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Interaction of Physical and Mental Work

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The objective of the research was to determine the effect of mental load on the physical capacity of an individual. An experiment involving 9 combinations of lifting tasks, 1 lowering task, and 3 treadmill tasks was conducted. Heart rate was measured and maximum acceptable weight of lift was determined using the psychophysical method. A simple multiplication task was used as the mental load. The output variables were determined with and without the mental task. The results indicate that the individual's physical capacity decreased with the mental task while lifting from floor to knuckle and shoulder to reach lifting heights.

physical work   mental work   psychophysical methods
acceptable load limit   fatigue

1. INTRODUCTION

In spite of mechanization and automation in the modern industrial environment, almost all jobs require some degree of manual materials handling and manipulation of materials. The detrimental effects these tasks have on the human body, especially the back, are evident in the statistics compiled by the National Safety Council (NSC, 1993). According to NSC, back injuries account for 20% of all occupational injury cases. Almost one third of all workers' compensation lost-time cases are due to back injuries. The Kansas

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Department of Human Resources (2000) cites manual lifting as the highest classified cause (19.6%) of accident incidence and also as the highest classified cause (31.1%) of injury on the job. The average compensable cost reported for injury resulting from lifting was US $11,793.

Back injuries are costly in terms of pain, employee turnover, medical bills, loss of time, productivity, and workers' compensation claims. According to Snook (1978) statistics compiled by the Liberty Mutual Insurance Company indicate that 79% of the manual materials handling injuries were to the lower back. In the USA, approximately 800,000 disabling back injuries occur at work each year, with the resulting cost to the industry estimated at US $22 bn a year (National Institute for Occupational Safety and Health [NIOSH], 1994). Each year, the estimated 46,000 disabling back injuries in the USA alone, cost industry US $10 to 14 bn in workers' compensation costs and up to 149 m workdays (National Academy of Sciences, 2001; Occupational Safety and Health Administration, 1992).

Although back pain ranks among the most widely experienced ailments in the western society, it is not well understood. Back injuries, resulting from lifting (and lowering) of loads continue to represent a leading cause of lost work time and compensation claims. It is now well established by NIOSH (1994) that the majority of materials handling related injuries in industry are caused by manual lifting. Statistics compiled in the USA by NSC (1993) indicate that 50% of back injuries are found to be the result of lifting activities and that manual handling tasks are the principal source of compensable work injuries. Total costs, in lost earnings and workers' compensation payments, exceed that of any other work-related health disorder.

In the area of lifting and carrying, Lu and Aghazadeh (1994) reported on the use of psychophysical approach in carrying. Ayoub, Mital, Asfour, and Bethea (1980), Mital (1983), and Snook (1978) extensively studied the effects of lifting heights on maximum acceptable weight of lift (MAWOL). Ayoub et al. (1980) reviewed, evaluated, and compared the models for predicting lifting capacity. Mital (1983) verified the psychophysical approach in manual lifting. Asfour, Ayoub, and Mital (1984) studied the effects of endurance and strength training program on the lifting capability of males, and concluded that the maximum acceptable weight lifted increased significantly. Aghazadeh and Mital (1987) found that when loads are lifted to overreach heights compared to when lifting to knuckle or shoulder heights, the maximum acceptable weights of lift decline significantly.

Nicholson and Legg (1986) conducted a psychophysical study of the effects of load and frequency upon selection of workload in repetitive lifting and found that the workloads were not significantly different. Wu and Chen (2001) used psychophysical methodology to determine the load carrying capacity of Chinese males. Studies by McGill and Norman (1993) and Dolan and Adams (2000) report that when lifting is performed shortly after rising from bed, the lumbar spine is more resistant to bending due to increased fluid content, thereby greatly increasing the stresses on the discs and ligaments.

Thus several studies have analyzed the effect of various parameters, such as parameters of the object lifted, parameters of the workplace, parameters of the job, and individual variability and have evaluated the models for predicting the lifting capacity in order to reduce the number and severity of injuries.

