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THE EFFECT OF FREQUENCY ON PSYCHOPHYSICAL RESPONSES TO LIFTING.

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ABSTRACT

One of the main goals of Ergonomics is to establish task requirements in order to prevent injury. This is of particular importance in Manual Materials Handling (MMH), as manual lifting represents a major cause of injury to workers and a significant cost to industry. In spite of the existence of established guidelines, there is evidence that the majority of injuries are caused by overexertion (Ayoub, 1992).

In support of Oborne (1987), Charteris and Scott (1993) have argued that frequency is one of several task-related variables which have an influence on the demands of a lifting task. Clearly, all other factors being equal, as the pace of the work is increased, so the load should decrease.

Utilising fifteen male volunteer subjects (age 21.3 yrs), this study investigated psychophysical responses to a lifting task at three different frequencies, namely 5, 10 and 15 lifts per minute, with the total task duration being 15 minutes. Heart rate (HR) and Ratings of Perceived Exertion (RPE) data were recorded, and the tasks were analysed using LIFTRISK and NIOSH.

There were significant differences between successive frequencies for all data recorded. As expected, HR and RPE increased with lifting frequency. There was no significant correlation between HR and RPE for any of the conditions. Correlations were however higher at low work intensities. RPE Central values were somewhat lower than Overall values; this finding seems to lend support to the contention that Central factors do not play as important a role in the perceptions of exertion as was originally thought (Pandolf, 1982; Olivier and Scott, 1993).

In conclusion, this study investigated the effect of frequency on psychophysical responses for a task with inherent high-risk characteristics. As lift frequency increased, the correlation between HR and RPE decreased. With low subject numbers precluding a firm conclusion, this study tentatively proposes that caution should be exercised when using RPE in self-determination of task limitations for a MMH task.

INTRODUCTION

One of the primary functions of Ergonomics is that of task assessment, with the aim of setting task requirements within the determined safe capabilities of those who perform the task. This is of particular importance in Manual Materials Handling (MMH) tasks, as manual lifting represents a major cause of injury to workers and a significant cost to industry. Much research has focused on identifying particular areas of stress in MMH in order to minimise musculo-skeletal injuries, whilst at the same time not adversely affecting productivity. However, the high incidence of injury in industry provides evidence that the preventive aim of Ergonomics is not being fully realised. Back injury, particularly in the lower back, occurs with alarming frequency, with recent studies indicating that back injuries in industry are a major source of lost time and compensation claims, the majority of such injuries occurring as a result of lifting tasks (Ayoub, 1992). Despite available guidelines such as NIOSH (1981) and Liftrisk (1990), epidemiological evidence points to the fact that the majority of injuries are caused by overexertion. Lifting is a common MMH activity which results in overexertion injuries, and Gamberale **et al.** (1987) report that one way to prevent injuries is via the application of restrictions on how much an individual is permitted to lift. In the past, much emphasis has been placed on Maximum Acceptable Workload (MAW), but recently Oborne (1987) and Charteris and Scott (1993) have argued that several task-related variables influence the demands of lifting. These include object size, shape and weight; the distance the object is to be moved; and lifting frequency. In line with the increasing realisation that the interaction of these factors is at least as important as the limitation on mass, this paper investigated the effect of frequency on MMH tasks.

Frequency forms a measure of the time dimension of a handling task, and refers to the pace associated with repetitive tasks (Ayoub and Mital, 1989). Lifting frequency is defined as the number of times a lift is executed per minute (Danz and Ayoub, 1992). Ayoub and Mital (1989) report that frequency in a lifting task is proportional to heart rate, work rate, the Rating of Perceived Exertion (RPE), and metabolic energy expenditure. Legg and Pateman (1984) state that it is of practical importance for industrial physiologists to quantify the relationships between load and lifting rate in order to establish the frequency which can be sustained without fatigue, while Zhu and

Zhang (1990) propose that when lifting weights ranging from 11-18 kg, efficiency is greatest at 5-6 $lifts.min^{-1}$. Frequency is thus increasingly being viewed as a critical task parameter in MMH activities, particularly where the rate of lifting exceeds $6.min^{-1}$ (Jiang and Smith, 1985).

Some doubt has been cast as to the efficacy of a psychophysical evaluation of MMH tasks with high frequencies, with Karwowski **et al.** (1992) stating that the application of psychophysical techniques leads to an overestimation of MAW for such tasks. They further state that the psychophysical approach should not be used to set lifting standards higher than 6 $lifts.min^{-1}$.

In actual industrial settings however, productivity often demands that frequency exceeds 6 $lifts.min^{-1}$. Particularly in Southern Africa, where a large proportion of industrial work is manual in nature, there is thus a need to examine whether or not a psychophysical approach to MMH evaluation is valid and reliable. What, however, is the psychophysical approach, and how is it applied to Ergonomics?

