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A COMPARISON OF APPROACHES IN ESTABLISHING MANUAL HANDLING LIMITS IN RESTRICTED WORKING POSTURES

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Various industries require workers to handle loads in restricted postures. As a result, researchers have attempted to establish acceptable loads in restricted postures using various ergonomic techniques. Two common approaches have been: (1) to use intra-abdominal pressure (IAP) to set manual handling limits, and (2) to use the psychophysical technique to establish acceptable loads. IAP studies suggest greatly decreased lifting capacity when stooping compared to kneeling. However, psychophysical studies indicate that acceptable loads are much lower in the kneeling posture than when stooping. This paper will examine the results of IAP and psychophysical experiments and will discuss benefits and drawbacks of these approaches in the design of stooping and kneeling tasks.

INTRODUCTION

Manual materials handling (MMH) tasks in industry are performed in a wide variety of postures. Certain industries present the worker with environmental restrictions that may inhibit the worker from using "preferred" lifting techniques. Underground coal mines are one such workplace, where the ceiling often is considerably lower than that necessary for upright standing. As a result, workers often adopt postures such as stooping or kneeling when engaged in MMH activities. Given the fact that such postures are utilized in manual lifting, it is essential that ergonomists attempt to establish acceptable workloads for workers who engage in MMH in restricted postures.

A number of methodologies exist for analyzing industrial MMH tasks. For example, ergonomists may employ physiological, psychophysical or biomechanical parameters to effect better design of MMH tasks. However, in analysis of restricted postures (stooped or kneeling), biomechanical models that use compression as the design criterion need to be improved before recommendations can rely solely on these models (Gallagher and Hamrick, 1991). As a result, two basic methods have been utilized to analyze the stresses of stooping and kneeling MMH. These methods are (1) psychophysics and (2) measurement of intra-abdominal pressure (IAP), sometimes called the 'force-limits' approach. The purpose of this paper is to examine the results of force limits and psychophysical experiments and discuss the advantages and limitations of these approaches for design of stooping and kneeling MMH.

THE FORCE LIMITS APPROACH

The concept of intra-abdominal pressure as a mechanism to enhance the mechanical efficiency of the trunk was suggested some time ago (Keith, 1923). Early studies indicated that IAP increased along with the trunk moment during static symmetric MMH tasks (Davis, 1956; Bartelink, 1957). This result was later confirmed by others (e.g., Andersson *et al.*, 1977). As a result, this measurement technique was later taken into the workplace, and was used to estimate safe levels for MMH tasks (Davis and Stubbs, 1977a, 1977b, 1978). IAP measurements in early studies made use of rubber balloons and tambour recorders. More recent studies have utilized pressure sensitive radio pills or strain gauge transducer catheters (Davis, 1985).

Results of Restricted Posture Studies

The force limits approach has been used by several investigators to examine the effects of lifting in confined postures. Particular interest has been paid to the IAP response to trunk flexion (stooped lifting) because of the apparent connection between bending moments with increased IAP response. For example, Davis and Troup (1964a) related that when lifting in the stooping position, IAP is commonly raised, and the rise in pressure is "in general proportion" to the load being lifted. These same authors posited that the raised pressure may act as an extensor mechanism (Davis and Troup 1964b). Davis *et al.* (1975) examined IAP responses under four ceiling heights (1.7 m, 1.62 m, 1.48 m, and 1.35 m) and found a progressive increase in IAP with reductions in ceiling height. This led to the conclusion that truncal stress was greater as the trunk flexion increased. A similar finding was reported by Davis and Ridd (1981). However, Sims and Graveling (1988) detected only minimal differences in IAP when comparing MMH tasks performed in unrestricted headroom conditions compared to those completed in confined ceiling spaces.

