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DESIGN OF WARNINGS FOR PHYSICAL TASKS: SLIPS, TRIPS, FALLS, AND MANUAL MATERIALS HANDLING

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ABSTRACT

This chapter describes the design of warning signs in the domain of physical ergonomics. The design of effective warnings for hazards regarding musculoskeletal injury requires knowledge about potential risk factors and injury mechanisms and should consider the anthropometric, biomechanical, and motor skill abilities of the target population. This information should be integrated with the warning design process as a means of reducing costly workplace injuries. Particular emphasis is given to hazards related to slips, trips, falls, and manual material handling tasks. Example prototype warnings are presented. Recommendations for future research and application are offered.

WARNING DESIGN PRINCIPLES AND PHYSICAL ERGONOMICS

Increased attention has been given to the use of warnings in addressing hazard control in various domains, including consumer products and work environments (Laughery & Hammond, 1999). According to Sanders and McCormick (1993), warnings are the last line of defense of a three-part hierarchy of hazard control. According to this hierarchy, the first and best method is to design out the hazard. The second-best method is to guard against the hazard. The third and last method is to use warnings. The first two methods are considered the most effective for safety, because if one can design out or effectively control the hazard then individuals are relatively safe without having to do anything themselves to prevent the hazard from causing injury (or property damage). However, in many instances, it is not possible to completely eliminate or to adequately guard against all hazards or risks in product usage or task performance. In those situations, warnings can play an important role as a third line of defense against recognized hazards.

Most standards and guidelines for the warning design (e.g., American National Standards Institute (ANSI), 2002; Wogalter, Conzola, & Smith-Jackson, 2002) generally identify four main textual components: (a) a colored panel with a signal word and an alert symbol (triangle surrounding an exclamation point) to attract attention and convey a level of hazard, (b) information

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identifying the hazard, (c) an explanation of the potential consequences if exposed to the hazard, and (d) directives for avoiding the hazard. A fifth component is a graphic, such as a pictorial symbol that may assist in conveying one or more of the other four components. Therefore, a warning should convey the level and nature of the hazard present in the situation, how to avoid it, and what could happen if the hazard is not avoided. Research (e.g., Frantz, Miller, & Lehto 1991; Laughery, Vaubel, Young, Brelsford, & Rowe, 1993) recommends that the message text pertaining to the hazard, consequences, and directives should be specific and complete, but also reasonably brief. If needed, the mechanisms of injury involved should be presented to explain the nature of the hazard, including reasons why it is important to comply with the directives (Wogalter et al., 2002). It should also provide directives that can be accomplished expeditiously. Not only should the actions named be specific but also they should be relatively easy to perform. People are less like to comply if the directive is effortful and time consuming (Wogalter, Allison, & McKenna, 1989; Wogalter et al., 1987).

Thus, the design of effective warnings requires knowledge of existing standards, guidelines, and research in the domain of risk communication. It also requires detailed knowledge about the hazards associated with the foreseeable modes of product usage and the environments in which such usage occurs (Frantz, Rhoades, & Lehto, 1999). Typically, in the initial phases of the design process, hazard analyses are conducted. Several kinds of hazard analyses (Laughery & Hammond, 1999) may be employed, including: (a) procedures analyzing various circumstances that will or might arise and the severity and probabilities of their occurrence (e.g., fault tree and failure mode analysis), and (b) accident data reports from various sources. These methods provide important opportunities to identify and understand the hazards. With respect to physical ergonomics, there is a considerable body of research and evaluation (hazard analyses) that have identified musculoskeletal hazards in various tasks and environments.

The purpose of this chapter is to explore how warnings might be used in physical (occupational) ergonomics. Physical ergonomics is concerned with human anatomical, anthropometric, physiological, and biomechanical characteristics as they relate to physical activity (Karwowski, 2001; International Ergonomics Association, 2004). It concerns the study of physical task performance considering the hazards and risks involved in work. A goal is to develop ways to eliminate or reduce known risk factors in jobs and to develop guidelines for safe task performance. Human body movements are studied in conjunction with environmental objects, considering factors such as sequence of movements and positions. Understanding of how these components interact and contribute to injures and accidents is a major challenge for the design of warnings in this domain.

The Importance of Warnings in Physical Ergonomics

According to Ramsey (1989), warnings should provide instructions that targeted individuals can carry out. A well-known concept in the warnings literature is the cost of compliance (Wogalter et al., 1987, 1989). If a warning instructs people to undertake a hazard avoidance activity that is effortful and time consuming, they will be less likely to comply relative to one that instructs them to undertake a relatively easy and quick activity. Thus, the prescribed avoidance actions should be as simple to perform as possible. Although this may seem straightforward, it also requires consideration of the skills, strength, and anthropometrics of the population expected to respond to the warning. For example, some individuals may lack the necessary reaction time, strength, arm length, manipulative skill, and other factors required by a warning's instruction to adequately or effectively perform the warning's hazard avoidance activity. Thus, a person might not be able to comply, even though the individual understands the message and wants to avoid the hazard. Therefore, in addition to the attentional, cognitive, and other factors that should be considered in the design of warnings, an effective warning must also be consistent with the biomechanical and motor skill abilities of the target population being warned.

In view of the previous discussion, the design of effective warnings requires consideration of the following issues:

- the potential hazards associated with products and equipment or environments;
- detailed information about the context and circumstances in which an injury pathway or accident sequence may occur;
- knowledge about how people behave when interacting with the product;
- foreseeable uses and misuses of the product;
- safe ways to perform a task or manipulate a product; and
- anthropometric, biomechanical, and motor skill abilities of the target population.