Similarly, several experiments studying the effects of physical tasks on a mental task have been conducted. Davey (1973) established an inverted-U relationship between physical exertion and mental performance. He concluded that moderately intense exercise results in improved mental activities. Gutin and Di Gennaro (1968) also found that physical exertion to the point of exhaustion had a significant negative effect on mental performance. However, McAdam and Wang (1967) found that various treatments such as exercise, rest, instructions, tests, and so forth, had no significant effect on mental performance. Lybrand, Andrews, and Ross (1954) found that prior rigorous exercise facilitated performance on manipulative problem solving and perceptual organization tasks. Flynn (1972) found that prior exercise and aerobic capacity were not significantly related to numerical accuracy or speed. McGlynn, Laughlin, and Rowe (1979) found that increasing levels of concomitant exercise do not affect significantly the accuracy of the participants in performing discrimination tasks. Tomprowski, Ellis, and Stephens (1987) also found no significant decrease in the cognitive ability of participants following strenuous exercise.

A review of the literature reveals several interesting points. A number of researchers have investigated the effect of physical work on mental work. The reported studies were conducted between 1954 and 1987, and recent studies are not available in this area. Many investigators have studied areas related to back injuries and manual materials handling tasks; their research continues. The effect of mental work on physical work is an ergonomics issue, and ergonomists are interested in this subject. However, because of a lack of studies in this area, very little is known about this subject.

Thus the objective of the present study is to evaluate the effect of mental work on lifting and lowering tasks (psychophysical effect) and on the task of walking on a treadmill (physiological effect).

2. METHODOLOGY

2.1. Participants

The participants for the study were 7 volunteers from the student population at Louisiana State University (USA). The participants were in good physical condition and did not have any history of musculoskeletal injuries.

Anthropometric measurements were conducted in accordance with the procedures outlined by Roebuck, Kroemer, and Thompson (1975). Table 1 shows means and standard deviations of all anthropometric measurements for the 7 participants.

TABLE 1. Summary of Anthropometric Measurements of the Participants (*n* = 7)

Variable	*M*	*SD*	Range
Age (years)	23.14	2.79	20–29
Height (cm)	168.9	13.24	150.0–183.5
Body weight (kg)	69.14	9.26	60.0–82.2
Acromial height (cm)	143.5	10.93	121.3–154.0
Standing iliac crest height (cm)	102.5	10.93	86.0–109.3
Knuckle height (cm)	75.41	6.34	63.5–82.2
Knee height (cm)	51.37	4.67	42.6–56.4
Forearm grip distance (cm)	32.18	1.56	29.6–34.6
Chest depth (cm)	20.65	1.73	17.6–22.6
Abdominal depth (cm)	19.92	2.19	16.0–22.5
Chest circumference (cm)	90.31	2.4	87.0–94.5
Abdominal circumference (cm)	82.97	5.76	75.8–90.0
Forearm circumference (cm)	24.52	1.68	21.5–27.0
Biceps circumference (cm)	28.20	3.11	24.5–32.0
Thigh circumference (cm)	49.92	3.12	46.5–54.0
Calf circumference (cm)	34.97	1.1	32.6–36.0

2.2. Experiment

An experiment was conducted to evaluate the effect of a mental task on the physical capability of individuals. MAWOL (maximum acceptable weight of lift) was determined for each combination of the lifting task. Two independent variables were studied: lifting heights and frequency of lifting. Specifically the tasks involved lifting from floor to knuckle, knuckle to shoulder, and shoulder to reach heights at 2, 4, and 8 lifts/min. The mental task chosen was a simple multiplication task wherein the participants were asked to calculate the product of a two-digit number and a single-digit number. The task was recorded on a cassette recorder at intervals of 15 s. A randomized complete block design was employed as an experimental design in this study. Different tasks were used as treatments and participants were used as blocks. Box size was kept constant for all phases of the experiment and the dimensions were 0.52 m wide, 0.37 m deep, and 0.24 m high. The handles were cut out on both sides of the box (0.05 × 0.15 m opening, 0.04 m below the top edge).