An IAP study comparing stooping and kneeling postures was reported by Ridd (1985). This study examined the IAP responses of 54 subjects to various types of spatial constraints. These restraints included limited headroom, frontal and lateral barriers, asymmetric activities, and fixed foot positions. Results indicated that restrictions in headroom had the greatest effect on IAP response. In fact, IAP was found to increase in a linear fashion from erect standing to a point which corresponded to 90% of stature after which the increase seemed to level off. In other words, IAP responses remained essentially equivalent from conditions where the subject was at 90% stature (a partial stoop) down to where the subject was at 66% stature (a full stoop). The predicted decrement in lifting capacity based on IAP design criteria in a fully stooped posture (compared to standing) was approximately 60%. On the other hand, the kneeling posture (at 75% stature) was found to result in only an 8% reduction in lifting capacity compared to the erect posture, according to the IAP criteria.

The results reported by Ridd (1985) would thus lead one to make the recommendation that, in restricted headroom conditions, the kneeling posture should be employed due to the relatively small increase in IAP related to lifting in this position. In fact, of all the postures investigated (standing, stooping at 97%, 93%, 90%, 80%, and 66% of full stature, and kneeling), kneeling was the second least stressful posture (after standing) according to the force limits parameter.

THE PSYCHOPHYSICAL APPROACH

The psychophysical methodology as described by Snook (1978) has been used extensively to determine lifting capacity. This technique relies on a subject's willingness

to establish an acceptable workload -- one that does not lead to unacceptable pain or discomfort. Snook (1985) has related that psychophysics permits the realistic simulation of industrial work, is reproducible, and that psychophysical results appear to be related to LBP. According to Karwowski and Ayoub (1984), the psychophysical maximum acceptable weight of lift (MAWL) is an integration of the biomechanical and physiological stresses imposed by a lifting task. Furthermore, an epidemiological study performed by Herrin *et al.* (1986) indicated that psychophysical models may be used to predict the incidence rate of overexertion injuries.

Results of Restricted Posture studies

Several studies examining the psychophysical lifting capacity of miners in restricted postures have recently been reported by the U.S. Bureau of Mines. Two initial studies examined a task that simulated the unloading of an underground supply car in both stooped and kneeling postures (Gallagher *et al.*, 1988; Gallagher and Unger, 1990). Both of these studies indicated significantly reduced lifting capacity in the kneeling posture compared to that found acceptable in the stooped posture. A later Bureau of Mines study examined lifting tasks in the same postures, but consisting of greater vertical load displacement (Gallagher, 1991). This investigation also demonstrated decreased lifting capacity in the kneeling posture. Thus, all tests using the psychophysical criterion suggests a significantly decreased lifting capacity in the kneeling posture. Psychophysical estimates of lifting capacity in the kneeling posture are generally 15% below those deemed acceptable in the stooped posture.

DISCUSSION

The preceding evidence identifies a rather large discrepancy between the force limits approach and the psychophysical approach in establishing manual handling limits in restricted postures. The IAP parameter clearly favors using the kneeling posture, as this posture results in relatively small increases in trunk pressure. However, psychophysical results suggest that acceptable loads are considerably lower in the kneeling posture. Thus, it seems incumbent upon us to examine these techniques in greater detail in an attempt to understand the reasons for such conflicting recommendations. Evidence suggests that these approaches are sensitive to quite dissimilar factors. The following sections will discuss possible reasons for the contradictory findings elicited by these two techniques, and the advantages and limitations of each of the approaches will be considered.

Sensitivity of IAP to factors limiting MMH capabilities

The use of IAP as a methodology to evaluate manual handling limits has been predicated on a relationship between compression and IAP observed in static symmetric situations. It does appear that IAP responds to differences in posture and lifting technique. This response appears to be prominent in tasks requiring trunk flexion. Furthermore, Mairiaux *et al.* (1984) found that IAP was correlated with increasing trunk moments in an erect posture. Other studies have indicated that IAP has reasonable correlations with both intradiscal pressure (IDP) and back muscle myoelectric activity (Ortengren *et al.*, 1981). In addition, Davis and Stubbs (1977a) reported that risk of back trouble increases if IAP for a task exceeds 100 mmHg.