This chapter mainly focuses on the anthropometric, biomechanical, and motor skills of the target population. A detailed description of all hazardous situations and risk factors associated with physical tasks is beyond the scope of this chapter. However, a few notable examples are given, which demonstrate where the biomechanical-type hazards have been well established and how warnings may be beneficial in reducing the risk of musculoskeletal injury.

The following sections of this chapter initially describe background into two main types of physical ergonomics injuries: slips, trips, and falls (STFs), and manual material handling (MMH). This background serves as justification for intervention by using warnings as a method of hazard control. The final sections describe examples of warnings that might be used to decrease accidents and injuries pertaining to STFs and MMH tasks.

(STFs)

STF-related injuries and mortality are considered a substantial problem, with falls representing 10% of all fatal accidents in the United States (Agnew & Suruda, 1993) and 26.9% in Japan (Nagata, 1991). Slips and falls are the second highest source of unintended death each year in United States (Fingerhut, Cox, & Warner, 1998). The National Safety Council (NSC; 1998)

FIGURE 53.1. Illustration of typical SFT signs.

reported that, in 1997, there were 14,900 deaths in the United States resulting from fall accidents. Other data show that falls represented about 15% of all unintended deaths and 21% of unintended injuries resulting in emergency department visits in 1995 (NSC, 1998). Among nine industries examined by Leamon and Murphy (1995), the direct cost of occupational injuries from slips and falls was highest of all of the accident categories for the construction, restaurant, and clerical industries. Slips and falls were also the second highest source of losses for the business sectors of manufacturing, trucking, retail and wholesale stores, health care, food products manufacturing, and professional drivers.

Warnings intended to prevent STFs are fairly common (e.g., wet floor signs). Figure 53.1 shows some typical warning signs used for STFs. However, few, if any, posted signs or labels give the necessary risk-related information important for effective warnings, including potential risk factors, mechanisms of injury, and specific injury consequences, for example, bone fracture, back dislocation, ruptured disc, sprains, or even fatalities.

Slipperiness can be defined as the condition underfoot that may interfere with travel, causing the foot to slide (Grönqvist et al., 2001b). Slipperiness may cause injury or harmful loading of body tissues resulting from a sudden release of energy. Slipping occurs when there is insufficient friction between the foot and the floor, causing unintended movement between the two surfaces. Slipperiness is a function of the coefficient of the friction that quantifies the resistance between an object and the surface. A fall sequence involves the following events: (a) occurrence of imbalance (slips, trips, etc.); (b) attempt to recover equilibrium and, in the case of failure to recover, (c) a fall, with body impact on a surface (Gauchard, Chau, Mur, & Perrin, 2001). Slipping can happen during either the toe-off or heel-strike phases of walking. The heel-strike form is usually more difficult to recover from because the forward momentum of the body is in the same direction as the slip (Chang, 2001; Haslam, 2001).

The Bureau of Labor Statistics (U.S. Department of Labor, 1992) Occupational Injury and Illness Classification Scheme distinguishes between three major groups of falls: falls on the same level, falls to a lower level, and jumps to a lower level. Falls on the same level occur when the point of contact is on the same level or above the surface level supporting the person. Falls to a lower level occur when the point of contact is below the level of the surface supporting the person. Finally, jumps to a lower level occur when a person voluntarily leaps from an elevation, even if an attempt is made to avoid an uncontrolled fall or injury. Tripping is less frequent than slipping, occurring when the foot collides with an obstacle while the body continues in motion, resulting in loss of balance and a subsequent stumble or fall (Gauchard et al., 2001; Haslam, 2001).

STF Risk Factors

Multiple interacting environmental and human factors are involved in causing slips and falls. The primary risk factor for slipping is poor grip or low friction between the footwear (foot) and the underfoot surface (floor, pavement, etc.; Grönqvist et al., 2001a, 2001b; Haslam, 2001; Redfern et al., 2001). Secondary risk factors for slipping are related to a variety of environmental factors. These factors include walking-surface properties, such as surface roughness, irregularities, compliance, topography, and the properties of adjacent areas and contaminants (Gauchard, et al., 2001; Grönqvist et al., 2001a, 2001b; Haslam, 2001; Leclercq, 1999a; Redfern et al., 2001). Unexpected changes in slipperiness are particularly hazardous (Grönqvist, 2001a, 2001b). Another important environmental factor causing falls is insufficient lighting and glare (Gauchard, et al., 2001; Redfern et al., 2001).

The presence of contaminants or lubricants on the contact surface are important risk factors for occupational and nonoccupational slips and falls (Grönqvist et al., 2001a, 2001b; Leclercq, 1999a; Manning, Ayers, Jones, Bruce, & Cohen, 1988; Myung & Smith, 1997). Slip-related injuries often occur on wet, dirty, oily, greasy, or other contaminated walking surfaces. Accident investigations of these slip-type falls have shown that the ground covering is soiled in approximately 80% of the cases (Manning et al., 1988). Liquids, strewn objects, and ice/snow contribute to 45%, 21%, and 15 % of the reported cases, respectively (Manning et al., 1988; Strandberg & Lanshammar, 1981). Individual characteristics contributing to the slips and falls include gait, expectation, and the capabilities of the sensory (i.e., vision, proprioception, somatosensation, and vestibular) and the neuromuscular systems (Gauchard, et al., 2001; Grönqvist et al., 2001a, 2001b; Haslam, 2001; Leclercq, 1999a; Redfern et al., 2001).

