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Reliability of the psychophysical approach to manual lifting of liquids by females

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The psychophysical method for setting lifting standards was evaluated by having seven, female college students lift at four different frequencies (1, 3, 6 and 12 lifts min^{-1}). Only one lifting session was performed in a 24 hour period. During the 4 hour lifting task, subjects were asked to select the amount of water that they believed they could lift comfortably for 8 hours. Subjects were encouraged to make as many weight changes as they needed. Each time the weight was changed the carton was weighed and the time was recorded. At 15 min intervals, subjects were asked about their degree of confidence (DOC) that the current weight was the maximum acceptable one for an 8 hour shift. Oxygen consumption was measured at 30, 120 and 240 min of the task. The weights chosen by the subjects at 30 min did not differ significantly from the 4 hour values for frequencies of 1, 3 and 6 lifts min^{-1}. However, at 12 lifts min^{-1} the weight decreased with time such that the 4 hour value was 23% lower than the weight chosen after 30 min. DOC increased over time and did not differ significantly between frequencies. Oxygen consumption was unchanged over time and accounted for 19, 25, 35 and 45·5% of $\dot{V}O_2$ max for frequencies 1, 3, 6 and 12 lifts min^{-1}, respectively. It was concluded that the psychophysical method in its present form should not be used to set lifting standards for frequencies higher than 6 lifts min^{-1}.

1. Introduction

The psychophysical methodology devised by Snook and Irvine (1967, 1968, 1969) has been broadly used in the past to determine the maximum acceptable workloads in both repetitive and occasional manual handling tasks. The method requires the subject to imagine working on the incentive basis and to select the maximum weight of load which can be comfortably lifted for a projected 8 hour workday, based on the individual's feelings of exertion, i.e. without getting overheated, out of breath or unusually tired (Snook and Ciriello 1974). Subjects are encouraged to make adjustments by adding or removing weight (usually lead shots); the number of adjustments is unlimited. Training may also be provided to ensure that the subjects gain sufficient experience in monitoring their feelings so they can make appropriate adjustments.

The main thrust of the psychophysical method is an assumption that given the adjustment time of 40 min (Snook and Irvine 1968), a person is capable of predicting the maximum comfortable weight he/she would be willing to lift or handle over a period of 8 hours. In other words, the method requires mapping of the subject's feelings about the weight lifted from a short period of time onto 'a normal 8 hour shift that allows [one] to go home without feeling bushed' (Snook and Ciriello 1974). However, relatively few studies have actually investigated whether the weight chosen during the 40 min period could be continuously lifted for extended periods of time.

Legg and Myles (1981) evaluated reproducibility of the psychophysical method for application in military ergonomics. In their experiment, 10 soldiers were allowed 20 min to select the maximum acceptable weight limit (MAWL). Subsequently, they were asked to lift that load without making further adjustments, for 8 hours during five consecutive days. Based on physiological measurements and subjective assessment of fatigue, it was concluded that the psychophysical method could be used to identify loads that can be lifted for an 8 hour day without undue fatigue.

Mital (1983) conducted a study to verify the psychophysical methodology as used for determining lifting capacity of industrial workers. A 25 min period was used by male and female subjects to select the MAWL for the simulated 8 hour shift. An additional 20 min of adjustments were allowed to simulate a 12 hour shift. Subjects were then asked to lift these weights for 8 and 12 hour shifts with the possibility of making further adjustments. Male subjects lifted about 65% (for an 8 hour day) and 61% (for a 12 hour day) of their estimated MAWL, while females lifted 85 and 77% of their estimated MAWL for 8 and 12 hour shifts, respectively. Although the rate of decrease of MAWL was not linear, Mital (1984) suggested that for female workers a 2% per hour decrease was a reasonable estimate. However, no information was given on whether this rate of decrease was uniform for all frequencies used, i.e. 1, 4, 8 and 12 lifts min^{-1}.

Based on a study performed at the Liberty Mutual Research Center, Ciriello and Snook (1983) concluded that 'The psychophysical technique produces overestimates of maximum acceptable weights and forces for the tasks with very high frequencies.' Similar results were reported by Karwowski and Ayoub (1984) for frequencies of 9 and 12 lifts min^{-1}. Nicholson and Legg (1984) indicated that the frequency of lifting was more appropriate manipulative variable than the load in psychophysical experiments aimed at determination of maximum acceptable workloads.

Recently, Karwowski and Yates (1984) re-examined the psychophysical approach to manual lifting by taking into consideration the effect of time on the amount of liquid selected at two levels of frequency (4 and 8 lifts min^{-1}). At 4 lifts min^{-1} they found no change in the maximum amount of weight lifted by female subjects from 20 min to 4 hours. However, at 8 lifts min^{-1} the maximum acceptable amount of liquid decreased with time from 10·43 kg at 20 min to 7·9 kg at 4 hours.

The above results suggest that the psychophysical methodology as applied to manual lifting may be reliable only for low/moderate frequencies. The primary objective of this study was to investigate this conclusion further, by considering the effect of time on the weight selected, at four different lifting frequencies.