Even given the apparent response of IAP to changes in trunk loading as described above, it should be noted that IAP may not be responsive to several other factors that may limit manual handling capabilities. For example, in high frequency tasks, physiological factors may be a limiting factor in manual lifting. IAP would be expected to have little or

no sensitivity to this variable. Furthermore, studies have indicated that in many circumstances, MMH limits may be due to strength capabilities of specific muscle groups, such as the forearm flexors or biceps (Yates *et al.*, 1985). These limits may be encountered well before IAP levels are beyond 100 mmHg. Moreover, other factors that may influence load handling capabilities (such as physical endurance, load couplings, and various psychological factors) are probably not well addressed by measurement of IAP. In addition, asymmetric lifting tasks often do not result in large IAP increases, in spite of significant loads on the supporting structures of the lumbar spine (Andersson, 1982). Thus, the force limits approach may have limited applicability to tasks involving a significant asymmetric component. Other ergonomic design parameters may be necessary for design of such tasks.

The discussion above would imply that while IAP may respond to some factors that may significantly impinge upon an individuals ability to safely perform MMH tasks, it may not be sensitive to many other factors that are known to limit lifting capacity. Thus, it would seem prudent to supplement analysis of IAP data with other parameters known to have a significant impact on MMH capabilities in establishing lifting limits. Failure to do so may lead to recommendations that may exceed limits based on other influential factors.

Sensitivity of psychophysics to factors influencing MMH capabilities

In comparison with IAP, the psychophysical approach appears to respond to an altogether different set of factors that limit lifting capacity. For example, evidence supports the sensitivity of psychophysics to the energy demands of a task (Karwowski and Ayoub, 1984), something the IAP approach cannot address. Furthermore, it has been suggested that limitations of lifting capacity due to "localized" muscle strength capabilities can be identified through psychophysical means (Yates *et al.*, 1985). Whereas the IAP approach cannot confront issues such as lifting frequency and task duration, there is ample evidence that the psychophysical approach does assimilate the effects of these factors in final determination of workload acceptability (e.g., Snook, 1978). Moreover, the fact that MMH capacity may often be affected by psychological factors bears noting. The psychophysical approach is currently the only method available for investigation of these important, though often overlooked, factors. Thus, psychophysics does appear to address many determinants of lifting capacity that are not observable through IAP.

However, the psychophysical approach is not without its limitations, some of which may seriously limit the ability of this technique to set manual lifting limits in restricted postures. For example, Snook (1985), in his critique of psychophysics, discussed certain disadvantages of the methodology. Of primary concern is his statement that "psychophysics does not appear sensitive to the bending and twisting motions that are often associated with the onset of low-back pain." The rationale for this statement was the fact that very heavy loads were chosen by subjects in floor-to-knuckle lifts, yet this bending action was associated with almost half of worker compensation LBP cases. Snook's concern about the high subjective estimates of lifting capacity for floor-to-knuckle lifts is reinforced by the findings of Nicholson (1989), whose work indicated that Snook's floor-to-knuckle height data imposed lumbar compressive forces in excess of biomechanical design criteria established by NIOSH (1981). The fact that subjects elect to handle heavy loads in situations associated with a high number of compensative LBP cases prompts one to question whether subjects are capable of designating workloads that reduce the risk of LBP in bending and stooping MMH tasks.

However, in spite of the apparent difficulties in using the psychophysical approach to design MMH tasks in the stooped posture, it should be noted that this technique does