Falls also occur in dual-task situations in which locomotion is a secondary task, to other tasks, such as talking, searching through store aisles for a particular object (e.g., grocery shopping), or carrying loads (Bentley & Haslam, 2001; Gauchard, et al., 2001; Grönqvist et al., 2001a, 2001b; Myung & Smith, 1997). In the latter case, the load carriage affects the center of gravity and adversely affects an individual's ability to maintain their equilibrium and to recover from an imbalance (Bentley & Haslam, 2001; Haslam, 2001; Myung & Smith, 1997). Pushing and pulling loads are also considered substantial risk factors for slips and falls (Haslam, 2001; Gauchard, et al., 2001). When pushing and pulling, the shear forces between the feet and the floor increase, which increases the likelihood of the slipping. Tripping can be caused by a permanent feature of the surface, such as a raised rock or step, or by a temporary item, such as, trailing electrical cable or a carpet fold (Bentley & Haslam, 2001; Haslam, 2001).

Accidents involving the steps and stairs are another major category of falls. Important features of steps and stairs include: riser and going (tread) dimensions, design of nosing, length of flight, nature and condition of surface material, position of handrail, and lighting (Cohen & Pauls, chap. 57, this volume; Haslam, 2001). It has been recommended that riser dimensions should be within 117 to 183 mm, with goings between 279 and 356 mm (Templer, 1992). Dimensional irregularities between adjoining steps and content of the visual field are contributory factors to accidents (Templer, 1992). User behaviors, which increase the risk of falls, include rushing, carrying items, and leaving objects on stairs. See Cohen and Pauls (chap. 57, this volume) for more risk factors involving the use of stairs and pedestrian walkways.

Falls from heights are a leading cause of serious injuries and fatal accidents at work in the United State (Cattledge, Hendricks, & Stanevich, 1996; Rivara & Thompson, 2000), United Kingdom (Haslam, 2001), and Denmark (Kines, 2001), with construction industry workers particularly at risk. Falls from heights tend to occur in locales where there is a sudden, unexpected change in floor level or where there is a need to climb to a height. They include falls from or through roofs, from scaffolding, off ladders, through windows, and from machinery. Frequently, serious fall-from-height injuries occur from relatively low elevations, suggesting that some people may not realize the extent of the hazard involved (Kines, 2003).

STF Avoidance

The risk of slips and falls depends on the capabilities of the postural control system and the mental set of the individual (Chang, 2001; Haslam, 2001; Leclercq, 1999a, 1999b; Redfern et al., 2001). The risk is also dependent on the subjective judgments of the user on potential slipperiness of actual floor conditions, particularly when vision is the only sensory mode affording its prediction (Chang, 2001; Gronqvist, et al., 2001a, 2001b; Haslam, 2001). With greater perceived slipperiness, postural control mechanisms are activated, and relevant postural adjustments are taken to maintain balance and to adapt to the low friction conditions. The adaptation actions include shorter steps and increased knee flexion, which reduces the vertical acceleration and the forward velocity of the body (Cham & Redfern, 2002; Chang, 2001; Gauchard et al., 2001). Adequate adaptation may not occur when it is not apparent that there is a change in the slipperiness (Chang, 2001; Leclercq, 1999a, 199b; Strandberg & Lanshammar, 1981). This explains why slips are more likely to occur where the properties of a walking surface change, - with the likelihood disproportiately higher when the change is sudden and unexpected. Therefore, methods that enable better detection of slipperiness and changes in the walking surface could help to avoid STF accidents. Markings and warnings could be used to facilitate detection and promote proper adjustments.

MMH TASKS

MMH tasks, such as unaided lifting, lowering, carrying, pushing, pulling, and holding, are common activities in the manufacturing, construction, and service industries. Injures resulting from MMH tasks are the primary source of compensable work-related injuries in the United State, concentrated predominately in the lower back (Battie et al., 1990; Bigos et al., 1986; Federal Register, 1986; National Academy of Sciences, 1985; National Institute for Occupational Safety, 1981). Besides the United State, there has also been international recognition of the adverse effects of MMH tasks. The use of safety and risk communication and warnings may be a useful way to avoid unwanted outcomes (Laughery & Hammond, 1999).

Current Practices in MMH

Over the years, researchers have examined the epidemiological bases of lower back disorders. Risk factors for low back pain and disorders include characteristics of the worker, the material or containers being moved, the tasks involved, and the workplace environment (Karwowski, Wogalter, & Dempsey, 1997). A comprehensive literature review of epidemiological studies on lower back disorders by Hildebrant (1987) revealed 24 work-related risk factors. These can be categorized into five basic groups as follows:

1. general: heavy physical work and general work posture;
2. static workload: static work posture and lack of variation, such as prolonged sitting, standing, or stooping, and reaching;
3. dynamic workload: heavy manual handling, lifting (heavy or frequent, unexpected or infrequent heavy, torque), carrying, forward flexion of trunk, rotation of trunk, pushing or pulling;
4. work environment: vibration, jolt, slipping or falling; and
5. work content: monotony, repetitive work, work dissatisfaction

The association between lower back disorder/injury or pain and MMH tasks has been well documented in the literature. One of the ways researchers and practitioners have attempted to reduce MMH disorders is through training workers in correct manual handling techniques (Kroemer, 1992). As reported in Burt, Nenningsen, and Consedine (1999), some studies show positive effects of training on MMH tasks (e.g., Chaffin, Gallay, Wooley, & Kuciemba, 1986; Miller, 1977), whereas others failed to note significant effects (Brown, 1975; Dehlin, Hedenrud, & Horal, 1976; Stubbs, Buckle, Hudson, & Rivers, 1983; Wood, 1987; Yu, Roht, Wise, Kilian, & Weir, 1984). Various types of training and measures were used in the studies, so it is difficult to determine the reasons for the failure to find positive effects in some and not other studies. One difficulty in showing a benefit probably relates to inadequate transfer of training, or in other words, the failure to make use of learned techniques and principles from the training situation to the actual work situation (Harber, Billet, Shimozaki, & Vojtecky, 1988; St-Vincent, Tellier, & Lortie, 1989). Yelon (1992) suggested that awareness plays an important role in using new skills following training. However, the failure to find positive effects of training in some studies suggests that simple awareness is probably not the whole story.