The ability of human subjects to project the weight lifted for a short period of time as the maximum acceptable weight for an 8 hour shift may be critical in verifying reliability of the psychophysical method. Therefore, the second objective of this study was to investigate the degree of confidence to which the subjects believed they selected the maximum amount of weight that can be lifted comfortably over a period of 8 hours.

2. Methods and procedures

Seven, physically active, female college students voluntarily participated in this experiment. The subjects were given medical examinations and were judged to be in a good health. The subjects were paid for their work on an hourly basis. Each subject

Table 1. Age, physical characteristics and strength of the subjects*.

	Mean	S.D.	Range
Age (years)	22·3	1·5	20–26
Body weight (kg)	55·6	6·9	47·1–63·6
Stature	164·8	8·3	154·9–179·1
Shoulder height	137·6	8·2	127·6–151·6
Iliac crest height	96·4	6·5	87·0–107·4
Shoulder breadth	39·7	4·3	34·1–44·5
Elbow flexion strength	20·6	2·7	19·5–24·0
Shoulder flexion strength	27·4	2·9	21·7–31·2
Back extension strength	59·0	9·4	38·5–70·2
Composite strength	73·3	5·8	64·7–80·6
$\dot{V}O_2$ max ($l\,O_2\,min^{-1}$)	1·92	0·23	1·5–2·2
$\dot{V}O_2$ ($ml\,O_2\,kg^{-1}\,min^{-1}$)	34·8	4·8	26·6–41·9

* All anthropometric data are in centimetres and all strength data are in kilogrammes.

read and signed an informed consent form prior to beginning the project. Several of the subjects had participated in a previous experiment using the same procedures (Karwowski and Yates 1984), and therefore were very familiar with the lifting task. The remaining subjects were active individuals experienced in lifting tasks. These subjects were throughly familiarized with the experimental task and participated in two to four sessions before beginning the lifting task.

Age, body weight, isometric strengths and anthropometric characteristics of the subjects are given in table 1. The strength measurements were made in accordance with procedures described by Chaffin (1975). The maximum aerobic capacity ($\dot{V}O_2$ max) was determined using a graded exercise treadmill test.

The lifting procedure was essentially the same as the one used in Karwowski and Yates (1984). The subjects were asked to lift a standard milk carton (33 cm × 33 cm × 27 cm) made of plastic, from the floor to 76 cm above the floor. The handles were located 19·7 cm above the bottom of the carton. The carton contained four milk jugs partially filled with water, each with a maximum capacity of 3·78 l. The top of the carton was covered with cardboard, such that the amount of liquid in the jugs was not known to the subject. The weight of the carton with empty jugs (low load) was 3·25 kg, while the maximum weight of the full carton (high load) was 21 kg. The starting load was selected randomly as either *low* or *high* for each experimental trial as recommended by Snook and Irvine (1967).

Four levels of frequency, 1, 3, 6 and 12 lifts min^{-1} with one replication of each, were used. The order of treatments was randomized, and in most cases 1 day was allowed between experimental runs for recovery. Dry-bulb temperature (20·5–22°C) and relative humidity (42–48%) were controlled. The subjects were allowed to utilize a free style of lift. The instructions given to them were basically the same as proposed by Snook and Ciriello (1974). None of the subjects was allowed to perform any of the lifting sessions during the menstrual period.

During the psychophysical experiment, subjects continuously project the weight lifted into the 8 hour period, such that a considerable mental effort is required (Legg and Haslam 1984). Although the mental load cannot be eliminated, it is possible to release the subject from the effort of actually changing the weight in the container. Therefore, one modification in the process of making weight adjustment was introduced. At any time the subject wished to change the load lifted, she asked a 'helper' to make the appropriate adjustments. Eight verbal levels of increase/decrease were allowed: 'a lot', 'much', 'some', and 'a little' more/less weight. These descriptors were translated into increments/decrements of approximately 1·8, 0·9, 0·45 and 0·225 kg, respectively. All 64 containers, available for making adjustments, were labelled using one of 16 levels of water which resulted in weight increments of approximately 0·225 kg. Each time a change was made the carton was weighed and the weight was recorded along with the time of the change.

A randomized complete block factorial design was used, with time and frequency of lift as independent variables. The dependent variables were weight selected, oxygen uptake, heart rate, rate of perceived exertion (RPE), and subjective assessments of fatigue and the degree of confidence (DOC). The subjects were given 30 min to make their initial weight determination. Following this period the subjects continued lifting, having the option to make further adjustments, for 210 min, with a 15 min break after 2 hours. Subjects were encouraged to make as many adjustments as they wished, and were reminded to project their selections into an 8 hour shift.

Expired air was collected in meteorological balloons for 4 min at times (T) of 30, 120 and 240 min in order to determine oxygen consumption. Oxygen and carbon dioxide contents were measured using an Applied Electrochemistry and Beckman LB-2 analysers, respectively. Gas volumes were measured with a Collins tissot spirometer. $\dot{V}O_2$ rates were expressed as litres per minute and were corrected to standard temperature and pressure of dry gas (STPD).

