Stranden (2000) found reduced edema formation in users' calves with variable ("free-floating") compared with fixed seat pan tilt; unfortunately, the extent of seat pan movement was not specified. Conversely, no advantages in terms of observed user movement or comfort evaluations have been found for office chairs featuring fixed forward-tilt or backward-tilt options compared with flat seat pans (Jensen & Bendix, 1992).

Whether or not passive rotary seat systems can be made sufficiently cost-effective to be widely adopted remains to be seen, but some available chairs allow "free-floating" seat pan tilt. Unfortunately, cost-effectiveness remains an important consideration among decision makers who purchase office furniture and equipment—somewhat irrespective of evidence-based ergonomics design guidelines. To illustrate, even though recent research has shown that electronically adjustable sit-stand work tables are used more frequently than manually adjustable ones (Wilks, Mortimer, & Nylen, 2006), because of poor demand, some manufacturers no longer offer that alternative; the additional cost per workstation can exceed $2,500 (USD).

COMPUTER WORKSTATION COMPONENTS

HFS 100 to HFES 100—Two Decades of Progress

Culminating a 20-year process of dissemination, public review, and comment, the Human Factors and Ergonomics Society recently published ANSI/HFES 100-2007, *Human Factors Engineering of Computer Workstations*, successfully updating HFS 100, *American National Standard for Human Factors Engineering of Visual Display Terminal Workstations* (1988). Important changes include research-based design considerations for color displays (e.g., VDTs), expansion of recommendations for input devices to include computer mice and other similar pointing devices, and an integration chapter that guides designers in synthesizing ergonomics recommendations for individual workstation components within their larger, system context without sacrificing relevant ergonomics principles.

Consistent with a broader, more applied perspective, the new chapter on office furniture outlines ergonomics criteria for four different postures, in contrast to HFS 100, which addressed only upright postures (Albin, 2008). This welcome clarification also accommodates the natural postural variation observed across individuals and tasks and throughout a typical workday.

Seating

Although Lueder and Noro (1994) remains an excellent reference for most of the important considerations related to user-centered seating design, more recent work has enlarged on the importance of an integrative systems framework for predicting seated comfort and discomfort. User-centered seating evaluations tend to emphasize user outcomes associated with long-term sitting such as low back disorders (LBD; e.g., Corlett, 2006; George, 2002). Recent reviews of these symptoms are compatible with the systems-level framework espoused throughout this chapter (cf. Marras, 2005). Marras reviewed research that demonstrated interactions between basic tissue and musculoskeletal biomechanics with individual differences (e.g., personality, gender, and LBD history), task demands, and stress. He argued that in order to increase our understanding and the long-term value of practical implications, investigations of LBD should focus on its causal etiology.

In light of Marras's review, practitioners should at least realize that occupant-centered design principles that include user characteristics as well as organizational and task contexts are critical, in addition to seating design itself, for preventing or ameliorating LBD among office workers. Still, some studies have managed to rank-order the importance of various interacting factors on specific seating criteria. For example, seat pan interface pressure appears to be determined most important by seating design, followed by user characteristics and postural differences (Vos, Congleton, Moore, Amendola, & Ringer, 2006).

Even stripped of its broader group and organizational contexts, a user-centered perspective for seating design still requires an understanding of the biomechanical, physiological, and postural interdependencies that characterize seated office workers. For example, the factors of hip rotation, posture of the lumbar spine, and tissue pressure under the ischial tuberosities all tend to interact. (Note that pelvic rotation can be forward [*positive*] or backward [*negative*]; using this convention, forward pelvic rotation involves lumbar lordosis, whereas backward rotation induces lumbar kyphosis; e.g., Moes, 2007.)

Among other salient implications, this structural interdependence means that the familiar, practical advice of encouraging a lordotic posture for the lumbar spine (e.g., Carcone & Keir, 2007) may increase pressure under the ischial tuberosities (Moes, 2007). Indeed, unsupported lordosis (no contact with seated lumbar support yet reclined against the upper seat back [thoracic spine contact]) while sitting may increase acute low back pain (Vergara & Page, 2000, 2002). These results may also explain why the available evidence does not favor sitting on a stability ball compared with an office chair for preventing low back pain—although this suggestion may not accommodate the additional finding of decreased pelvic tilt for participants on the stability ball (Gregory, Dunk, & Callaghan, 2006).

Thus, an integrated, user-centered perspective appears to be necessary to harmonize the basic research findings for practical applications related to seat design. Although lordotic postures involve minimal vertical loading of the lumbar spine and supporting muscle activation, contact with lumbar support while seated is required to realize the comfort benefits of lordosis and to minimize chronic discomfort (e.g., Vergara & Page, 2002). Additionally, in order to avoid pressure under the thighs (Hermans, Hautekiet, Haex, Spaepen, & Van der Perre, 1999) and unload the spine and associated supporting musculature by increasing the hip angle (Corlett, 2006), the front edge of the seat pan should slope down (the familiar “waterfall edge” design suggestion).

Other laboratory investigations have found gender and postural (pelvis rotation) differences in interischial tuberosities distance and both maximum pressure and pressure distribution (Moes, 2007). Moes also found important asymmetries in pressure distributions and the location of ischial pressure points across participants. Expanding on this point, Bellingar, Beyer, and Wilkerson (2005) and Fredericks and Butts (2006) demonstrated reliable left-right and vertical asymmetries in the preferred location and extent of seated lumbar support (see Figures 7.1 and 7.2).

Corlett (2006) reviewed several decades of seating research and provided a very helpful summary of its design implications. He recommended maintaining for seated postures the same neutral loading of the spine and supporting musculature that standing lumbar lordosis and slight thoracic kyphosis affords (the sagittal S-curve for the upright spine). In seat design, this requires seated contact with an adjustable lumbar support that can fit the “natural” lumbar curve—both its radius of curvature and its inflection point. However, the angle between the seat pan and seat back needs to allow unloading of the spine and its surrounding musculature by increasing the hip angle (which also promotes lordotic lumbar posture; Helander, 2003) and supporting the reclining postures favored by

Figure 7.1 *Some office chairs accommodate left-right asymmetries in lumbar support preferences among users. (Photo courtesy of Haworth.)*

Figure 7.2 *Illustration of laboratory setup used to conduct test-retest reliability assessments of user lumbar support asymmetries. (Photo courtesy of Haworth.)*

many users. If such reclined postures need to be maintained for long periods (more than two hours), then the chair should provide head and neck support.

In addition to uniformly loading the areas surrounding the ischial tuberosities, the seat pan must also feature a waterfall front edge to prevent pressure under the thighs—particularly behind the knees. Finally, the upper seat back supporting the thoracic and cervical spine should again maintain the natural S-curve of the spine yet not constrain the arms or require that the shoulders be maintained in an awkward (e.g., flexion) or static posture.