Job or task experience may be a factor in MMH-related injury. Other studies have suggested that the techniques used by more experienced, better-performing workers differ from the behaviors carried out by novices (Authier, Lortie, & Gagnon, 1996; Gagnon, Plamondon, Gravel, & Lortie, 1995; Mital, 1987; Noe, Mostardi, Jackson, Porterfield, & Askew, 1992; Patterson, Congleton, Koppa, & Huchingson, 1987). Despite the difference in behaviors between these two groups, the correct methods for safe performance of MMH tasks are rarely used (Kroemer, 1992). Several field studies (e.g., Baril-Gingras & Lortie, 1995; Drury, Law, & Pawenski, 1982; Imbeau, Beauchamp, Normand, Courtois, & Marchand, 1990; Kuorinka, Lortie, & Gautreau, 1994) have shown that it is not uncommon for workers to perform the MMH tasks in ways that increase the risk of musculoskeletal injury.

Besides formal training (and perhaps experience), another related way of reducing MMH problems is to provide appropriate recommendations or guidelines on proper work practice. Indeed, a growing number of organizations provide workers with specific recommendations on how to perform an MMH task. Typical work practice guidelines for lifting are shown later in the chapter and are discussed in more detail at that point.

Although many work practice guidelines exist, they do not necessarily ensure that the worker is performing a manual handling task according to the prescribed manner. Reasons proper MMH techniques are not employed include: (a) failure to recall the appropriate techniques, (b) selective attention to the prevailing work tasks and environmental aspects, and (c) inadequate information processing while performing a MMH task. According to Burt et al. (1999), one way to enhance awareness and to help with the transfer of lifting principles is to remind employees of the appropriate handling principles when they are about to undertake an MMH task. However, it would be unrealistic to have another person (e.g., a supervisor) always available to oversee this process. Therefore, Burt el al. (1999) proposed using a visual cue or reminder (e.g., a warning of some type) that could be presented near or on the materials being handled by the workers (see also Wogalter, Barlow, & Murphy, 1995). A visual cue could facilitate the recall of appropriate techniques for MMH that were taught during specialized training.

Application of Warnings in MMH

To date, there are various commercial organizations that produce numerous safety/hazard-related warning signs and labels. Unfortunately, few of these warnings convey much, if any, information related to injuries arising from MMH tasks. Furthermore, little empirical research has been conducted on warning signs for physically demanding and, therefore potentially dangerous, manual tasks (Burt et al. 1999; Mackett-Stout & Dewar, 1981). A notable exception is a study by Burt et al. (1999), who conducted three separate experiments with nine variants of labels displaying correct posture during manual lifting tasks. Figure 53.2 shows the posture labels that were used in the experiments.

The first study found that there were no significant differences among Symbols A, E, H, and I, but all of these symbols received significantly higher "appropriateness" ratings than the

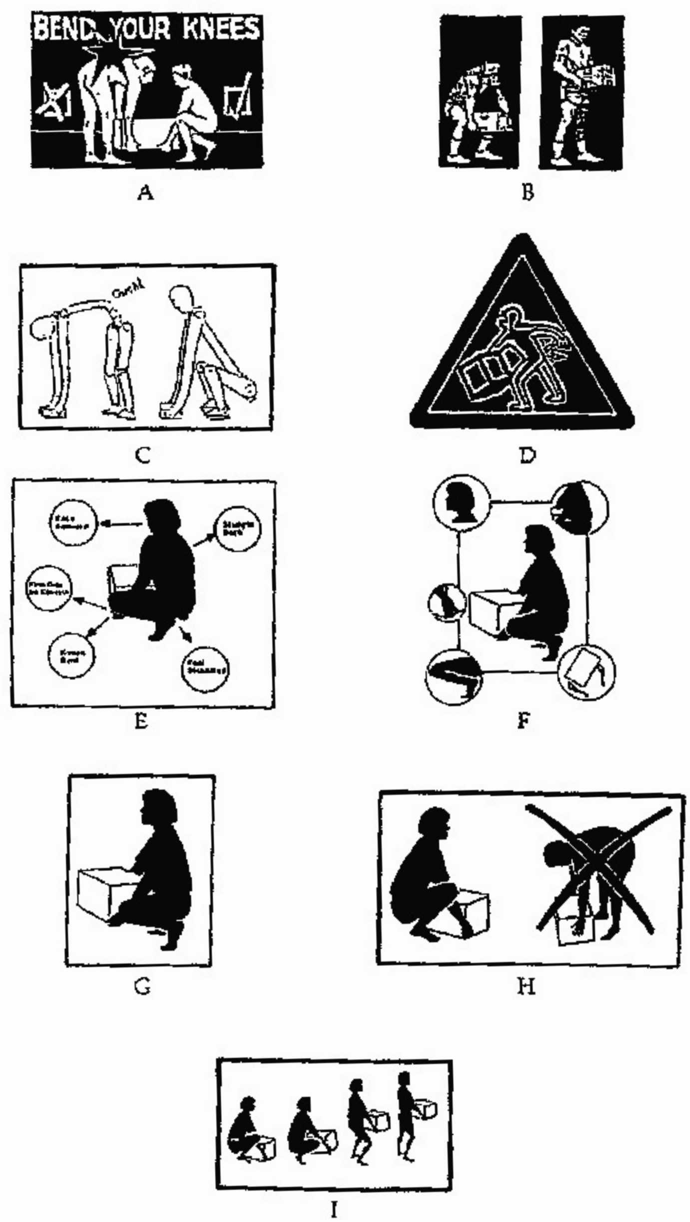

FIGURE 53.2. Lifting symbols used in the study by Burt et al. (1999) used with permission.

remaining symbols. The second study examined whether the participants could discriminate between the symbols in terms of the information communicated about the correct lifting posture. It was found that Symbol I produced the highest proportion of responses for the "keep back straight" criterion and was highly consistent across other criteria. Symbol I also had the largest proportion of participants who mentioned that this symbol showed the correct steps required for lifting. Subsequently, this symbol was used in the third study to examine the lifting techniques adopted by the participants. The study found that the symbol prompted a consistent increase in the use of correct lifting technique for all criteria. Burt et al.'s (1999) research is an initial step in demonstrating the potential benefit of a symbolic warning for an MMH task. Further research is needed to evaluate how and to what extent the symbol's presence changes the adopted body postures and joint motions.