2.3. Equipment

The equipment used to perform the lifting experiment consisted of a sturdy wooden frame with two platforms. The frame has holes at regular intervals to facilitate height adjustments for the platforms. The dimensions of the wooden frame are 2.50 × 1.30 × 1.20 m, with a two-piece base with dimensions of 1.30 × 0.09 × 0.035 m. The platform has dimensions of 1.14 × 0.76 × 0.10 m. Metallic cylindrical pieces of different unknown weights were used for the purpose of loading the wooden box for the lifting task.

2.4. Experimental Procedure

The 7 male participants were divided into two groups. Group I comprised of 4 participants and Group II consisted of 3 participants. Group I performed Experiment I first and then Experiment II, whereas Group II performed Experiment II first and then Experiment I. The order of experiments for both cases was completely randomized. The experiment was conducted in two sessions. In Session I (Experiment I), MAWOL was determined without the mental task for each participant using the psychophysical method (Aghazadeh & Ayoub, 1985). The experimental procedure was identical for each participant.

Subsequent to anthropometric measurements, and on a different day, participants were instructed in the lifting procedure. Participants performed all combinations to determine the maximum acceptable weight for each lifting task. The participants followed recorded bell sounds that rang at a frequency of 2, 4, or 8 lifts/min. The participants were asked to lift at each bell sound from the three different lifting heights. Two research assistants lowered the box before the next lift. Each lifting task was repeated two times, with light and heavy loads. The average of the two was used for analysis. The initial weight in the box was selected randomly and was either very light (approximately 3 kg) or very heavy (approximately 45 kg), and the participants were permitted to make adjustments to this initial weight by adding or removing weights, in order to arrive at MAWOL. They were asked to assume an 8-hr work shift, including breaks, and make as many adjustments as necessary to arrive at the maximum weight they thought they could lift comfortably, without straining themselves, or without becoming unusually tired, weakened, overheated, or out of breath (Aghazadeh & Ayoub, 1985). No incentives or emotional appeals were given. Participants were encouraged to make as many adjustments as they wished, and were reminded to project their selections into an 8-hr shift. The entire adjustment process took about 20 min, at the end of which the weight was recorded as MAWOL for that participant.

The aforementioned procedure was repeated for all nine conditions of lifting for each participant. Nine conditions consisted of three different heights and three different frequencies. The same nine conditions were repeated adding the mental task. For each participant, operations were performed in random order and data were collected over a period of several days. During the experiment, participants wore comfortable clothes. In Session II (Experiment II), a mental task was added to the physical task. Questions were asked through the cassette recorder while the participants performed the physical tasks. MAWOL was recorded in the case of lifting in the same way as in Session I.

3. RESULTS

3.1. Analysis of Data for the Lifting Task

Means and standard deviations of MAWOL for the nine task conditions without and with the mental task are given in Table 2.

Figure 1 shows the general trend in the loads lifted for different lifting heights at 2, 4, and 8 lifts/min, respectively. Similarly Figure 2 shows the general trend in the loads lifted at various frequencies for floor-knuckle, knuckle-shoulder, and shoulder-reach lifting heights.

A paired *t* test with participants as blocks was utilized to conduct the analysis. Participants lifted less weight when a mental task was added to the physical task (Table 2). Statistically, the paired *t* test conducted showed no significant difference at 5% significance level (alpha = .05).