How these recommendations can accommodate the recently discovered asymmetries in the location of ischial pressure points, preferred lumbar and observed seat pan pressure distributions, as well as other individual differences (e.g., somatotype, gender, see Dunk & Callaghan, 2005; weight, muscular, and tissue tone) is not yet clear. In any case, seats that induce an acute hip angle or excessive forward rotation of the pelvis tend to decrease the interischial distance and expose the Vena Cava to pressure, especially for flat seat pans; this can interfere with venous drainage of the legs and other hemodynamics of the lower extremities. Thus, both the lateral (coronal) and horizontal (sagittal) curvature of the seat pan—particularly for solid materials—must be carefully considered to encourage healthy hemodynamics in seated users (Goonetilleke, 1988).

Objective, physical characteristics of seats such as pressure maps (false-colored 2-D images of empirical buttock-seat interface pressure contours) do not predict comfort or discomfort in any simple, straightforward way (e.g., the relationship is probably not linear and may be mediated by psychosocial and motivational factors; cf. Thakurta, Koester, Bush, & Bachle, 1995). Whether or not pressure mapping can predict long-term seat comfort for seat pans or seat backs remains problematic (e.g., Gyi, & Porter, 1999; but see Li, Aissaoui, Lacoste, & Dansereau, 2004, for a recent, more optimistic outlook), but work style trends among office workers suggest that fewer and fewer of them remain seated for long periods (more than two hours at a time), though there are clear exceptions (e.g., call centers; Bagnara & Marti, 2001). Such trends toward increased mobility of work tasks during the work day reduce the impact and value of many, if not most, of the recommendations outlined throughout this chapter. (However, see Sillanpää, Huikko, Nyberg, Kivi, & Laippala, 2003, who provide evidence based on a review of 56 workplaces in which perceived poor ergonomic design of office workstations predicted the prevalence of musculoskeletal disorders better than exposure time over one year. Also see Goossens, Snijders, Roelofs, & van Buchem, 2003, who maintained that more people sit all day in an office now than ever before.) Indeed, Legg, Mackie, and Milicich (2002) found that employees within different job types had different preferences regarding a prototype seat, possibly because of their varying degrees of mobility (how often and how long they worked while seated).

Related to seating and other office design considerations, anthropometry has shifted from deriving standardized body dimensions and proportions based mostly on military populations (e.g., young and physically fit) to the whole-body scanning of representative samples of the civilian population. These data have been a boon for designers of office seating, just as they have been for other seating designers (e.g., in vehicles). Perhaps not surprisingly, the primary changes observed when comparing these more recent databases with the previously available ones point to heavier, broader populations of typical users of office workstations and other equipment (e.g., Robinette & Daanen, 2006; Scanlon, 2004).

Other changes in seat design that may require more research evaluation include a shift from various forms of foam padding to frame-and-mesh designs for task seating. This change has not uniformly provided consistent improvement over more traditional foam seat pans and seat backs (Brand et al., 2000). Although some findings suggest that with the proper density and thickness, foam can still compete with mesh and gels on several ergonomics criteria (e.g., Apatsidis, Solomonidis, & Michael, 2002), recent data argue that more expensive gel technologies may be needed to improve long-term comfort and diminish long-term discomfort for office seating (Goossens, 2006). Additionally, at least one study found that a woven fabric may be superior to a cross-stitched fabric for the user-seat interface (Vos, 2001).

Finally, as the market for office seating expands globally, the instructions for adjusting task chairs (as one example) must shift from text/written instructions to iconic, cross-cultural displays that rely on pictorial symbols or representations. Even beyond seating, as more corporations expand their products and services across national boundaries, more attention must be paid either to culturally appropriate designs, warnings and controls, or at least culturally neutral alternatives.

From VDTs to Laptops and LCDs: Challenges and Opportunities

The systems-level theoretical perspective recommended here also requires updates to visibility/legibility recommendations for characters, print, and text presented on video display terminal (VDT) and/or liquid crystal display (LCD) computer screens (e.g., Helander, 1988). Recent improvements in refresh rates and other high-resolution screen technologies (including user-selected text size, contrast, and brightness levels) ensure that many, if not most, office technology screens and displays can exceed relevant minimum visual comfort and performance thresholds. Thus, in order to address any character resolution (visual acuity) problems adequately, a systems perspective must be adopted that combines conditions from ambient task lighting (see below), user posture(s), display selections, task requirements, and the configurative, spatial relationships among seating elements, display position, and placement of work surface input device(s).

In this regard, the visual angle subtended at the eye for individual characters and related content takes precedence over actual, absolute dimensions. Therefore, placement and angle of displays relative to the user, along with lighting conditions, determine the visibility and legibility of text and other symbols rather than direct dimensions such as height, stroke width, and maximum penumbras for individual characters (e.g., Rempel, Willms, Anshel, Jaschinski, & Sheedy, 2007). In a laboratory experiment, these authors found that of the three visual display distances investigated (mean: 52.4, 73.0, and 85.3 cm), the middle and far viewing distances were associated with more negative visual symptoms (blurred vision, dry or irritated eyes, slower convergence recovery), and at the far distance, participants adopted more high-risk postures compared with the most proximal distance because of character resolution and other visual acuity–related challenges. These changes—from specifying character dimensions to observations of the postural effects of display viewing distance—directly affect recommendations and requirements for work surface accommodation of technology. (See Human Factors and Ergonomics Society, 1988, 2007, for reviews of research supporting detailed design requirements for visual displays based on the characteristics [e.g., limitations] of human vision.) They also can influence behavioral risk factors for the development of musculoskeletal disorders. For example, in most cases, laptops do not support neutral postures of the upper extremities. The fact that their screens are linked with their keyboards presents several problems when viewing workstation design from a systems perspective (see Figures 7.3 and 7.4).

Research on Designed Support for the Upper Extremities

A lot of work has been published over the last decade evaluating this important area for optimizing office ergonomics. Although there are some mixed results, surprisingly convergent design implications emerge if these investigations are considered collectively. First, and saliently, Serina, Tal, and Rempel (1999) empirically established the risks inherent in seemingly innocuous office tasks. They directly measured postural variation of the wrists and forearms and derived joint movement velocities and acceleration for 25 participants typing at a computer workstation adjusted for their individual anthropometries. Results indicated that wrist extension and ulnar deviation in particular remained within high-risk ranges most of the time, and joint velocities and acceleration equaled those of industrial workers performing tasks involving high risk of developing cumulative trauma disorders (CTDs).

In addition to the potential risks documented in laboratory studies, careful applied research across broad participant cohorts (e.g., Gerr et al., 2005) seems to establish that computer use has contributed to the increase in MSDs in the general population.