SUDDEN LOADING

The etiology of back pain and injuries is complex and multifactorial. A substantial number of low back injuries are associated with sudden and unexpected loading during MMH and sudden or unexpected body movements, such as those involved in slips and falls (Gauchard, et al., 2001; Magora, 1973; Manning, Ayers, Jones, Bruce, & Cohen, 1988). Epidemiological studies show that the occurrence of musculoskeletal injuries depends on the frequency of sudden maximal efforts and the "degree of preparedness" prior to the effort (Magora, 1973). Manning et al. (1984) determined that 78% of back injuries recorded in an industrial setting were associated with unanticipated body motions during slips and falls (66%) and sudden loading (12%). Another study of back injuries showed that 66% of first events associated with acute back injuries were related to some type of underfoot accident and that 46% of these accidents were slips without falls (Mitchell, Blanchfield, & Manning 1983).

Exposure to sudden loading takes many forms and may occur both during work and leisure pursuits. The unexpected slipping of a lifted object or hand-held object is a known precursor of sudden loadings. For example, such events have been identified in the work of nurses and physical therapists during patient handling tasks (Molumphy, Unger, Jensen, & Lopopolo, 1985; Owen & Damron, 1984). Tripping is another example of the sudden load application through the lower limbs (Magora, 1973; Manning et al., 1984, 1988). During loading or unloading trailers, truck drivers are exposed to situations in which they try to catch materials. Less obvious sudden loading situations occur with occupants in traveling vehicles. Examples include vertical impact forces in a high-speed boat, a pothole strike by a vehicle with stiff suspension and tires (e.g., forklifts), and rough rides in off-road situations (Wilder, Aleksiev, Magnusson, Pope, Spratt, & Goel, 1996).

Biomechanical Studies

Empirical evidence suggests that there is a fairly consistent biomechanical scenario for MMH injuries. The neuromuscular system overreacts to an unanticipated event, creating excessive forces on the trunk due to the overcompensation of the trunk muscles, resulting in damaged tissue. According to this muscle force regulation model (Kroemer & Marras, 1981; Marras, Rangarajulu, & Lavender, 1987), the muscle force onset rate is linearly related to the magnitude of the intended force exertion. Under normal lifting conditions, large trunk muscle forces are generated to stabilize the spine in order to handle the external load. When the loads become extreme, muscle forces in the trunk are large, creating compressive and shear loads on the spine that may result in back injuries.

In situations of unexpected and extreme loading, the increase of muscle forces within the trunk is larger and more rapid, which may lead to an overload of the spine. Marras et al. (1987) suggested that, during unexpected conditions, the trunk muscles contract to their maximum, regardless of the magnitude of the external load. The exaggeration of the muscular force in an unexpected loading may lead to a particularly dangerous situation, because trunk forces are increasing very rapidly.

Several studies have analyzed trunk muscle recruitments in response to unexpected loads applied to the hands (Lavender et al., 1989; Lavender, Marras, & Miller, 1993; Marras et al., 1987) and torso (Carlson, Nilsson, Thorstensson, & Zomlefer, 1981; Cordo & Nachmias, 1982; Omino & Hayashi, 1992; Thomas, Lavender, Corcos, & Andersson, 1988) and during slips and falls (Greenwood & Hopkins, 1979; Romick-Allen & Schultz, 1988). These studies show common muscle-response patterns to sudden loading in different situations. Unexpected perturbations lead to a rapid onset and high peak amplitudes in muscle activity, confirming the aforementioned injury scenario. In addition, when a sudden load is imposed on the body, the dynamic application of external force recruits additional muscle force to be generated to counteract, stabilize, and minimize disturbance to body posture. The increased muscle tension stiffens the spinal system, thereby magnifying the impact of the sudden loading (Bouisset & Zattara, 1981; Houk, 1979). For example, with an unexpected loading, the mean muscle force was more than twice as large as with an expected loading, and peak muscle forces were on average 70% greater (Maras et al., 1987).

The internal loading was reduced when expectancies were developed based on temporal (Lavender et al., 1989, 1993; Marras et al, 1987) and spatial (Bouisset & Zattara, 1981; Cordo & Nashner, 1982; Mardsen, Merton, & Morton, 1977) cues about the upcoming loading. Spinal loading severity was reduced as alerting time was increased from 0 ms to 400 ms (Lavender, 1989). Thus, where sudden loading can be anticipated (some kind of warning presented), some preparatory muscular responses can occur, minimizing the negative effects of loading and postural disturbances. When loads are applied to the lumbar region of the torso, these preparatory responses include muscle tensioning, whole body postural changes, and development of the increased levels of intra-abdominal pressure.