TABLE 2. Means and Standard Deviations (kg) of MAWOL (maximum acceptable weight of lift) Data for Different Lifting Tasks With (W) and Without (W/O) the Mental Task

	Lifting Frequency (lifts/min)		
Lifting Height	**2**	**4**	**8**
Floor-knuckle (W/O)	8.46 (1.23)	9.12 (0.47)	7.38 (0.86)
Floor-knuckle (W)	8.51 (0.81)	8.70 (0.63)	7.24 (1.01)
Knuckle-shoulder (W/O)	9.18 (0.97)	8.20 (0.56)	7.20 (1.46)
Knuckle-shoulder (W)	8.51 (0.94)	7.70 (1.22)	6.95 (1.17)
Shoulder-reach (W/O)	6.65 (1.23)	6.35 (1.23)	6.18 (1.57)
Shoulder-reach (W)	6.47 (0.65)	6.60 (0.65)	5.65 (0.69)

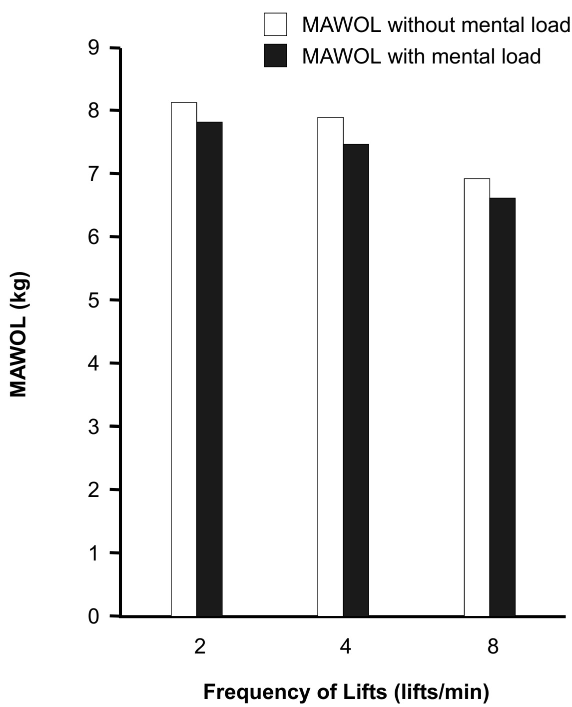

Figure 1. Comparison of MAWOL (maximum acceptable weight of lift) at different frequencies of lift.

The data was further analyzed to study the effect of lifting height on the physical capability of the person with (W) and without (W/O) the mental task. The results indicated no significant difference between the load lifted without and with the mental task for floor-knuckle lifting height: 8.32 (W/O) and 8.15 (W); $t = 0.73$, $p < .4713$. The results did show a significant

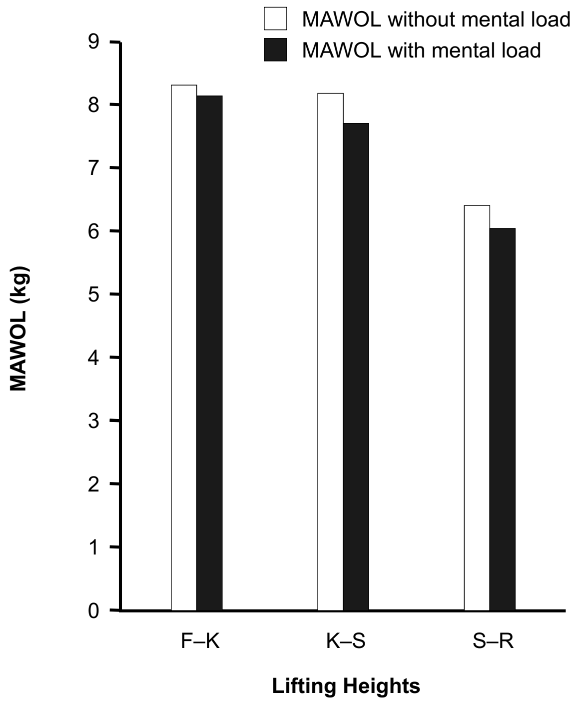

Figure 2. Comparison of MAWOL (maximum acceptable weight of lift) at different lifting heights.

difference between the loads lifted without and with the mental task for knuckle-shoulder lifting height: 8.19 (W/O) and 7.72 (W); $t = 3.05$, $p < .0062$; and shoulder-reach lifting height: 6.40 (W/O) and 6.05 (W); $t = 2.097$, $p < .0488$. The conclusion drawn from this analysis is that mental load affects the capability of a participant when lifting from knuckle to shoulder and shoulder to reach lifting heights and that the results are statistically significant at alpha = .05 level of confidence.