In light of these documented risks, the best practical guidelines must be established based on the latest empirical evidence related to supporting the upper extremities. Thus, a systems perspective should be maintained that integrates across laboratory and field

Figure 7.3 *Users of laptop computers can exhibit postures associated with musculoskeletal disorders of the back, neck, shoulders, elbows, and hands. (Image courtesy of Lem Montero.)*

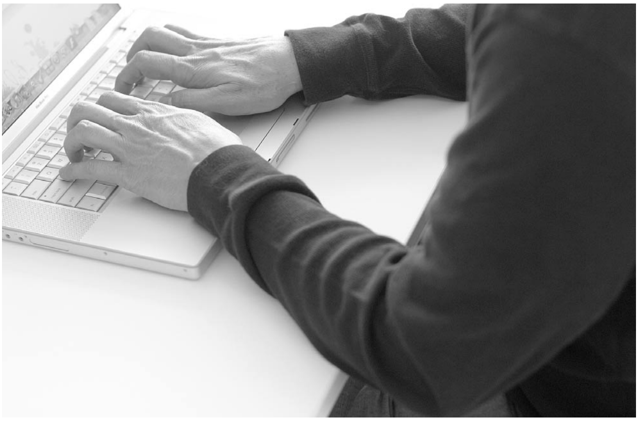

Figure 7.4 *Detail of ulnar deviation caused by the small size of laptop keyboards. (Image courtesy of Lem Montero.)*

studies to derive simultaneous, user-centered design criteria. To illustrate, if the keyboard or other input device is placed too high or distal relative to the user, a wrist rest might be requested if the user experiences fatigued anterior deltoid and/or trapezius muscles. The wrist rest also might be necessary to reduce pressure points under the forearms when resting the arms against sharp-cornered work surfaces, rather than from an ergonomics need for wrist or forearm support per se. Nonetheless, from the available literature, it would seem that providing lateral- and height-adjustable forearm support(s) is usually preferable to wrist or palm rests, as long as the supports do not require the shoulders or upper arms to depart from relaxed, neutral postures and do not result in pressure points at the elbows or under the forearms. However, if the choice is between wrist and palm rests, the latter of these two appears to be preferable, as wrist rests have the potential over time to cause hemodynamic constriction, particularly with wrist extension.

Of necessity, controlled laboratory studies and, indeed, many well-conducted field studies often pose and answer questions that leave similar, related issues unsolved. Some studies evaluate muscle activation or postural variation—but not both. Aarås, Fostervold, Ro, Thoresen, and Larsen (1997) showed that resting the forearms on the work surface reduced EMG-assessed muscle activity in the musculus trapezius and erector spinae lumbalis compared with sitting or standing without support; however, they did not explore potential postural effects or possible pressure points under the forearm. Although they did not evaluate the possibility of velar-forearm, wrist, or elbow pressure points, Dennerlein and Johnson (2006b) measured the wrist, forearm, upper arm, and shoulder postures and EMGs of 15 female and 15 male participants in a laboratory experiment evaluating mouse position during mouse-intensive office tasks. Coplanar configurations of the mouse and keyboard yielded more neutral postures and less EMG activation compared with when they were placed on different levels. The condition in which the mouse was placed between the keyboard and users was actually best, although this design is rarely used in practice.

There were also advantages of removing the number keypad (NKP) from the keyboard. If task demands require extensive mousing and no NKP, it might be best to specify a keyboard without the NKP and leave sufficient desk surface to allow mousing between the keyboard and the front edge of the work surface (cf. Sommerich, Starr, Smith, & Shivers, 2002; Visser, de Looze, de Graaff, & van Dieën, 2004).

Regarding adequate work surface area, Kotani, Barrero, Lee, and Dennerlein (2007), in a laboratory experiment measuring forearm, wrist, and upper arm postures and EMGs of 10 male and 10 female subjects, found that moving the keyboard away from users (on the desktop) decreased ulnar deviation by 50%. Additionally, forearm extensor activation decreased slightly, although flexor EMG increased slightly. Wrist extension also increased unless a palm rest was used, and upper arm abduction and internal rotation decreased. Although the "far" keyboard position was preferable for upper extremity comfort, the "near" position was favored for back comfort.

A similar laboratory experiment measuring both posture and muscle activity (Cook, Burgess-Limerick, & Papalia, 2004) compared forearm and wrist support conditions with typically recommended "free-floating" (upper arms hanging loosely at the sides; forearms, unsupported, holding the hands over the keyboard) postures during 20 min of word processing in each condition. Wrist support but not forearm support decreased trapezius and anterior deltoid EMG. Participants used a wrist rest in all conditions, but the free-floating condition featured a slightly lower work surface.

These results suggest that for acute laboratory tasks, upper back tension may compensate for velar-forearm, wrist, and elbow pressure points, but in the long term, this may result in wrist, forearm, or elbow hemodynamic problems, upper back pain, or both.

Although these studies found upper extremity advantages (both postural and muscle activation) for resting input devices (e.g., the keyboard and mouse) on the desk surface, the potential in field settings for forearm, wrist, and elbow pressure points to develop over time under these conditions has spurred the exploration of armrests as an alternative way to improve postures and minimize muscle activity (see Hasegawa & Kumashiro, 1998). Using a laboratory experiment to compare four armrest designs, Barrero, Hedge, and Muss (1999) measured the wrist postures of 12 female and 12 male participants, who were chosen to represent the 5th, 50th, and 95th percentiles for stature. They found no differences in postural deviations as a function of the four armrests, but EMG activation was not measured. Forearm supports (concave "shells" at the ends of two articulating arms with three rotation points) but not wrist supports reduced EMG-measured trapezius activation in 10 female participants performing both keying and mousing tasks (Visser, de Korte, van der Kraan, & Kuijer, 2000).

Delisle, Larivière, Plamondon, and Imbeau (2006) compared the use of chair armrests with resting the forearms (not elbows) on the work surface while participants performed computer work. EMGs indicated greater variability in trapezius and deltoid muscle activity (reduced MSD risk) for a corner work surface compared with two linear workstations, but EMGs also showed greater amplitude in forearm muscle activity (increased MSD risk) during mousing. Findings also suggested that alternating between using armrests and resting forearms on the desk surface could increase muscle activity variation without increasing amplitude—perhaps helping to prevent the development of WRMSDs.

In a laboratory experiment, Appenrodt and Andre (1999) found evidence that providing forearm support by using armrests increased neutral wrist postures during computer work. However, armrests did not improve shoulder motion during mousing. (The type of chair armrest may be important for supporting computer mousing; see Paul, Lueder, Selner, & Limaye, 1996.) Chair armrests also increased the potential for contact points at the elbows and velar forearms; however, contact pressure and possible hemodynamic constriction were not measured.

In a related, longitudinal field study of call center employees, Cook and Burgess-Limerick (2004) found some long-term (at 6 and 12 weeks) advantages of forearm support for neck, shoulder, and back symptoms (assessed with EMG and subjective comfort/discomfort ratings). Still, there were some disadvantages involving pressure points under the forearms, and there was participant attrition attributable to general discomfort with or inability to adjust to resting the forearms on the desktop while typing.