Minimizing postural disturbances also decreases mechanical (compression) loading on the spine (Lavender et al., 1989, 1993; Marras et al., 1987). Studies have shown that muscle recruitment was a function of the amount of time available provided by the warning prior to loading (Lavender et al., 1989; Omino & Hayashi, 1992). Further investigations revealed that accurate warning information and the knowledge about load characteristics (such as the mass and the center of mass position) facilitate the anticipatory control of trunk muscles (van Dieën & de Looze, 1999; Lavender & Marras, 1995). In the case of lifting loads with unknown characteristics, it is advised to perform a slow lift to minimize loading and possible postural perturbations. However, only a few studies have examined the relationships between the specific warning characteristics and the effectiveness of biomechanical preparation for sudden physical loading on the body. Given the neuromuscular and biomechanical evidence summarized earlier, adequate warnings may be useful to signal the extent of loading. Armed with appropriate expectations, the individual can better prepare to handle the load to avoid adverse biomechanical consequences of sudden loading or postural perturbations.

RESEARCH-BASED GUIDELINES AND SIGNS/LABELS FOR PHYSICAL TASKS

Currently, consideration of warnings design from the physical ergonomics point of view is substantially underrepresented. As witnessed by the other chapters in this volume, there is a large body of knowledge concerning the characteristics of warnings to facilitate perception, comprehension, compliance, and other related processes. However, there is very little empirical research on the design and application of warnings with respect to the hazards involved in physical (manual) tasks performed in industrial environments. This state of affairs is partially a result of modern dependence on technological advancement and automation and on engineering and management control efforts to eliminate, reduce, or guard against workplace hazards. Where such methods can be practically placed in operation, they are preferred methods of hazard control. However, as described earlier, statistics show that there are still a large number of injuries associated with work-related musculoskeletal disorders. Thus, there is a need to explore other ways besides the distribution of recommended practices (guidelines) and formal training interventions as attempts to reduce physical ergonomics risks (U.S. Department of Health and Human Services, 1997). One of those ways, and the main basis of the remainder of this chapter, is to propose that warnings play a part in efforts to reduce musculoskeletal injuries.

In this section, several prototype designs for warnings relating to physical tasks are proposed. The aim is to illustrate how they can be applied to real task situations and to offer them to researchers so that they can determine if such warnings reduce STF accidents and can facilitate safe performance of MMH tasks. The proposed warnings were developed based on recommendations in the ANSI (2002) Z535 warning sign and label standard, as well as guidelines developed from research on warnings (see Peckham, chap. 33 this volume). At the outset of this chapter, several recommended warning components were described. However, the development of warnings and safety-related instructions is a much more complex process than simply following the ANSI (2002) Z535 standard or a set of guidelines.

According to Wogalter et al. (2000), warning design should be viewed as an activity that is initiated by requirements gathered from the users, including: (a) end-users, who are the focus of loss prevention or loss control efforts (i.e., employees in an occupational setting or consumers); (b) organizations, who will deploy the warnings and provide the context of use (e.g., employers, government agencies); and (c) product/equipment manufacturers, who develop the products to which warnings will be applied. Frantz et al. (1999) proposed a systematic process of developing warnings. Part of the process is to identify and understand product hazards, followed by the development of potential warning prototypes. In the previous sections of this chapter, hazards were identified for STFs and MMH load-carrying tasks. In this section, several prototype warnings are presented. The final stage of the Frantz et al. (1999) process involves evaluating warning prototypes. Future work is needed concerning this stage. Thus, the ANSI-type warning designs proposed in the following sections are only the starting point and should not be taken as finished products to be used in the real workplace and other environmental settings.

For application in real work environments, the following steps are proposed in the development of a warning intervention:

1. Perform a thorough job analysis to determine the nature of the MMH task.
2. Evaluate and select the most appropriate hazards that need warning (i.e., prioritization).
3. Develop appropriate warning signs and labels as required.
4. Evaluate the warnings using measures that assess effectiveness (such as ratings, comprehension, memory, and behavior).
5. Apply the best warning(s) in context.
6. Monitor the progress with respect to occurrence of incidents.
7. Adjust or refine the intervention as needed.

Thus, the design of warnings for workplace safety requires integrating many processes. The purpose of the following sections is to give a basis for warnings in the hazard domains previously described: STF and MMH.

Design of STF Warnings

Walking surfaces should be thoroughly analyzed to establish any potential risk factors for slip and fall accidents, including the areas used, slip resistance, roughness, and irregularities. Of course, building codes and standards should also be examined. The surrounding environment should be analyzed to reveal any potential factors that could cause significant changes of the surface friction, for example, the possibility of surface contamination by the presence of liquids, soil, and objects. In cases where there are potential problems, attempts to eliminate the hazard or guard against it should be considered first. If the problems cannot be eliminated or barricaded, a warning (or the addition of markings, e.g., see Cohen and Pauls, chap. 57, this volume) may be appropriate. The work environment and the tasks performed by workers should be considered to determine whether there

FIGURE 53.3. Example of a sign warning against a slippery surface.

are factors that may obscure walking surfaces or increase the risk of slipping in other possible ways. For example, rolling trolleys and trucks may obscure vision and disrupt monitoring of the walking surfaces. Special attention should be given to marking or warning about locations where there are or may be an increased likelihood of surface friction changes, such as a change from carpet to tile, where the latter may become wet with water or oil. As noted earlier, rapid and sudden changes in surface friction are one of the main contributing factors to slip and fall accidents. The warning or marking itself should be placed in a location where people at risk will see it near the hazard but also have enough time to avoid the hazard or compensate for it in their behavior.