The data was also analyzed to see whether the frequency of lift affects the physical capability of a person without and with the mental task. The results showed that there is no significant difference between the load lifted without and with the mental task for 2 lifts/min: 8.14 kg (W/O) and 7.83 kg (W); $t = 1.18$, $p < .2488$; and 8 lifts/min: 6.92 kg (W/O) and 6.61 kg (W); $t = 1.79$, $p < .0876$. The results indicated a significant difference between the loads lifted without and with the mental task for 4 lifts/min: 7.90 kg (W/O) and 7.47 kg (W); $t = 2.469$, $p < .0227$. Thus, the load lifted at 4 lifts/min without the mental task was 7.90 kg and with the mental task was 7.47 kg. The reduction in the weight lifted was significant statistically at .05 level of confidence.

3.2. The Lowering Task

The same psychophysical methodology was used to determine the MAWOL for the lowering task. The independent variables were the height and frequency of lowering, and the dependent variable was the amount of the lowered load (MAWOL). Means and standard deviations of MAWOL without and with the mental task are given in Table 3.

Figure 3 shows the comparison of the MAWOL with and without the mental task. MAWOL increased on addition of the mental task: 7.44 kg

TABLE 3. Means and Standard Deviation (kg) of MAWOL (maximum acceptable weight of lift) Data for Lowering Task Without (W/O) and With (W) the Mental Task

Lowering Height	Lowering Frequency (lifts/min): 4
Shoulder-knuckle (W/O)	7.44 (0.805)
Shoulder-knuckle (W)	7.97 (1.470)

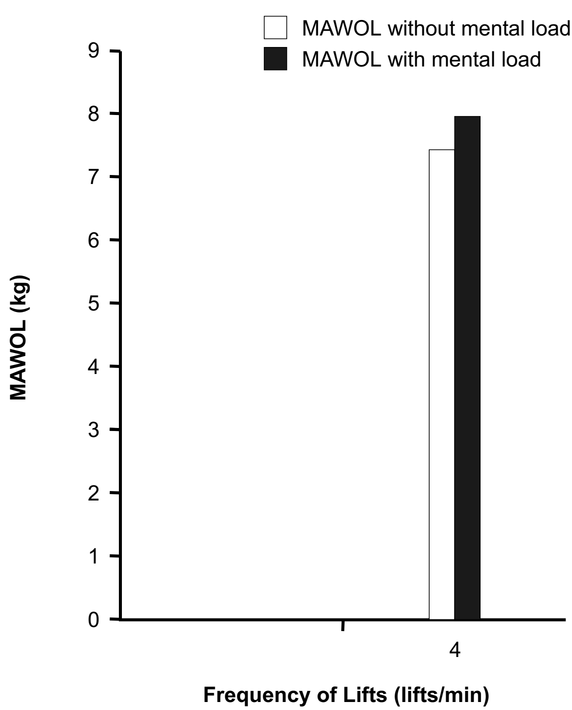

Figure 3. Comparison of MAWOL (maximum acceptable weight of lift) for shoulder to knuckle lowering task.

(W/O) and 7.97 kg (W). A paired *t* test was conducted on the data to test the difference is statistically significant. The test indicated that there is not a significant difference ($t = -1.48$, $p < .1871$) at 5% significance level (alpha = .05).

3.3. Treadmill Task

The participants were instructed to walk at different speeds on a treadmill but at the same gradient level. The participants walked at different speeds for 4 min and heart rate values exactly at the end of the 4th minute were noted down, both without and with the mental task.

Means and standard deviations of heart rate for the three task conditions without and with the mental task are given in Table 4.