appear to respond to factors that limit lifting capacity in the kneeling posture -- factors to which the force limits approach may not be sensitive. Psychophysical data indicates a significantly reduced lifting capacity in the kneeling posture. This is probably due in part to the fact that a significantly smaller muscle mass can be recruited to perform lifts in the kneeling posture. In addition, physiological influences may affect psychophysical lifting capacity in the kneeling pose. Astrand and Rodahl (1977) state that the size of the muscle mass involved with a work task is directly proportional to the length of time that a workload can be tolerated. These authors also state that the subjective feeling of strain associated with performing a work task is related more to the metabolic rate *per square area of muscle* than to total metabolism. Moreover, the perceived psychological strain of the task will be greater as muscle mass involved in the work is reduced. These factors must be assumed to be relevant in the determination of psychophysical lifting capacity, and would serve to limit the acceptable workload in the kneeling position. It should be realized that use of the force limits (IAP) method would not be sensitive to physiological or psychophysical factors which may regulate acceptable lifting capacity in the kneeling posture. Thus, the psychophysical methodology may be the preferred technique to use when evaluating factors that limit lifting capacity when kneeling.

Implications for the design of MMH tasks

Biomechanical modeling would, of course, be the preferred method of establishing lifting limits in restricted postures. Unfortunately, current models do not appear to provide realistic assessments of the spinal load in restricted postures, such as stooping or kneeling (Gallagher and Hamrick, 1991). While we wait for more accurate models to be developed in the near future, our attention must be turned to other parameters that can be used in ergonomic design of MMH tasks. The two techniques discussed in this paper both seem to exhibit significant limitations in accomplishing this task; however, both techniques also appear to provide some useful information that can be helpful in ergonomic design of MMH tasks in restricted postures.

Neither methodology appears able to address the effects of all factors that may limit lifting capacity in restricted postures. For example, the psychophysical methodology does not appear to give any indication that the stooping engenders any significant reduction in lifting capacity, in spite of the traditional view that this lifting posture is quite hazardous. In light of the ambiguity surrounding the relationship between compression and IAP, it cannot be said that IAP explains the reasons that this posture is hazardous either. While we cannot take comfort from the fact that IAP remains poorly understood, it may be preferable to use this parameter to design MMH tasks in the stooped posture, simply because this criterion results in more conservative estimates of lifting capacity in this position.

Use of the IAP criteria would not suggest significant limitations with kneeling tasks; however, psychophysical evidence indicates that lifting capacity is significantly reduced in this posture. Factors other than trunk pressure appear to be responsible for this reduction in lifting capacity. For example, the reduced muscle mass that can be recruited in this posture may have a significant effect on load acceptability. Lifting limitations based on this factor may not be uncovered by the force limits approach. The decreased efficiency of the oxygen transport system and increased psychological strain (due to the higher metabolic loading per unit of muscle mass) presumably also play an important role in this regard. Consequently, several factors overlooked by the IAP parameter may limit lifting capacity in the kneeling posture. As a result, psychophysics may be the design parameter of choice for kneeling lifting tasks.

It should be duly noted that reliance on one of these techniques, to the exclusion of the other, may result in establishment of limits that might exceed worker's capabilities due to other factors. For example, the high psychophysical estimates of lifting capacity in the stooped posture may neglect the high trunk forces associated with this posture. Conversely, the relatively low IAP response in the kneeling posture may not address lifting limitations due to the reduced muscle mass that can be employed to accomplish a lift in this posture. These factors point to the need for a multivariate approach in examination of the stresses of lifting tasks, as well as in the design of industrial lifting jobs. Failure to do so may result in inappropriate recommendations for the design of MMH tasks.

CONCLUSIONS

Until biomechanical models are validated for use in the analysis of restricted lifting postures, ergonomists must turn their attention to other parameters in an attempt to effect proper ergonomic design of lifting tasks when workers stoop or kneel. The two parameters commonly used to identify lifting limitations in restricted postures (the force limits approach and psychophysics) disagree as to which posture manifests the most severe lifting limitations. Use of the IAP criterion suggests the kneeling posture is to be preferred; however, the psychophysical approach leads to significantly reduced estimates of lifting capacity in this position. These findings underscore the multivariate influences affecting lifting capacity, and indicate that both methodologies are limited by insensitivity to certain of these influences. It is concluded that proper design of MMH tasks must not rely on any one methodology. Efforts must be made to address as many stresses associated with the tasks as possible in order to effect appropriate lifting limits.

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