In applied settings such as a call center, it can be very difficult to address, simultaneously, every ergonomics principle that is relevant for optimal support of the upper extremities. In this regard, Feng, Grooten, Wretenberg, and Arborelius (1997) sought to bypass complications caused by pressure points for forearm support by comparing three types of support—fixed, horizontal-movable, and spring-loaded—in a laboratory experiment. They measured normalized EMGs from the anterior and lateral deltoid (shoulder), trapezius, and wrist extensor muscles in 12 women (age 23–37 years) during simulated typing and two fine-assembly tasks. Results showed a main effect of forearm support in reducing shoulder and trapezius muscle activity. The horizontal-movable support showed some advantages over the other types for reducing shoulder muscle activity during tasks performed at table surface height.

Five women and six men performed five seated and five standing tasks with and without a prototype dynamic forearm support device that surrounded them with fixed articulating arms and linkages (Odell, Barr, Golberg, Chung, & Rempel, 2007). Results showed lower activation in the supraspinatus, triceps, and forearm extensor muscles during tasks requiring horizontal movement of the arms. Because supporting the forearms reduced upper back muscle activity, these results lend some support to the upper back compensation hypothesis outlined earlier to account for the lack of pressure experienced while resting the forearms and wrists on the work surface in laboratory tasks. Overcoming the inertia inherent in the device linkages erased any possible advantages during vertical movement tasks. Unfortunately, no performance or subjective ratings data were reported in these studies.

Gustafsson and Hagberg (2003) collected performance (productivity) data in a somewhat related laboratory experiment comparing neutral and pronated wrist postures while using a computer mouse. Nineteen experienced VDU operators (10 females and 9 males) provided ratings of comfort and exertion while performing a standardized text-editing task. Their wrist postures were monitored with electrogoniometry, and muscle activity in the shoulder, wrist, extensors, and first dorsal interossei (FDI) was recorded using EMG. Mousing with neutral wrist posture produced lower muscle activity and smaller postural deviations compared with the pronated (typical) wrist posture.

Because these are risk factors in the development of WRMSDs, the results suggested that neutral postures for input devices may reduce the likelihood of MSDs. However, comfort, exertion, and preference ratings—as well as editing performance—favored the pronated wrist posture. Thus, ergonomics design suggestions based on job performance and/or subjective preferences may not coincide with those that minimize risk exposure.

After all, even acute, moderate muscle pain does not interfere with keying or mousing performance (Birch, Arendt-Neilsen, Graven-Nielsen, & Christensen, 2001).

As mentioned previously, in most applied situations, these multiple criteria must be balanced—along with the relative costs and benefits of injuries and task performance differences—to derive useful guidelines for practitioners.

Research Developments for Future Input Devices

Future-oriented studies of ergonomics designs for the upper extremities include some mixed results for improving the traditional computer mouse. In a laboratory experiment, Lee, Fleisher, McLoone, Kotani, and Dennerlein (2007) showed that altering the direction of activation for mouse keys reduced EMG-measured muscle loading of finger extensors but increased both loading of finger flexors and movement times. Whether these disadvantages could eventually be compensated for through experience was not investigated.

Also using a laboratory experiment, Brown, Albert, and Croll (2007) assessed the postural and performance data of participants using a mouse replacement device that attached to the user's hand and fingers. They found no hand or wrist postural disadvantages and no appreciable performance differences for 24 experienced computer users. These researchers suggested possible advantages over time because of the more relaxed overall postures facilitated by this device compared with traditional computer mice.

Meijer, Formanoy, Visser, Sluiter, and Frings-Dresen (2006) found subjective comfort and hemodynamic advantages (indicated by increased arm temperature stability during and after mousing tasks) in the wrists and forearms using a thermal-insulating mouse pad compared with a placebo pad on the desktop alone.

Whether or not the traditional computer mouse can be improved upon, Flodgren, Heiden, Lyskov, and Crenshaw (2007) provided a laboratory model for studying risk exposure assessment during computer mouse work. This model may finally provide a foundation for optimizing the design and placement of computer mice and related input devices—particularly for graphics-intensive tasks such as in architecture and design.

With regard to keyboard design, Rempel, Barr, Brafman, and Young (2007), using assessments of wrist and forearm postures, found that participants preferred a fixed keyboard split for right and left hands at a 12° angle, with an 8° gable and 0° slope. Participants had more neutral postures while using a similar keyboard but with a 14° gable. However, keying performance favored a traditional keyboard, and the authors cited evidence that learning curves for alternative keyboard designs may reach weeks, perhaps months.

Slijper, Richter, Smeets, and Frens (2007) evaluated the effectiveness of "pause-software," software that requires office workers to take periodic breaks by rendering their computers inaccessible for a brief time (versions vary in terms of user override features). They found that such software does not provide an adequate alternative to ergonomics design of computer workstations; it does not improve on spontaneous micro-pauses and may not reduce cumulative postural or muscle loads. The authors suggested encouraging more variety of activity rather than more rest periods for intensive computer users (but see van den Heuvel, de Looze, Hilderbrandt, & The, 2003).

Finally, Knight and Baber (2007) uncovered challenges in maintaining neutral postures (and thus minimal loads) for paramedics wearing head-mounted displays that provided computer-generated images from monitoring equipment.

Ambient and Task Lighting

The Illuminating Engineering Society of North America (IESNA, 2004) recommends maximum luminance ratios of 1:3 or 3:1 between central task materials and the immediate visual surround (approximately 25° visual angle, centered at fixation) and 1:10 or 10:1 between task materials and more remote surroundings. Similar guidelines are provided by the American National Standards Institute (ANSI, 1993). Wolska and Switula (1999) reviewed other relevant standards for office lighting (see also CIBSE, 1993; Harris, Duffy, Smith, & Stephanidis, 2003). Unfortunately, in actual practice, the conditions relevant to these recommendations are rarely measured in situ, and anecdotal evidence suggests that luminance ratios often exceed this advice. Furthermore, recent research points to the possibility of improving on these guidelines in order to match occupant preferences.

In addition to their helpful review of previous lighting research that is salient for the design of office lighting, Sheedy, Smith, and Hayes (2005) employed a laboratory experiment featuring fixed head position to clarify and extend current design recommendations. Distinguishing between *disability* (related to visual task performance) and *discomfort* glare (related to visual quality), they described transient adaptation effects from fixating back and forth between two disparate luminance levels—a frequent situation confronting employees in office work environments.

Sheedy et al. compared younger ($N = 20$, mean age 27.9 years, range 23–39) and older ($N = 17$, mean age 55.5 years, range 47–63) participants performing a central task (presented at 91 cd/m^2) at surround luminances of 1.4, 2.4, 8.9, 25.5, 50, 91, 175, 317, and 600 cd/m^2. Disability glare was assessed with low-contrast (20%) visual acuity charts; discomfort glare was measured with a questionnaire and preferred (surround) luminance by the method of adjustment. Younger participants performed best at a surround luminance of 50 cd/m^2 and older ones at 91 cd/m^2 (equivalent to task luminance). Surround luminance influenced transient adaptation at low but not high levels for both age groups.