TABLE 4. Means and Standard Deviations of Heart Rate for Three Different Speeds Without (W/O) and With (W) the Mental Task

Speed of the Treadmill	Gradient (0.5º)
1 m/s (W/O)	87.57 (3.55)
1 m/s (W)	94.71 (11.01)
2 m/s (W/O)	94.57 (4.68)
2 m/s (W)	102.42 (14.15)
3 m/s (W/O)	106.42 (10.96)
3 m/s (W)	111.71 (12.73)

Figure 4 shows the comparison of heart rate for the three different speeds. As it is clear from Table 4, heart rate for the participants increased as the speed increased. Furthermore the figure also indicates that heart rate increased on addition of the mental task (Figure 4): at 1 m/s, 87.57 (W/O) and 94.71 (W); at 2 m/s, 94.57 (W/O) and 102.42 (W); at 3 m/s, 106.42 (W/O) and 111.71 (W).

The paired *t* test conducted on the heart rate data collected showed that there is no significant difference in the values of heart rate without and with the mental task, whether the participant runs at 1 m/s: 87.57 (W/O) and 94.71 (W); $t = -1.38$, $p < .2153$; or at the speed of 2 m/s: 94.57 (W/O) and 102.42 (W); $t = -1.36$, $p < .2211$; or at 3 m/s: 106.42 (W/O) and 111.71 (W); $t = -0.696$, $p < .5121$, at 5% significance level (alpha = .05).

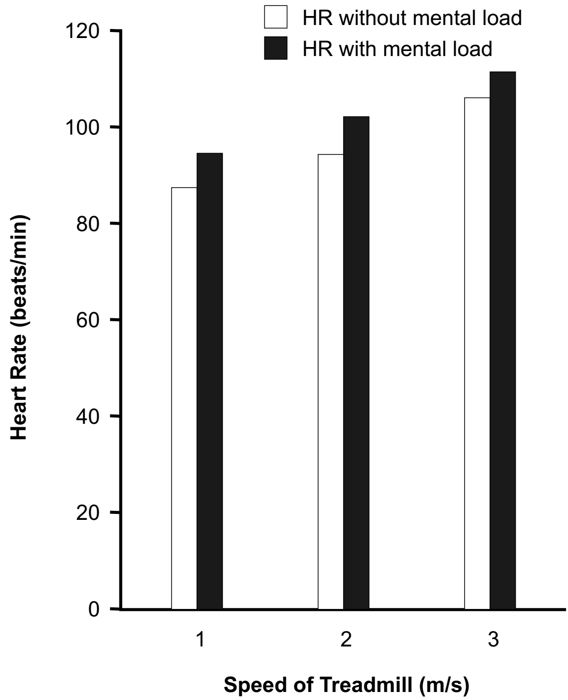

Figure 4. Comparison of HR (heart rate) for the treadmill task.

4. CONCLUSIONS

The study evaluates the effect of a mental task on MAWOL (psychophysical effect), in the case of lifting and lowering activities, and on heart rate (physiological effect) in the case of walking on a treadmill. In the case of the lifting task, the load lifted by the participants decreased on addition of the mental task while lifting from knuckle to shoulder and shoulder to reach lifting heights. Further, the capacity of the participant decreased when lifting at 4 lifts/min on addition of the mental task. For all other combinations, although the capacity decreased while lifting with the mental task, the differences were not significant statistically. In the case of the lowering task, although the capacity of the participants increased with the addition of the mental task, the difference was not significant statistically at 95% confidence interval.

For the physical task of walking on a treadmill, the general indicative trend was an increase in heart rate of the participant with the addition of the mental task. The results were not statistically significant at 95% confidence interval.

In summary, the analysis of the data shows that the mental task affects the physical capability of a person both psychophysically and physiologically. Although the results were not statistically significant in the case of the treadmill task, a further study might prove otherwise. The mental task as another parameter needs to be considered for future lifting standards.