Prior to the air collections, subjects were asked to estimate their subjective DOC regarding the appropriateness of the weight selected for an 8 hour shift. A 10 cm scale, labelled 'completely uncertain' on the left and 'absolutely sure–positive' on the right was used. A similar scale with 'very relaxed' and 'extremely tired' values on the ends was used to assess their subjective feelings of fatigue. In addition to these evaluations, heart rate and RPE values (Borg 1971) were recorded every 15 min during the entire period of lifting.

Experimental data were analysed using a two-way analysis of variance (ANOVA) with repeated measures on both frequency and time. When significant differences were found, the Newman–Kuels test was used for *post-hoc* comparisons. An alpha $p = 0.05$ was selected as the minimum level of significance.

3. Results

3.1. *The effects of time and frequency on weight lifted, oxygen uptake and heart rate*

The ANOVA showed a significant interaction between frequency and time, therefore, a separate ANOVA for each of the simple effects was performed (Huck *et al.* 1974). The changes in maximum acceptable amounts of liquid lifted over time are illustrated in figure 1. For frequencies of 1, 3 and 6 lifts min^{-1} the time effect on the MAALs was not significant. However, there was a significant decline over time in the maximum amount of liquid lifted with a rate of 12 lifts min^{-1} ($F = 2.36$, $p < 0.05$).

At the end of 4 hours all levels of frequency showed significantly different values of MAAL. On the average, at $T = 240$ min, 13·74, 11·71, 9·69 and 7·19 kg of water were lifted at rates of 1, 3, 6 and 12 lifts min^{-1}, respectively (see table 2).

Although there was no significant time effect on the oxygen uptake, there was a difference in the metabolic energy expenditure rate due to frequency ($F = 43.3$, $p < 0.001$). Similar results were observed for heart rate, which varied considerably between frequencies of lift ($F = 18$, $p < 0.001$). At $T = 240$ min the heart rates for 3 and 6

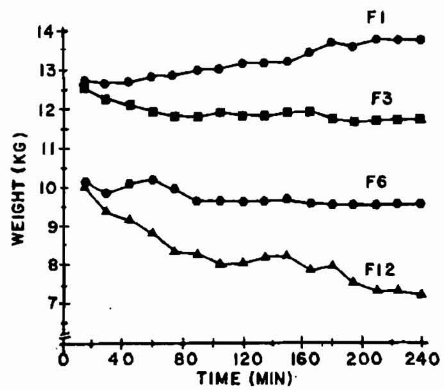

Figure 1. Changes in the maximum acceptable amounts of liquid lifted over time.

Table 2. Summary of the experimental results.

	Frequency (lifts min^{-1})	$T = 30$ min	$T = 120$ min	$T = 240$ min
Weight selected (kg)	1	12·60 ± 1·76	13·12 ± 1·66	13·74 ± 2·19
	3	12·20 ± 2·72	11·78 ± 2·59	11·71 ± 2·75
	6	9·83 ± 2·56	9·59 ± 1·31	9·49 ± 1·17
	12	9·33 ± 3·35	8·02 ± 2·54	7·19 ± 1·42
Oxygen uptake $\dot{V}O_2$ (l min^{-1})	1	0·36 ± 0·05	0·34 ± 0·03	0·36 ± 0·30
	3	0·50 ± 0·05	0·48 ± 0·07	0·48 ± 0·06
	6	0·72 ± 0·08	0·67 ± 0·08	0·64 ± 0·07
	12	0·90 ± 0·18	0·87 ± 0·20	0·87 ± 0·13
Percentage of $\dot{V}O_2$ max	1	18·8 ± 3·3	18·1 ± 2·1	18·9 ± 1·9
	3	24·1 ± 3·9	25·4 ± 3·4	25·0 ± 2·1
	6	37·4 ± 4·5	35·3 ± 0·6	34·8 ± 3·5
	12	47·9 ± 11·2	46·5 ± 10·1	45·5 ± 5·3
Heart rate (beats min^{-1})	1	99 ± 11	94 ± 12	98 ± 13
	3	108 ± 13	106 ± 11	111 ± 13
	6	114 ± 13	115 ± 8	115 ± 5
	12	141 ± 18	126 ± 16	132 ± 9
RPE (Borg 1971)	1	9·3 ± 2·7	10·0 ± 2·1	10·7 ± 2·3
	3	10·4 ± 1·5	11·7 ± 1·1	12·4 ± 1·4
	6	10·7 ± 1·6	12·1 ± 1·6	12·3 ± 0·8
	12	12·4 ± 2·6	14·0 ± 2·5	15·0 ± 2·3
Subjective degree of fatigue	1	1·1 ± 0·7	3·4 ± 1·7	4·4 ± 2·4
	3	2·6 ± 1·5	3·7 ± 1·9	5·3 ± 2·0
	6	2·3 ± 1·6	4·6 ± 1·1	6·0 ± 1·2
	12	4·0 ± 2·2	6·0 ± 2·2	7·1 ± 1·8
Subjective degree of confidence	1	4·6 ± 2·3	5·9 ± 2·4	8·1 ± 1·1
	3	5·4 ± 1·7	6·3 ± 1·7	8·3 ± 1·3
	6	4·0 ± 1·5	6·1 ± 0·7	8·3 ± 1·0
	12	5·4 ± 2·6	7·3 ± 1·9	8·3 ± 1·3

lifts min^{-1} (110·9 and 114·6 beats min^{-1}, respectively) were not significantly different from each other. The average heart rates observed at frequencies of 1 and 12 lifts min^{-1} were 98·4 and 132 beats min^{-1}, respectively.