Although participants read at typical office luminance levels, neither acuity nor visual symptoms were influenced by surround luminance, but preferred surround luminance levels varied widely, with a mean of 86.9 cd/m^2 for younger and 62.2 cd/m^2 for older participants. Suggesting slightly more stringent guidelines than those currently provided, the authors recommended that low surround luminance levels compared with task luminance should be avoided in practice, and that surround luminances at or slightly below task luminance will be preferred.

The design of lighting and daylighting has also experienced a shift from direct guidelines—such as adjustable task lighting to provide adequate luminance and legibility/contrast for work materials or the elimination of glare—to the importance of the larger, perceptual context for understanding user-centered design. Research and practice in office lighting have thus changed focus somewhat from an emphasis on prescriptive, static design recommendations to an appreciation for the entire user and organizational context(s) for which lighting and daylight are needed.

Some recent results involving the influence of image content on subjective glare assessment illustrate the need for this broader perspective to properly inform the design of office lighting and its associated experiential effects. Tuaycharoen and Tregenza (2005) used variants on the psychophysical methods of adjustment and paired comparisons to investigate glare tolerance for images of scenes with and without natural elements such as water and sky. Compared with their glare ratings of neutral backgrounds matched on hue, luminance, brightness, and other essential criteria, participants exhibited higher glare tolerance when rating images of scenes featuring natural elements.

Although Veitch and McColl's (2001) review of the then-available literature suggested a skeptical conclusion concerning the potential benefits of full-spectrum lighting for vision and cognitive work (see also Veitch, Van den Beld, Brainard, & Roberts, 2004), Juslén, Wouters, and Tenner (2007) investigated the effect of illuminance on speed and accuracy in the assembly of electronic devices in a production environment. They conducted a test during the summer and again during the winter and found that although a horizontal luminance difference did not influence errors, speed of production increased 2.9% in summer and 3.1% in winter at 1200 versus 800 lux.

Because of the greater control afforded by laboratory experiments compared with these compelling field studies, and the (at best) mixed results from lab studies regarding a link between lighting and productivity, practitioners must remain somewhat cautious when making human performance claims for office lighting. Buchner and Baumgartner (2007) found an exception to this caveat. Across four experiments using a between-subjects design to eliminate the confounding effects of performance-effort trade-offs, they demonstrated a proofreading advantage with positive polarity (dark text on a light background) for both black/white and blue/yellow combinations. However, proofreading performance could not compensate for the lack of luminance contrast with red text on a green background, and ambient illumination did not influence proofreading performance.

Irrespective of these mixed results concerning lighting and productivity, both lighting and color have been shown to influence psychological outcomes in office environments. Küller, Ballal, Laike, Mikellides, and Tonello (2007) studied 988 employees working in offices in Argentina, Saudi Arabia, Sweden, and the United Kingdom. Mood followed an inverted-U function of perceived light levels, but objective illuminance had no effect on mood. The relationship between mood and distance to the nearest window was bimodal (this distance ranged from 0.5 to 100 m, *Md* = 2.0 m). Workers in countries far north of the equator experienced significant variation in mood throughout the year; those in countries near the equator did not. Perceptions of light and color depended somewhat on each other, but mood was better throughout the year for workers in the most "colorful" work environments. However, just as previously noted for office lighting, somewhat less optimistic results for the influence of color on mood and performance have been found under controlled laboratory conditions (e.g., Stone, 2003). Yet, similar to most field studies, in Küller et al., the subjective assessment of lighting was more important than its objective characterization. In this regard, more recent studies have not improved much on Flynn's (1977) subjective dimensions for perceptions of lighting: overhead–peripheral; bright–dim; uniform–nonuniform; visually warm–cool. Unless they encounter extreme lighting conditions, office ergonomics practitioners can no doubt concentrate their efforts on the subjective assessment of worker perceptions of lighting—particularly if time and budget do not permit more objective evaluations.

However, some evidence paints a more optimistic picture of providing useful, objective guidelines for office lighting (Newsham & Veitch, 2001; Veitch, Geerts, Charles, Newsham, & Marquardt, 2005; Veitch & Newsham, 2000b). In the latter study, age- and sex-matched pairs of participants provided lighting preferences in simulated offices under controlled laboratory conditions. Using digital photometry, 17 objective lighting measures, and 11 subjective measures, the authors derived several practical guidelines, including the following: (a) mixtures of direct and indirect lighting, with 40% indirect; (b) desktop illuminances within recommended practice ranges; (c) moderate interest, defined as maximum-to-minimum luminance ratios in the visual field of around 20:1; (d) somewhat uniform ratios of average luminance between VDT screens and other vertical surfaces in the visual field; (e) low to no reflected luminaire (light source) images on VDT screens; and (f) window(s) with glare control (e.g., adjustable blinds or shades).

Nonetheless, Veitch and Newsham (2000b) acknowledged some practical difficulties attributable to high variability in user preferences for various lighting conditions, high intercorrelations among objective measures, differences between the aesthetics (interest) and functional (task-related) aspects of lighting, and lack of consistency in method protocols across both laboratory and field studies. Yet, they argued that by using affordable techniques and standardization of approaches, one can predict the physical characteristics of lighting that influence indoor environmental quality (IEQ). Surprisingly, no gender or age differences in lighting preferences were found, but low glare level variance and high satisfaction with lighting under all conditions may have attenuated potential age-related discomfort with glare.

Regarding ambient color effects on satisfaction and performance, Kwallek, Soon, Woodson, and Alexander (2005), under controlled, laboratory conditions, found advantages for white and predominantly blue-green rooms over red rooms (only those three colors were compared) and advantages regardless of color for participants with high stimulus-screening ability, “instinctive perceptual filtering of irrelevant stimuli.” These results agree with unpublished work (Brand, Reuschel, Lee, & Inman, 2003) that replicated a three-way interaction across two field studies showing user preferences for warm-colored “figures” (objects) and cool-colored “surrounds” (walls).

Kwallek, Soon, and Lewis (2007) extended these results to productivity and found that stimulus-screening ability and exposure time (to room color) determined the effect of color on task performance. Clearly, more careful research using a wider range of colors is needed to understand fully color’s influence on ergonomics issues such as IEQ.

In addition to interior lighting and color, daylight has been implicated in occupancy quality for office work environments because of its regulation of circadian rhythms for the sleep/wake cycle, body temperature, and heart rate (van Bommel, 2006). Given daylight’s potential for heat load and glare (e.g., Shih, & Huang, 2001), very few office environments use it as the primary source of lighting (Choi, Song, & Kim, 2005). However, because of daylight’s potential health benefits and accurate color rendering, integrating it with artificial lighting within office interiors can benefit occupants and save energy as well (e.g., Granderson & Agogino, 2006; Han & Ishida, 2004).

Some evidence suggests that office occupants prefer access to an exterior view rather than simply being exposed to daylight per se (Brand, 2006), but it has been very difficult to disentangle these factors in field studies. At the very least, ergonomists should recommend that office occupants have optional access to daylight and views (outside their building); ideally, workers sitting for 4 hours or more per day would have seated access to both daylight and views.