As described earlier, a person's awareness and perception of slipperiness activates mechanisms of postural adjustment to the conditions. Thus, a warning that provides this information could promote compensatory behaviors and musculoskeletal adjustments compared with when this information is not given. A prototype warning for the slippery floor hazard is presented in Fig. 53.3. In this sign, there is a signal word panel (and alert symbol), information describing the hazard, a proscriptive statement on how to avoid the hazard, and an explicit safety symbol. However, note that in this sign, there is no separate statement of consequences. The reason for its omission is that other parts of the sign provide some of that information (e.g., the hazard statement contains the term "slippery," which implies the consequence of slipping and falling, and the symbol also provides this information. A consequences statement, such as "You may fall and have a severe injury," is probably known from the other information already given and is probably unnecessary in this case (Wogalter et al., 1987). Another similar example of a prototype warning about a tripping hazard is illustrated in Fig. 53.4.

FIGURE 53.4. Example of a sign warning against a trip hazard.

Earlier, it was noted that epidemiological research shows that falls frequently happen from relatively low heights. These statistics suggest that the hazardousness of a situation may be underestimated. Therefore, the warning for a fall hazard may need to present information about the extent of danger, emphasize the consequences, and indicate which specific fall protection equipment (e.g., a lanyard) needs to be used. A prototype warning about a fall hazard is illustrated in Fig. 53.5. In this case, a

FIGURE 53.5. Example of a sign warning against falls.

TABLE 53.1. Guidelines for manual lifting

Things to follow

1. Try to eliminate manual lifting (and lowering). If it is necessary, perform it between the heights of the knuckle and shoulder.
2. Be in good physical shape. If not used to lifting and vigorous exercise, do not attempt to do difficult lifting or lowering tasks.
3. Think before acting. Place material in a convenient position. Make sure sufficient space is cleared. Have handling aids available.
4. Get a good grip on the load. Test the weight before trying to move it. If it is too bulky or heavy, get a mechanical lifting aid or somebody else to help, or both.
5. Get the load close to the body. Place the feet close to the load. Stand in a stable position, with the feet pointing in the direction of movement.
6. In lifting, involve primarily straightening of the legs.

Things to avoid

1. Do NOT twist the back or bend sideways.
2. Do NOT lift or lower, push or pull, awkwardly.
3. Do NOT hesitate to get help, either mechanical or from another person.
4. Do NOT lift of lower with arms extended.
5. Do NOT continue heaving when the load is too heavy.

Note. Adapted from "Manual Materials Handling" by M. M. Ayoub, P. G. Dempsey, and W. Karwowski, 1997, in G. Salvendy (Ed.), *Handbook of Human Factors and Ergonomics* (2nd ed.), New York: Wiley.

higher level of signal word is used (according to ANSI Z535, 2002), and explicit consequences are included.

Design of Warnings for MMH Tasks

There are numerous guidelines published on performing safe MMH tasks, in the forms of textbooks, manuals, guidelines, and regulations. As mentioned earlier, one potential problem is that workers may not transfer their training in the guidelines to actual work behaviors for various reasons. A typical set of text book guidelines for MMH tasks (adapted from Ayoub, Dempsey, & Karwowski, 1997) is shown in Table 53.1. These guidelines outline what to do or not do in terms of load-carrying postures required for performing a manual lifting task.

Graveling, Melrose, and Hanson's (2003) guidelines for the Health and Safety Executive of the British Government are shown in Table 53.2, which are somewhat more detailed than Ayoub et al's. (1997) instructions. They provide specific directions for correct and safe MMH tasks regarding load, posture, and exertion. Generally, the MMH literature (see also University of Maryland, 2004) suggests that safe material handling encompasses a few fundamental rules: (a) keep the load as close to the body as possible, (b) avoid twisting, and (c) keep the back straight, bend the knees, and lift using the legs (i.e., the "straight-back/bent knees" method).

TABLE 53.2. MMH Guidelines Proposed in HSE Regulations

1. Stop and think (plan the lift).
2. Place the feet.
    - Have the feet apart, giving a balanced and stable base for lifting.
    - Have the leading leg as far forward as is comfortable.
3. Adopt a good posture.
    - Bend the knees so that the hands, when grasping the load, are as nearly level with the waist as possible. Do not kneel or overflex the knees.
    - Keep the back straight, maintaining its natural curves (tucking in the chin while gripping the load helps).
    - Lean forward a little over the load, if necessary, to get a good grip.
    - Keep the shoulders level and facing in the same direction as the hips.
4. Get a firm and secure grip.
    - Try to keep the arms within the boundary formed by the legs.
    - The optimum grip may vary, but it should be secure.
    - If you vary the grip while lifting, do this as smoothly as possible.
5. Don't jerk.
    - Carry out the lifting movement smoothly. Raise the chin as the lift begins, while keeping control of the load.
6. Move the feet.
    - Don't twist the trunk when turning to the side.
7. Keep close to the load.
    - Keep the load close to the trunk for as long as possible.
    - Keep the heaviest side of the load next to the trunk.
    - Slide the load toward you before attempting to lift it.
8. Put the load down, and then adjust its position.

Note. Adapted from *The Principles of Good Manual Handling: Achieving a Consensus*, by R. A. Graveling, A. S. Melrose, and M. A. Hanson, 2003, Norwich: HMSO.

A proposed warning system for MMH tasks might contain a list of basic guidelines. One example is shown in Fig. 53.6. Although this sign is longer than is usually advocated for warnings, it illustrates that a more extensive listing can be made relatively easy to read because of its formatting. This warning and other variations would need to be assessed from the standpoint of readability, understandability, and compliance. In addition, including a symbol might further benefit this placard.

Symbols are an excellent way to capture attention and communicate information quickly (assuming the symbols are adequately legibile and understandabe). Using the best symbol from Burt et al.'s (1999) research described earlier in this chapter, a warning could be developed to warn about using correct lifting practices. Figure 53.7 shows one of many that could be created.