3.2. *Subjective assessments of fatigue and the degree of confidence*

The analysis of variance for RPE values indicated that there was a significant effect of time ($F = 19{\cdot}3$, $p < 0{\cdot}001$) and frequency of lift ($F = 4{\cdot}47$, $p < 0{\cdot}05$) on the RPE expressed on the Borg scale (1971). The subjective degrees of fatigue also increased with time ($F = 26{\cdot}98$, $p < 0{\cdot}001$), and were higher for higher lifting rates ($F = 4{\cdot}7$, $p < 0{\cdot}05$).

Results for both, the degree of fatigue and the RPE (values of which correlated with each other, $r = 0{\cdot}886$) are shown in figure 2. On the average, the subjects perceived their effort at being close to 'fairly light' (or 10·7), 'somewhat hard' (or 12·42 and 12·28) and 'hard' (or 15), when lifting with rates of 1, 3, 6 and 12 lifts $\min^{-1}$, respectively.

There was a significant time effect ($F = 74{\cdot}7$, $p < 0{\cdot}001$), but no frequency effect, on the subjects' DOC that the selected MAALs could actually be lifted for an 8 hour shift. Although statistically insignificant at the $p = 0{\cdot}05$ level, it can be seen (figure 3) that there was a difference in the pattern of DOC for lifting rates of 1, 3 and 6 lifts $\min^{-1}$, and the one corresponding to 12 lifts $\min^{-1}$. At $T = 120$ min the subjects were more convinced that they selected the appropriate value of MAAL for an 8 hour lift when lifting at 12 lifts $\min^{-1}$ than lifting at lower frequencies.

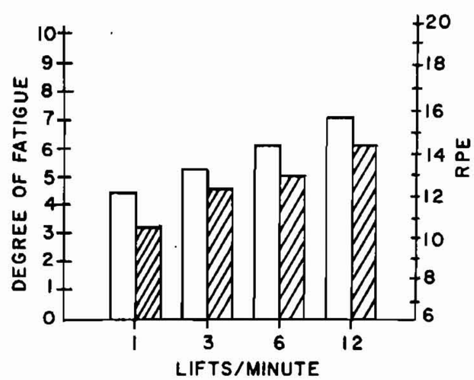

Figure 2. Subjective degrees of fatigue and RPE values.

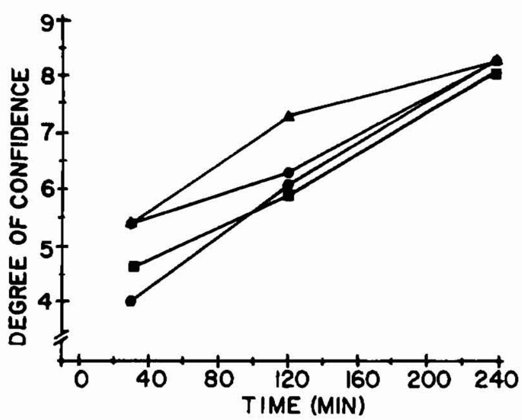

Figure 3. Changes in the degrees of confidence versus time (■, 1 lift $\min^{-1}$; ●, 3 lifts $\min^{-1}$; ●, 6 lifts $\min^{-1}$; ▲, 12 lifts $\min^{-1}$).

4. Discussion

4.1. *The effects of time on MAAL*

The results of this study show that there were no significant changes in MAALs when lifting with rates of 1, 3 and 6 lifts $\min^{-1}$. However, the psychophysical weight lifted 12 times per minute (see figure 1) significantly decreased over time. This decline was approximately 23% (from 9·33 kg at $T=30$ min to 7·19 kg at $T=240$ min). A linear regression was used to fit the actual values of MAAL in order to express the rate of decline over time. The following equation which explains 94·9% of the variance (standard error of 0·21) was found:

$$\text{weight (kg)} = 9{\cdot}304 - 0{\cdot}00908 \times \text{time (min)}$$

According to the above equation, the maximum amount of liquid lifted between $T=30$ min and $T=240$ min decreased at a rate of approximately 5·85% per hour. Mital (1983) reported a uniform decline in the maximum acceptable weight for all lifting frequencies (1, 4, 8 and 12 lifts $\min^{-1}$) between 25 min and 12 hours of approximately 2% per hour. An estimated decline in weight lifted during the first 4 hours was about 11%. Since the average responses for all frequencies were considered, it is possible that the actual decline in weight lifted at rates of 1 and 4 lifts $\min^{-1}$ was negligible, and the decrease was present only for higher frequencies. This conclusion can be supported by the results of our earlier study (Karwowski and Yates 1984) when a 24% decline in MAAL lifted between $T=20$ and $T=240$ min was observed (approximately 6% per hour) for the frequency of 8 lifts $\min^{-1}$.