Daylight within an interior space can be accurately modeled to predict its penetration through an office workspace before construction (Li, Lau, & Lam, 2004). Vertical obstructions and their surface areas represent the single most important element in predicting light loss in interior rooms (Hadwan & Carter, 2006); thus, to provide views and daylight access along with privacy, floor-to-ceiling glazing may be needed to separate group work areas from individual workspaces.

Recent evidence suggests that the optimal design of office lighting can influence environmental satisfaction, which in turn can positively influence job satisfaction and other job performance-related outcomes (Veitch, Charles, & Newsham, 2004; Veitch & Newsham, 2000a). It seems likely that lighting and other aspects of the physical environment in general influence work outcomes through the mediation of work attitudes and other psychosocial factors (Newsham et al., in press). For practitioners, these results indicate that in addition to optimizing lighting conditions in the office, office ergonomists must also communicate with workers about the possible benefits of ambient and task lighting and how they might best adjust these for their changing needs (e.g., Akashi & Neches, 2005; Shikakura, Morikawa, & Nakamura, 2003).

These conceptual changes in the understanding of optimal office lighting have also been spurred by a number of recent findings demonstrating the value of providing personal control over lighting fixtures and lighting conditions for individual office workers (Lee & Brand, 2005; Veitch, Charles, & Newsham, 2004; Leaman & Bordass, 2001). Nonetheless, the primacy of providing optimal luminance ratios for various kinds of visual tasks, adequate resolution, and visual contrast for task visibility, and eliminating glare for both ambient and task lighting—particularly for older employees—remain important priorities for office ergonomics practitioners.

One final note of caution for ergonomics practitioners: It may be impossible to eliminate glare and optimize luminance ratios within office environments by relying on the selection and design of office lighting alone. Testing and measurement of office workstations under controlled conditions prior to—or in situ assessment after—designed installations or renovations will usually be necessary to ensure the proper reification of ergonomics design criteria.

OFFICE WORKSPACE DESIGN

There is perhaps no more popular trend in office design with so little scientific support than the general shift over the last three or four decades (e.g., Ilozor, & Oluwoye, 1999) from private (cellular) offices to some version of open-plan offices. Open plans are distinguished from closed plans as having minimal floor-to-ceiling divisions inside the building shell other than structural or supporting elements. Problems with inadequate privacy and personal control implicated in early reviews (e.g., Hedge, 1982) have largely been replicated and extended by subsequent research to include impaired organizational performance (Monk, 1997), greater stress and cognitive workload, lower intrinsic motivation, more difficulty concentrating, and less likelihood of adjusting so-called ergonomic furniture among workers in open-plan offices compared with those in enclosed offices (Banbury & Berry, 2005; de Croon et al., 2005; Evans & Johnson, 2000; Leather, Beale, & Sullivan, 2003; cf. Bowman & Enmarker, 2004; Gray, 2004; Wallenius, 2004).

Very few longitudinal evaluations of this issue have been published, but those that have suggest more disadvantages than advantages as a result of moving from more enclosed to more open offices (Brand & Smith, 2005; Brennan, Chugh, & Kline, 2002). In some situations, complaints about lack of privacy ultimately conflict with the desire for daylight and views (cf. Strasser, Gruen, & Koch, 1999).

It would seem that the continuing high incidence of changes from enclosed to open office work environments depends more on economics than ergonomics. However, recent studies have provided some support for the notion that open-plan offices improve communication and collaboration—in specific situations (Bonnetam, 2003; Johnson, 2004; Rashid, Kampschroer, Wineman, & Zimring, 2006; cf. Cohen & Prusak, 2001). A remaining weakness of such studies purporting to demonstrate potential advantages for open-plan offices is the lack of a reliable, empirical definition of *collaboration*. Furthermore, other authors disagree with these positive claims for open offices (e.g., Brill & Weidemann, 2001; Kupritz, 2000), arguing that personal regulation of privacy for "knowledge workers" (office employees facing unpredictable task demands yet consistently high task complexity) outweighs any benefits from increased social interaction.

Perhaps the critical insights for practitioners needing to make recommendations on this issue come from Maher and von Hippel (2005), who measured 60 male and 49 female office workers in a field study of two open-plan office environments. Their results pointed to the importance of individual differences and salient job characteristics, as well as to a discrepancy between the visual-symbolic nature of partial enclosures (cubicles) and their actual effectiveness as acoustic barriers. These findings suggest that employees engaged in complex tasks or with low stimulus-screening ability (thought to influence concentration) may need enclosed (cellular) offices; they will almost certainly prefer them. And although enclosure visually signals privacy, partitioned workstations do not provide *acoustic* privacy—especially in high-density (crowded) situations, a common occurrence in many corporate office environments. This discrepancy between users' expectations about and the performance of the office environment may be stressful or at least frustrating to employees, resulting in the anecdotal *Dilbert effect.*

This ubiquitous transition from enclosed and private to more open and public workspaces apparently rests on a number of loosely connected trends other than user-centered design. First, young office employees spend a greater proportion of their time working in groups or teams than individually compared with older employees. This trend increases in more open work environments and for younger employees (see Figures 7.5 and 7.6). Overall, it would seem that the nature of work is shifting from mostly individual to mostly group work (cf. Barber, Laing, & Simeone, 2005).

However, whether group-oriented workspaces adequately support individual work remains unanswered, and whether tasks designed for group work enhance job performance

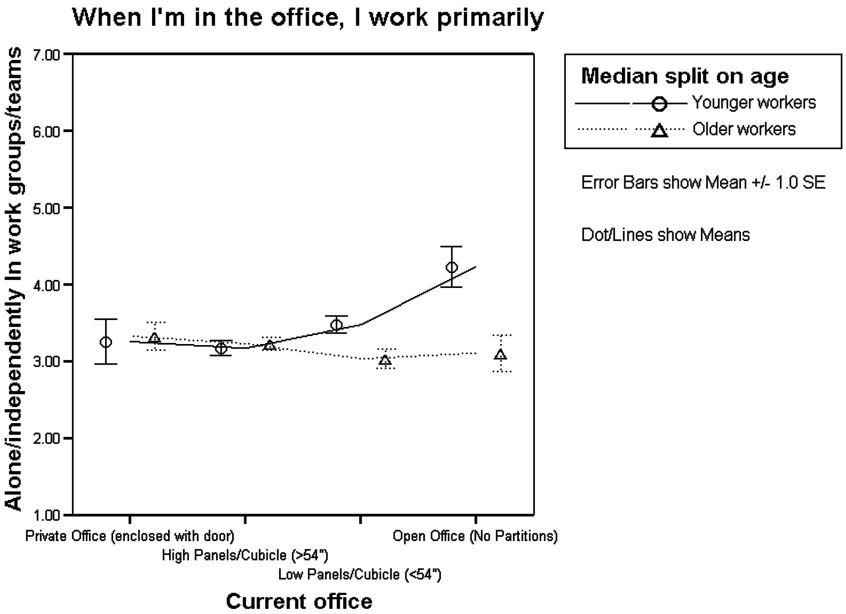

Figure 7.5 *Age difference (median split) in collaborative work as a function of office enclosure; this trend does not depend on job level, job role, or gender. (Photo courtesy of Haworth.)*