REFERENCES

Aghazadeh, F., & Ayoub, M.M. (1985). A comparison of dynamic and static strength models for predicting lifting capacity. *Ergonomics, 28*(10), 1409–1417.

Aghazadeh, F., & Mital, A. (1987). Psychophysical lifting capabilities for overreach heights. *Ergonomics, 30*(6), 901–909.

Asfour, S.S., Ayoub, M.M., & Mital, A. (1984). Effects of an endurance and strength training program on lifting capability of males. *Ergonomics, 27*(4), 435–442.

Ayoub, M.M., Mital, A., Asfour, S.S., & Bethea, N.J. (1980). Review, evaluation, and comparison of models for predicting lifting capacity. *Human Factors, 22*(30), 257–269.

Davey, C.P. (1973). Physical exertion and mental work. *Ergonomics, 16*, 595–599.

Dolan, P., & Adams, M.A. (2000). When do bending stresses on the spine rise to damaging levels? In *Proceedings of the International Ergonomics Association 2000/Human Factors Engineering Society 2000 Congress* (Vol. 4, pp. 635–638). Santa Monica, CA, USA: Human Factors and Ergonomic Society.

Flynn, R. (1972). Numerical performance as a function of prior exercise. *Research Quarterly, 11*, 86–95.

Gutin, B., & Di Gennaro, J. (1968). Effect of treadmill run to exhaustion on performance of simple addition. *Research Quarterly, 39*, 958–964.

Kansas Department of Human Resources. (2000). *Workers compensation, 26th annual report, fiscal year 2000*. Topeka, KS, USA: Author.

Lu, H., & Aghazadeh, F. (1994). Psychophysical determination and modeling of load carrying capacity. *International Journal of Industrial Ergonomics, 13*, 51–65.

Lybrand, W., Andrews, T., & Ross, S. (1954). Systematic fatigue and perceptual organization. *American Journal of Psychology, 67*, 704–707.

McAdam, R., & Wang, Y. (1967). Performance of a mental task following various treatments. *Research Quarterly, 38*, 208–212.

McGill, S.M., & Norman, R.W. (1993). Low back biomechanics in industry: The prevention of injury through safer lifting. In M.D. Grabiner (Ed.), *Current issues in biomechanics* (pp. 69–120). Champaign, IL, USA: Human Kinetics.

McGlynn, G.H., Laughlin, N.T., & Rowe, V. (1979). The effect of increasing levels of exercise on mental performance. *Ergonomics, 22*, 407–414.

Mital, A. (1983). The psychophysical approach in manual lifting—A verification study. *Human Factors, 25*(5), 485–491.

National Academy of Sciences. (2001). *Musculoskeletal disorders and the workplace: Low back and upper extremities.* Washington, DC, USA: National Academy Press.

National Institute for Occupational Safety and Health (NIOSH). (1994). *Application manual for the revised NIOSH lifting equation*. Cincinnati, OH, USA: Center for Disease Control.

National Safety Council (NSC). (1993). *Accident facts*. Chicago, IL, USA: Author.

Nicholson, L.M., & Legg, S.J. (1986). A psychophysical study of the effects of load and frequency upon selection of workload in repetitive lifting. *Ergonomics, 29*(7), 903–911.

Occupational Safety and Health Administration (OSHA). (1992). *OSHA technical manual* (TED 1-0.15A). Washington, DC, USA: Author.

Roebuck, J.A., Kroemer, K.H.E., & Thompson, W.G. (1975). *Engineering anthropometry methods*. New York, NY, USA: Wiley.

Snook, S.H. (1978). The design of manual handling tasks. *Ergonomics, 21*, 963–985.

Tomprowski, P.D., Ellis N.D., & Stephens R. (1987). The immediate effects of strenuous exercise on free-recoil memory. *Ergonomics, 30*, 121–129.

Wu, S., & Chen, C. (2001). Psychophysical determination of load carrying for 1-h work period by Chinese males. *Ergonomics, 44*(11), 1008–1023.