Despite the fact that the RPE values (Borg 1971) correlated well with the subjective degree of fatigue (Pearson $r=0{\cdot}886$), the correlation between heart rate and corresponding RPE values was not significant. It should be recalled here that according to Borg (1982), the RPE values and the heart-rate measures complement each other, and both should be used as an indicator of strain. The correlation between heart rates and degrees of fatigue was significant ($r=0{\cdot}476$, $p<0{\cdot}05$). Also, the RPE values and degrees of fatigue significantly correlated with the DOC ($r=0{\cdot}604$ and 0·884, respectively).

Although the DOC that the weights selected could actually be lifted over an 8 hour shift increased over time for all frequencies, the 30 min period seems to be sufficient for females to determine the maximum amount of liquid to be lifted for 4 hours with rates of 1, 3, 4 and 6 lifts $\min^{-1}$. These results agree with the study by Snook and Irvine (1968) on the maximum frequency of lift acceptable to industrial workers. The psychophysically determined lifting rates (from floor level to knuckle height) were estimated from the reported maximum workloads. When continuously lifting the weights of 22·6 and 15·8 kg the selected rates were $3{\cdot}8 \pm 1{\cdot}1$ and $4{\cdot}2 \pm 0{\cdot}83$ lifts $\min^{-1}$ for the above weights, respectively. Despite the fact that male subjects were used, the lifting rates chosen were very close to the frequencies employed in the present study that resulted in no significant decline in MAALs over a period of 4 hours.

However, the 30–40 min allowed by the psychophysical method for weight selection cannot be justified for higher frequencies of lift. First, it seems that the method, as originally proposed by Snook and Irvine (1968), was not intended for the high frequencies of lift, since the reproducibility of results (reported to be within $\pm 15\%$ of the weights obtained in the first trial) was confirmed only for low lifting rates. In the present study, at $T=30$ min the average differences between MAALs first selected and the second trial were 9·6, 8, 0·4 and 35·6% for rates of 1, 3, 6 and 12 lifts $\min^{-1}$, respectively. At $T=240$ min these differences were 4·8, 9·4, 0·5 and 15·7%, for the above frequencies, respectively. Secondly, DOC increased on the average from 4·9 at $T=30$ min to 8·2 at

$T = 240$ min. However, DOC was not different between frequencies, despite the fact that MAAL decreased significantly over time when lifting with rates of 8 (Karwowski and Yates 1984) and 12 lifts min^{-1}. Therefore, the assumption that a person can project the weight selected at $T = 30$ or 40 min into an 8 hour shift, cannot be supported for higher frequencies of lift.

The results of this study indicate that subjects monitor different factors in determining their MAAL at high lifting frequencies than they do at low lifting frequencies. Further evidence of this fact comes from the metabolic requirements of the lifting task as measured by oxygen consumption. The average values of oxygen uptake remained stable, and were approximately 18·9, 25, 34·8 and 45·5% of $\dot{V}O_2$ max, when lifting at rates of 1, 3, 6 and 12 lifts min^{-1}, respectively. The value reported at 12 lifts min^{-1} is comparable to that reported by Evans *et al.* (1980) for 1·5 hours of hard self-paced work. They reported that both males and females tended to choose an energy output level that corresponded to approximately 45% of their $\dot{V}O_2$ max. However, this level of energy expenditure cannot be maintained for long. Williams *et al.* (1982) reported evidence of fatigue in female subjects working in 50% of their $\dot{V}O_2$ max while lifting a 15·9 kg box. In the study by Myles *et al.* (1979) the self-pacing subjects working for 6·5 hours selected on the average an exercise level corresponding to about 36% of their $\dot{V}O_2$ max which is almost 10% lower than the value reported here. The conclusion to be reached from this discussion is that the psychophysical method is not reliable for setting lifting guidelines at frequencies above 6 lifts min^{-1}.

This conclusion is supported further when one considers the heart rates produced by the various lifting frequencies. It has often been suggested that heart rate should not exceed 110 beats min^{-1} for an 8 hour shift (Brouha 1967). However, as is clear for the data shown in table 2, in this study the subjects worked consistently at heart rates of 130 beats min^{-1} when performing 12 lifts min^{-1}. This inability to judge the strain of the task may be due to the increased metabolic demand with a simultaneous decrease in muscular tension. At high lifting frequencies (above 6 lifts min^{-1}) movement of the body alone will result in a relatively high oxygen consumption. This may cause the subjects to misjudge the MAAL because they are cueing on muscle tension instead of the metabolic demands.