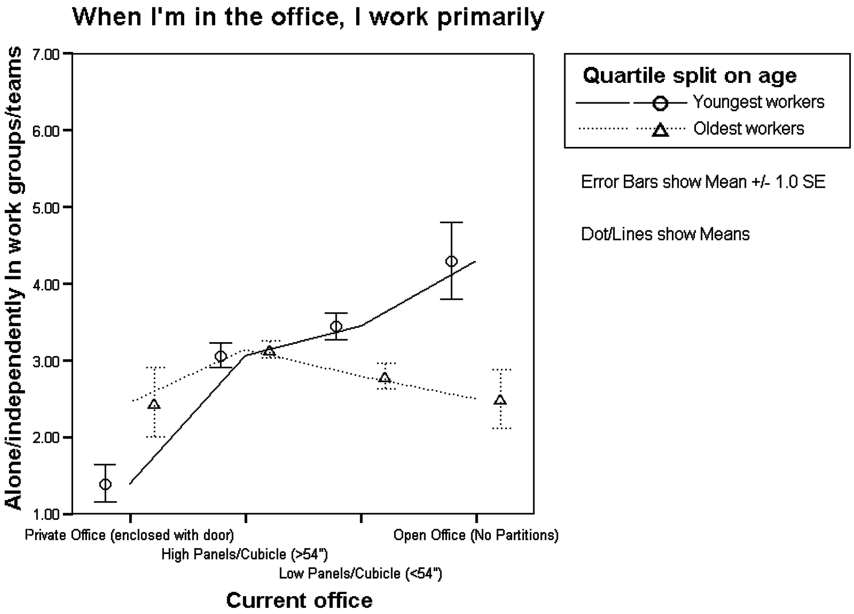

Figure 7.6 *Age difference (quartile split) in collaborative work as a function of enclosure. Note the increased difference relative to the median split, suggesting a continuing, cross-generational trend. (Photo courtesy of Haworth.)*

or organizational effectiveness compared with individually oriented tasks has not endured much scrutiny (but see Bowman & Enmarker, 2004; Laughlin, Hatch, Silver, & Boh, 2006). Still, many organizations assume if they provide remote access to company resources through technology, employees can self-select where to accomplish individual, private work (e.g., Johnson, 2003), allowing corporate office design to focus on supporting primarily group or team tasks.

Based on the available literature, it must be concluded that any individual, group, or organizational advantages of moving from closed to open offices depend on a conceptual framework that links a number of merely interesting assumptions still lacking adequate empirical investigation. What appear on the surface to be compelling claims of improved communication, collaboration, community, creativity, and innovation among employees in open offices have received only mixed support at best. Whether these potential advantages of more public work environments at group and organizational levels outweigh the documented disadvantages for individuals engaged in complex tasks largely remains to be determined. However, the results from a recent case study (Peponis et al., 2007) suggest that with adequate space planning, at least for one vertical market (i.e., business type: marketing), open-plan offices may harbor some organizational advantages. Nonetheless, the viewpoint of corporate real estate and facilities planning professionals usually guides praise for open offices (e.g., Hassanain, 2006) rather than an occupant-centered (i.e., user-centered) perspective (cf. Imrie, 2003).

Based on recent evidence, it would seem that in order to mitigate their disadvantages for individual work, the design of open-plan offices should address individual differences and task design in addition to workspace considerations. Using a laboratory experiment, Forster and Lavie (2007) found that high perceptual load resulting from a person's primary task decreased the deleterious effect of distractions on task performance—even for individuals classified as highly distractible by the Cognitive Failures Questionnaire (Broadbent, Cooper, Fitzgerald, & Parkes, 1982). Once again, a systems perspective for workplace design should be adopted that considers not only physical components of workspace design but also the individuals and groups present as well as the nature of their tasks and work processes (i.e., *people*, *process*, and *place*—see below under Summary and Conclusions).

Shifting Perspectives from Health and Safety to Hedonomics, Organizational Effectiveness, and System Performance

Among both researchers and practitioners, there has been a broad, continuing shift in focus from merely promoting safety to demonstrating value to the entire organization for human factors/ergonomics designs and interventions. Certainly health and safety will never diminish in importance, but they have begun to be integrated into a larger systems perspective in order to account for important differences in the success achieved by seemingly very similar ergonomically designed interventions across various organizations and settings (e.g., Carayon, Smith, & Haims, 1999). This change comes from an increased interest in using ergonomics design principles to improve the quality of work life in addition to employee productivity. Additionally, at least since the publication and wide dissemination of Herzberg's two-factor theory (Herzberg, Mausner, & Snyderman, 1959), but no doubt dating from the Hawthorne studies (Mayo, 1933), the design of the physical environment has not been consistently viewed as important in introducing positive benefits and optimal employee conditions; rather, ergonomics principles have been viewed primarily as representing injury prevention measures (e.g., Wong, Chow, Holmes, & Cheung, 2006; Mirka, 2005). Only relatively recently has there been renewed interest in exploring ergonomics design criteria to enhance various aspects of office employees' experience at work (Banbury & Berry, 2005; Brand, 2006; De Croon et al., 2005; Genaidy et al., 2007; Hancock, Pepe, & Murphy, 2005).

As an example, Wigö and Knez (2005) focused on thermal conditions and used a realistic classroom setting with 48 participants age 16–18 years (12 males and 12 females in each of two conditions) to explore the impact of air velocity on subjective perceptions of room temperature, air quality, self-reported affect, and cognitive performance. In two experiments, the authors compared a control group under constant low-velocity conditions with an experimental group under variations of low- and high-velocity conditions. In experiment 1, the authors assessed the impact of a temperature increase of 21° to 24° C and, in experiment 2, an increase of 25° to 27° C. The variable velocity conditions were created by high-velocity diffusers mounted above a false ceiling (rendering them invisible) immediately above each participant. These diffusers emitted 5-min pulses with a mean velocity of 0.40 ± 0.05 m/s with 45% turbulence intensity. These pulses separated 30 min of constant low velocity for the experimental groups; when the diffusers were turned off, naturally free convection flow returned within 45 s. The control groups experienced 80 min of constant low velocity. All conditions involved relative humidity levels of 40%–50%.

Neither perceptions of air quality nor draught (aversive perceived air movement; cf. Griefahn, Künemund & Gehring, 2002) were influenced by the conditions. However, under the variable velocity conditions, self-reported affect (pleasantness) increased and perceived room temperature decreased—even though objective room temperature de facto increased. These results imply that it would be possible to use variable velocity conditions in office environments to reduce the required cooling load on HVAC systems in warm climates.