Moreover, symbols could show other aspects related to the hazards involved. Warnings could include prohibition symbols (circle-slash) over graphical depictions of awkward postures known to be risky in MMH tasks, such as those involving trunk flexion (forward bending), side bending, axial rotation (twisting), and so forth. They could also show the correct posture surrounded by a green circle or a green check mark adjacent to them.

Besides general guidelines, there is a need for more concise and specific warnings applicable to particular MMH tasks. Studies on behavioral expectancies related to MMH tasks (Woodson, Tillman, & Tillman, 1992) reported that workers systematically underestimate the weight and size of the handled load. Such underestimations can significantly increase the probability of injury caused by sudden loading. A warning could provide specific information about the weight of the object to be lifted. A label could be placed on the object itself, so that the worker can become aware of its heaviness before the MMH task is carried out and thus would be better able to anticipate and prepare for the load. An example is presented in Fig. 53.8.

CAUTION

Lower Back Injury Hazard!!!

1. Plan the lift.
2. Test the weight before you move it.
3. For bulky or heavy object, get a mechanical lifting aid, or somebody else to help, or both.
4. Get a firm, secure grip on the load.
5. Hold the load close to the body.
6. Use the strength in your legs to lift or lower.
7. Do NOT twist the back or bend sideways.
8. Keep body aligned – No awkward movements.
9. Do NOT jerk – Move smoothly.
10. Do NOT lift or lower with arms extended.
11. Do NOT continue if the load is too heavy.

FIGURE 53.6. An MMH placard.

CAUTION

Lift Hazard

Improper Lifting Can Cause Lower Back Injury

Proper Lift:
- Get a Firm, Secure Grip on Load
- Hold Close to Body
- Use Strength of Legs to Lift

FIGURE 53.7. Example of a proposed sign warning against a lift hazard.

CAUTION

75 lb/34 kg

Heavy Object!!!

Handling May Permanently Damage Spine and Back

Use Mechanical Lift, or Ask Someone Else to Help, or Both

FIGURE 53.8. Warning label for a heavy object.

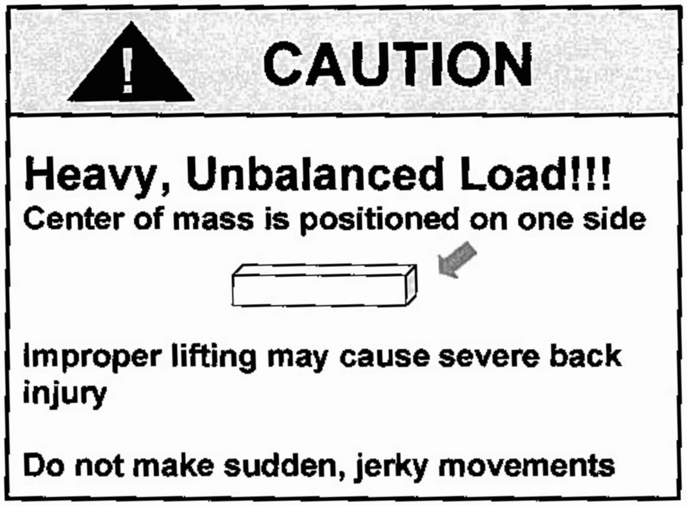

FIGURE 53.9. Example of possible warnings against sudden loading.

Another variant of the label in Fig. 53.8 could contain a bar graph (like a thermometer) to quickly and graphically convey the load's heaviness relative to a standard scaling, for example, 100 lbs, or relative to other size loads. Also, specific information about unusual load characteristics, such as an unbalanced center of the mass, may also be helpful because it could allow preparatory muscular responses and postural adjustment. One approach is illustrated in the Fig. 53.9. The specific message used in such warnings will vary depending, on the characteristics of the handled load and type of task likely to be performed. If it is not possible to present highly specific information, the hazard avoidance instruction should emphasize that slow and careful movements are necessary to minimize loading and postural instability.

Again, although prototype warnings are presented in this chapter, these and other possible variations should be evaluated with regard to how well they attract attension, how well they are understood, and whether appropriate changes to manual lifting behavior results before any particular warning is placed into actual use.

CONCLUSIONS

Although engineering and ergonomic task design are of primary importance to effectively guard against physical loading on the human body and prevent musculoskeletal hazards, warnings can be a useful tool to promote safe behaviors and reduce the risk of injuries. In this chapter, hazards associated with STF and MMH tasks are emphasized. A set of example prototype warnings is presented, based on knowledge from both the physical ergonomics and the warning design literature. Given that these are prototypes, future research should evaluate these and other variant warnings before they are adopted into specific applications.

The relative dearth of research at the intersection of physical ergonomics and warnings suggests that this is a fruitful area for research. The effectiveness of warnings in the physical ergonomics domain can be evaluated in a number of ways in both laboratory and field settings, using measures involving: (a) subjective ratings, comprehension tests, and behavioral compliance; (b) electromyograms of associated muscles; and (c) kinematic characteristics of joint motions.

The present review shows a need for integrating existing knowledge concerning hazards and risk factors of musculoskeletal injury, including their mechanisms, with the process of warnings design. The physical ergonomics literature provides much of the content that would go into the warnings, for example, what kinds of hazards exist, when and in what situations can they be expected to occur, and what type of actions are needed to be taken to avoid danger. That knowledge needs to be applied to warnings. Measurement of the biomechanical characteristics (such as muscular activity and equilibrium perturbations) can provide useful indicators of the warning effectiveness and offer directions for design improvements. At present, there is vast potential for the applicaton of occupational ergonomics knowledge to serve as the basis for warnings concerning hazardous manual activities. It is, therefore, an opportunity and a challenge for professional ergonomists to apply the existing and substantial knowledge base to the development and evaluation of warnings for the purpose of reducing injuries.

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