4.2. *Physiological cost of lifting—recommendations*

Based on the above results, recommendations for the upper limit of metabolic energy expenditure for females lifting continuously over a 4 hour period can be made. So far such limits have been proposed for male populations only. Petrofsky and Lind (1978 a, b) suggested a 25% $\dot{V}O_2$ max limit (based on a cycle ergometer test) for lifting boxes over 1–4 hour periods. Using a lifting frequency of 2·5 lifts min^{-1}, Legg and Myles (1981) concluded that a workload of 21% $\dot{V}O_2$ max (treadmill) was the acceptable upper limit for an 8 hour day. In a recent study, Legg and Pateman (1984), indicated that '23% $\dot{V}O_2$ max (treadmill) should be adopted as a guide to the maximum load lifting rate combination that will not induce fatigue over an 8 hour work day'. Mital (1984) reported that the female subjects worked at 28% of their average aerobic capacity at the end of an 8 hour shift. However, this finding refers to the average of all frequencies used (1, 4, 8 and 12 lifts min^{-1}), and the values of average aerobic capacities were estimated rather than measured. The above results are similar to the 25% (present study) and 28% $\dot{V}O_2$ max (Karowowski and Yates 1984), and lead us to suggest this range as the upper limit of energy expenditure for lifting by females over a 4 hour period.

Table 3. Comparison of the results with published data for females. Lifting in a sagittal plane, from floor level to knuckle height.

Psychophysical study	Time allowed for selection	Type of material used	Frequency of lift (lifts min^{-1})	Weight of load (kg)	
				Mean	S.D.
Ayoub *et al.* (1980)[a]	20–30 min	Lead shots	1	19·79	3·11
			4	15·82	3·23
			6	13·93	3·53
			8	13·18	3·21
			12	11·39	3·11
Snook (1978)[b]	20 min	Lead shots	4·3	12·00	—
			6·7	11·00	—
			12	8·00	—
Snook and Ciriello (1974)[c]	40 min	Lead shots	4·3	12·67	—
Mital (1983)	4 hours	Lead shots	Combined	13·12	3·10
	8 hours	Lead shots	Combined	12·32	2·73
Mital (1984)[d]	8 hours	Lead shots	1	13·33	2·39
			4	11·84	3·47
			8	10·47	3·76
			12	8·41	2·30
Karwowski and Yates (1984)[e]	4 hours	Water	4	11·94	3·51
			8	7·90	2·58
Present study	4 hours	Water	1	13·74	2·18
			3	11·71	2·75
			6	9·49	1·17
			12	7·19	1·42

[a] Recommendations for workers, box size of 30·48 cm.
[b] Recommendations for 90% of the female population, and box size of 36 cm in width, vertical distance of 76 cm.
[c] Recommendations for 90% of industrial women, when lifting from floor to 50·8 cm above the floor.
[d] Data based on industrial workers, box size of 30·48 cm, lifting from floor to knuckle.
[e] Data for college students, box size of 33 cm, vertical distance of 76 cm.

As indicated previously (Levine *et al.* 1982), one could expect that the upper limit for an 8 hour work day would be somewhat less, and should be close to the physiological limit of 23% $\dot{V}O_2$ max proposed for the male population (Legg and Pateman 1984). Williams *et al.* (1982) reported that there was no significant difference between $\dot{V}O_2$ max for cycling and lifting boxes of 15·7 and 22·7 kg for female subjects. Also, males and females do not differ in their perception of physical effort when the levels of exercise are expressed as a percentage of $\dot{V}O_2$ max (Noble *et al.* 1981). Therefore, it can be concluded that the upper limit of lifting workload for females for an 8 hour shift (expressed as a percentage of $\dot{V}O_2$ max) should not be different from that proposed for males.

Regarding the new procedure for weight adjustment, it was observed that the female subjects liked the idea of using the verbal descriptors to inform their assistants about the desired changes. The method did not lead to confusion or misunderstanding between lifters and lowerers.

Comparison of the results concerning the maximum acceptable weight of lift for females with the data reported in the literature (see table 3) is difficult, since no data for lifting liquids which are based on a 4 hour period exist. When lifting with the frequencies of 1 and 4 lifts min^{-1}, the maximum amounts of liquid (13·74 and 11·94 kg using 4 hours) are very close to the maximum amounts of solids (13·33 and 11·84 kg based on 8 hours), respectively, reported by Mital (1984). Further comparisons of the amounts of liquid with solids (Mital 1984) indicates that on the average 24·5 and 14·5% less liquids than solids can be lifted by females at rates of 8 and 12 lifts min^{-1}, respectively. However, the differences shown in this table might also be related to different subject populations used, rather than the material itself.

5. Conclusions

Since psychophysical methodology is based on self-selected workload, and the important consideration in determining the work output is what a person thinks (feels) he/she is doing (Siegel *et al.* 1984), the method seems to fail in producing reliable results at frequencies of lift higher than 6 lifts min^{-1}. Therefore, the use of the psychophysical method in its present form, as applied to manual materials handling, should be limited to the low and moderate frequencies only, as originally intended by Snook and Irvine (1968).