Although air movement, relative humidity, and temperature combine to determine many aspects of thermal comfort, ventilation, or air exchange, rates have been shown to be important determinants of task performance and worker attitudes in both field and laboratory studies (Seppänen, Fisk, & Lei, 2006). In general, empirical findings suggest that office occupants would benefit from increasing air exchange rates above current recommendations (from 10 liters/s/person to 15 1/s/person or higher) and typical practice (6–8 l/s/person; ventilation rates below 6 l/s/person have been associated with *sick building syndrome*, or SBS). Regular maintenance and cleaning of air filtration elements is necessary for high air exchange rates to be beneficial.

The air quality outside the building must also be considered, along with possible increased draught and ambient mechanical noise. Additionally, underfloor air distribution for ventilating office workspaces may be less efficient than traditional techniques (Wan & Chao, 2005). Using computer simulations and objective measurements in a controlled laboratory experiment, Wan and Chao found increased temperature stratification with underfloor air ventilation, particularly at low dispersion pressures, but they did not measure occupants' reactions.

At least one unpublished field study showed a 34% improvement in subjective thermal conditions one year after installation of underfloor ventilation compared with the previous ceiling-mounted forced-air system (Brand, 2005). These discrepancies may be attributable to currently unknown interactions among air velocity, relative humidity, temperature, climate, individual differences, ceiling height, and perhaps other factors.

Individual differences such as personality and gender have also been explored within this broader, "positive" perspective on office ergonomics, along with their influence on the evaluation of the success of ergonomic designs and interventions from an organizational investment perspective. Recent developments reflecting the latter focus include linking the design of the physical work environment to environmental satisfaction and job satisfaction using structural equation models (Newsham et al., in press) and investigating the moderating role of an increased sense of personal control on perceived distractions and work outcomes (Lee & Brand, manuscript submitted for publication).

Finally, those who study office ergonomics have begun to explore how office environments might, in addition to preventing injury, cue people (stimulus value) in positive ways (*Theoretical Issues in Ergonomics Science* [special issue], 2004; *Ergonomics* [special issue], 2003). For example, exposure to elements of natural environments can contribute to recovery from cognitive work (Berto, 2005; but see Staats & Hartig, 2004) and reduce the pain of medical procedures (e.g., Diette, Lechtzin, Haponik, Devrotes, & Rubin, 2003). Other concerns include how office workspaces can be optimally designed to support individual work (e.g., privacy, territoriality; Wallenius, 2004) as well as collaborative work (e.g., team communication and coordination; Heerwagen, Kampschroer, Powell, & Loftness, 2004).

SUMMARY AND CONCLUSIONS

Several strong design guidelines and many well-established implications for both researchers and practitioners can be drawn from the research literature reviewed in this chapter. For example, design standards and guidelines relevant to office ergonomics have increasingly taken a user-centered rather than a product-centered approach to ensure that musculoskeletal loadings, awkward postures, and the negative aspects of workload have been optimized for the office occupant(s). In this chapter, I have outlined the importance of group and organizational contexts in the design and successful implementation of ergonomics products, programs, and interventions and suggest that organizational outcomes (not just individual worker outcomes) may in fact be used to evaluate the success of human factors/ergonomics designs and services within office environments.

Several detailed recommendations for the design and implementation of computer workstations within typical office environments have also been provided. Such guidelines ideally will be informed by corporate culture and other important characteristics of the psychosocial and organizational context. Those that simultaneously address *people* (e.g., individual differences), *process* (e.g., task requirements) and *place* (e.g., display viewing angle/distance, indoor air quality) will likely be more effective than isolated, independent approaches that ignore local or regional nuances.

An integrated approach to the design and construction of office environments might be best to reach these and related systems-level goals (Reffat & Harkness, 2001). Such adaptable workspaces can be used to address occupant needs, preferences, expectations, and individual differences while accommodating organizational priorities and other criteria. This broader understanding recognizes the importance of occupant-centered, intermediate variables that modify the direct relationship between the physical design of office workspaces and its effect on organizational and individual outcomes—even WRMSDs. As an example, Sprigg, Stride, Wall, Holman, and Smith (2007) found that psychological strain mediated the relationship between work characteristics and musculoskeletal disorders among call center employees.

Several case studies based on this systems-level perspective have been published, with mostly positive outcomes (Heerwagen, 2000; McFall & Beacham, 2006; Pullen, 2001). Suggestive evidence even exists that this more integrative approach to ergonomics design allows certain positive characteristics (e.g., personal control) to counterbalance certain negative features (e.g., distractions; Lee & Brand, manuscript submitted for publication; Moore, Carter, & Slater, 2005; Leather, Beale, & Sullivan, 2003; Thörn, 2000). Future applications of intelligent light sensors for the integration of daylight and artificial light will mimic characteristics of human visual perception and experience more closely than will current systems (Mistrick & Sarkar, 2005), producing harmonious, ambient, and possibly individualized lighting for particular worker/task characteristics and combinations (cf. Houser, Tiller, & Hu, 2004).

Humphrey, Nahrgang, and Morgeson (2007) provided a theoretical framework that could place office ergonomics design evaluations within their larger, organizational context(s)—allowing estimates of the relative impact of various kinds of interventions. They evaluated how work design influences the motivational, social, and work contexts. Using meta-analysis based on 259 studies and 219,625 participants, Humphrey et al. examined the impact of 14 work design characteristics on 19 worker attitudes and behaviors (e.g., job satisfaction, organizational commitment, role perceptions, stress, subjective performance). Office ergonomics design considerations would fall under their "work context" characteristics; these factors explained 4% of the variance in job satisfaction and 16% of the variance in stress—incrementally beyond the substantial influence of motivational and social contexts of work.

Finally, it seems that ergonomics researchers and practitioners have begun using organizational outcomes data (e.g., job satisfaction, organizational commitment; organizational performance/effectiveness)—in addition to more traditional health and safety measures—to assess the efficacy of ergonomics design guidelines and interventions. This trend should be informed by recent research showing practice-specific results of industrial-organizational psychology interventions (Gibson, Porath, Benson, & Lawler, 2007). Briefly, theoretical and empirical links should be established a priori between the extant problems to be addressed by office ergonomics design and the definition of success for implementing those guidelines (i.e., assessment measures). Otherwise, the effects of successful, user-centered design may be obscured by complex, unspecified organizational phenomena (e.g., Harris, 1994).

Perhaps more relaxed organizational cultures that embrace occupant-centered needs (e.g., Takahashi, Nakata, Haratani, Ogawa, & Arito, 2004) and intelligent buildings that truly respond to dynamic worker requirements (cf. Mawson, 2003) but do not disorient their occupants (Werner & Schindler, 2004; but see Cornell, Sorenson, & Mio, 2003) or discriminate against employees with disabilities (Kaufman-Scarborough & Baker, 2005) will constitute the centerpiece of a world in which the quality of work life simply derives from a broader, consensual focus on saving the planet to ensure quality of life in general for future generations (Epstein, 2005).

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