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Une technique psychophysique pour la détermination des normes de levage a été évaluée à partir d'un échantillon de 7 étudiantes qui devaient effectuer des levages à quatre cadences différentes (1, 3, 6 et 12 levages par minute). Une seule séance avait lieu par période de 24 heures. Au cours de la tâche qui durait quatre heures, les sujettes devaient indiquer quelle quantité d'eau elles pensaient pouvoir soulever confortablement pendant 8 heures. On les avait encouragées à faire autant de changements de poids qu'elles désiraient. Chaque fois qu'elles changeaient le poids, le récipient était pesé et le temps noté. Toutes les 15 min, on leur demandait d'indiquer avec quel degré de confiance (DOC) elles estimaient que le poids choisi était le maximum acceptable pour un levage pendant une tournée de 8 heures. La consommation d'oxygène a été mesurée à 30, 120 et 240 min depuis le début de la tâche. Les poids choisis par les sujettes à 30 min ne différaient pas significativement de ceux pour les 4 heures en ce qui concerne les cadences de 1, 3 et 6 levages par min. Cependant à la cadence de 12 par min, les poids décroissaient avec le temps tels que la valeur pour les 4 heures était de 23% plus basse que celle du poids choisi après 30 min. Le DOC augmentait avec le temps, mais ne variait pas significativement entre les cadences. La consommation d'oxytène ne variait pas avec le temps et correspondait à 19, 25, 35 et 45·5% de la $\dot{V}O_2$ max pour les cadences de 1, 3, 6 et 12 levages par min respectivement. On conclut que cette technique psychophysique dans sa forme actuelle ne devrait pas être utilisée pour fixer des normes de levage pour des cadences supérieures à 6 levages par min.

Eine psychophysiologische Methode zur Ermittlung von Standardwerten für das Heben von Lasten wurde untersucht. Sieben weibliche Studenten führten Versuche mit 4 Hebefrequenzen (1, 3, 6 und 12 min^{-1}) durch. Während der 4-stündigen Versuchsdauer wurden die VPn aufgefordert, die Menge Wasser zu wählen, welche sie nach ihrer eigenen Einschätzung bequem für die Dauer einer 8-stündigen Schicht heben können. Die VPn wurden aufgefordert, das Gewicht so häufig wie nötig zu korrigieren. Der Zeitpunkt jeder Gewichts-Korrektur und das neue Gewicht wurde registriert. In 15 Minutenintervallen wurde die VPn befragt inwieweit sie damit übereinstimmen, daß das momentane Gewicht das maximal akzeptierte für die Dauer einer 8-stündigen Schicht darstellt. Der Sauerstoffverbrauch wurde nach 30, 120 und 240 Minuten Tätigkeitsdauer ermittelt. Bei den Hubfrequenzen 1, 3 und 6 min^{-1} unterschied sich das nach 30 Minuten gewählte Gewicht nicht signifikant von dem Gewicht in der 240 Minute. Bei der Hubfrequenz 12 min^{-1} nahm das gewählte Gewicht mit der Arbeitsdauer ab und betrug nach 4

Stunden 77% des Gewichts, das nach 30 Minuten Tätigkeitsdauer gewählt wurde. Der Grad der Übereinstimmung (DOC) nahm in Abhängigkeit von der Tätigkeitsdauer zu. Signifikante Unterschiede zwischen dem Messungen bei variabler Hubfrequenz ergaben sich nicht. Die O_2 Aufnahme war konstant während der Tätigkeitsdauer und betrug 19, 25, 35 und 45% von $\dot{V}O_2$ max bei den Hubfrequenzen 1, 3, 6 und 12 min^{-1}. Wir kommen zu dem Ergebnis, daß die psychophysiologische Methode in ihrer heutigen Form nicht zur Bestimmung von Standardwerten bei einer Hubfrequenz oberhalb 6 min^{-1} angewandt werden sollte.

持上げ作業の基準値設定のための精神物理学的方法の評価を女子学生７名に４通りの持上げ頻度（1, 3, 6, 及び12回/分）で作業を行わせ調査を行った。24時間に１種類の持上げ作業実験１回だけに限り，４時間の持上げ作業の間，被験者は８時間楽に作業を続けることができると思われる水の量を選択し，必要なだけ重量の変更を行う様求められる。重量変更の度にボール箱は加重され，時間が記録される。15分間隔で被験者は現在の重量が８時間作業の最大許容量であるかどうかの信頼度（DOC）を報告させる。酸素摂取量を作業開始後30, 120, 及び240分の時点で測定を行った。持上げ頻度１，３，及び６回/分の場合，作業30分の時点で被験者が選んだ重量は作業４時間の時点で選んだ重量と有意な差は見られなかった。しかし，持上げ頻度12回/分の場合には重量は時間とともに減じ，作業４時間の時点の重量は30分の時点の値に比べ23%減少していた。DOC は時間とともに増加し，持上げ頻度による有意な差異は見られなかった。酸素摂取量は時間による変動はなく，持上げ頻度１，３，６，及び12回/分に対しそれぞれ，最大酸素摂取量の19, 25, 35, 及び45.5%であった。持上げ頻度６回/分以上の作業に対しては今回用いた様な精神物理学的な方法は持上げ作業の基準設定には使用すべきでないことが結論づけられた。

References

AYOUB, M. M., MITAL, A., BAKKEN, G. M., ASFOUR, S. S., and BETHEA, N. J., 1980, Development of strength and capacity norms for manual material handling activities: the state of the art. *Human Factors*, **22**, 271–283.

BORG, G., 1971, In *Frontiers of Fitness* (Edited by R. J. SHEPARD) (Springfield, Illinois: CHARLES C. THOMAS), pp. 280–294.

BORG, G., 1982, Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, **14**, 377–381.

BROUHA, L., 1967, *Physiology in Industry* (Oxford: PERGAMON PRESS).

CHAFFIN, D. B., 1975, Ergonomics guide for the assessment of human static strength. *American Industrial Hygiene Association Journal*, **36**, 505–511.

CIRIELLO, V. M., and SNOOK, S. M., 1983, A study of size, distance, height, and frequency effects on manual handling tasks. *Human Factors*, **25**, 473–483.

EVANS, W. J., WINSMANN, F. R., PANDOLF, K. B., and GOLDMAN, R. F., 1980, Self-paced hard work comparing men and women. *Ergonomics*, **23**, 613–621.

HUCK, S. W., CORMIER, W. H., and BOUNDS, W. G., 1974, *Reading Statistics and Research* (New York: HARPER & ROW).

KARWOWSKI, W., and AYOUB, M. M., 1984, The effects of frequency on the maximum acceptable load of lift. In *Trends in Ergonomics/Human Factors I* (Edited by A. MITAL) (Amsterdam: NORTH HOLLAND), pp. 167–172.

KARWOWSKI, W., and YATES, J. W., 1984, The effect of time in the psychophysical study of the maximum acceptable amounts of liquid lifted by females. *Proceedings of the Human Factors Society's 28th Annual Meeting*, San Antonio, Texas, pp. 586–590.

LEGG, S. J., and HASLAM, D. R., 1984, Effect of sleep deprivation on self-selected workload. *Ergonomics*, **27**, 389–396.

LEGG, S. J., and MYLES, W. S., 1981, Maximum acceptable repetitive lifting workloads for an 8 hour workday using psychophysical and subjective rating methods. *Ergonomics*, **24**, 907–916.

LEGG, S. J., and PATEMAN, C. M., 1984, A physiological study of the repetitive lifting capabilities of healthy young males. *Ergonomics*, **27**, 259–272.

LEVINE, L., EVANS, W. T., WINSMANN, F. R., and PANDOLF, K. B., 1982, Prolonged self-paced hard exercise comparing trained and untrained men. *Ergonomics*, **25**, 393–400.

MITAL, A., 1983, The psychophysical approach in manual lifting—a verification study. *Human Factors*, **25**, 485–491.

MITAL, A., 1984, Comprehensive maximum acceptable weight of lift database for regular 8 hour work shifts. *Ergonomics*, **27**, 1127–1138.

MYLES, W. S., ECLACHE, J. P., and BEAURY, T., 1979, Self-pacing during sustained, repetitive exercise. *Aviation, Space and Environmental Medicine*, **50**, 921–924.

NICHOLSON, L. M., and LEGG, S. T., 1984, The effect of load and frequency upon selection of workload in repetitive lifting using psychophysical methodology. In *Proceedings of the 1984 International Conference on Occupational Ergonomics* (Edited by D. A. ATTWOOD and C. MCCANN) (Toronto: HUMAN FACTORS CONFERENCE, INC.), pp. 328–332.

NOBLE, B. T., MARESH, C. M., and RITCHEY, M., 1981, Comparison of exercise sensations between females and males. In *Women and Sport* (Edited by T. BORMS, M. MEBBELINCK and A. VENERANDO) (Basel: S. KARGER), pp. 175–179.

PETROFSKY, T. S., and LIND, A. R., 1978 a, Metabolic, cardiovascular, and respiratory factors in the development of fatigue in lifting tasks. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, **45**, 64–68.

PETROFSKY, T. S., and LIND, A. R., 1978 b, Comparison of metabolic and ventilatory responses of men to various lifting tasks and bicycle ergometry. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, **45**, 60–63.

SIEGEL, D., JOHNSON, T., and KLINE, G., 1984, Attentional load and the reproduction of physical load. *Research Quarterly for Exercise and Sport*, **55**, 146–152.

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

SNOOK, S. H., and CIRIELLO, M. S., 1974, Maximum weights and work loads acceptable to female workers. *Journal of Occupational Medicine*, **16**, 527–534.

SNOOK, S. H., and IRVINE, C. M., 1967, Maximum acceptable weight of lift. *American Industrial Hygiene Association Journal*, **28**, 322–329.

SNOOK, S. H., and IRVINE, C. M., 1968, Maximum frequency of lift acceptable to male industrial workers. *American Industrial Hygiene Association Journal*, **29**, 531–536.

SNOOK, S. H., and IRVINE, C. H., 1969, Psychophysical studies of physiological fatigue criteria. *Human Factors*, **11**, 291–300.

WILLIAMS, C. A., PETROFSKY, J. S., and LIND, A. R., 1982, Physiological responses of women during lifting exercise. *European Journal of Applied Physiology*, **50**, 133–144.

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