While a purely physiological approach to a work task focuses primarily on oxygen transportation and utilization systems, psychophysics deals with the relationship between human sensations and their physical stimuli. It is assumed that psychophysical strain is an integration of physiological and biomechanical stresses, and one of the advantages of this approach is that it permits the realistic simulation of industrial work. Ayoub (1992) however contends that still more integrated investigations are needed to accurately estimate the combined stresses imposed on the body during MMH activities.

Equating subjective feelings of effort with numerical values derived from a standardised scale has become increasingly common in research evaluating work tasks. Until fairly recently, such tools have been less seriously considered than the more readily definable physiological indicators. The reason for this neglect is that subjective reactions have been difficult to define and measure (Gamberale, 1985). These fundamental difficulties are connected with the nature of the measurement itself. As a privately experienced event or sensation, perceived exertion can only be measured indirectly through the use of self-report techniques. This self-report thus only constitutes a distal reaction, and the extent to which this is a reflection of the proximal reaction (i.e. the reaction within the individual organism) relies very heavily on the adequacy of the measurement tool or procedure adopted (Olivier, 1990).

Numerous ratio- and category scaling techniques have been devised, the most commonly used being the Borg scale as revised in 1973 (Dunbar, 1993). This scale is based on a correlation between perceived exertion and heart rate, with Borg (1973) suggesting that the addition of a zero to the RPE value should yield a figure which approximates the exercising subject's heart rate. This assumption has however been challenged (Pandolf **et al.**, 1972; Pandolf **et al.**, 1978; Mihevic, 1981; Morgan, 1981; Rejeski, 1981; Pandolf, 1982 and Robertson, 1982). The achievement of a linear relationship between RPE and workload was, in fact, one of the objectives in the construction and development of the scale (Olivier, 1990), and Borg himself (1982) cautioned that this close relationship ought not to be taken too literally.

There is no perfect scale for all kinds of subjective intensities in all kinds of situations, and different scales should be used depending on the purpose of the study. There is general agreement (Morgan, 1973 and 1981; Mihevic, 1981; Gamberale, 1985) that the Borg scale should be used in most cases, as it has shown versatility, parsimony and validity. This is particularly true when there is a need to make comparisons between work tasks or between individuals (Olivier, 1990). Despite its reliability and validity in certain situations and extensive use in research settings, the RPE scale is still under-utilised in industry.

Pandolf (1978) suggests that the interrelationships between subjective perceptual ratings and specific physiological responses to various types of work can be better defined and compared using differentiated RPE. This makes provision for differentiating into Central, Local and Overall ratings.

The model suggests that undifferentiated RPE from the Borg category rating scale is probably associated with the "superordinate" level of subjective reporting, and represents overall body responsiveness that results from the integration of various sensory cues having different perceptual weightings. At this level of subjective reporting, undifferentiated RPE is not necessarily closely related to the underlying physiological substrata (Pandolf, 1978 and 1982). The model suggests that the interrelationships between subjective perceptual ratings and specific physiological responses to various types of work can be better defined and compared using "subordinate" differentiated ratings which appear to be in close proximity to the level of the "discrete symptoms" (Pandolf, 1978). Put another way, the physiological substrata constitute the most basic level upon which the ratings of perceived exertion rest. Discrete symptoms arise from these cues and they are further tied to specific subordinate and/or ordinate levels of organisation. There is both a vertical hierarchy among levels and a horizontal interrelationship of categories within specific levels. The "superordinate" (undifferentiated) level is the most general level of subjective assessment and most closely approximates Borg's original measure of RPE. The link/process between the physiological substrata and the superordinate level is probably best characterised by reciprocal causation (Rejeski, 1981). The model then encourages comparisons between local and central factors with further contrasts to the overall exertion (Noble and Allen, 1984). Acceptance of this model for research presupposes that, as a result of the multidimensional nature of RPE, it is critical that researchers provide experimental subjects with specific instructions about the use of exertional scales (Rejeski, 1981). Using Borg's category rating scale, subjects should be asked to indicate a "local" muscular rating from feelings of strain in the working muscles and joints, a "central" rating from sensations involving the cardiopulmonary systems, and an overall rating in which subjects can integrate the local and central feelings with whatever weightings they deem appropriate (Pandolf, 1978).

Much of the work supporting the importance of central systemic factors as critical for perceived exertion has been directed towards validation of Borg's proposal that perceived exertion covaries directly with heart rate (Mihevic, 1981). Numerous other studies have since demonstrated that under certain conditions there exists a strong linear relationship between the two variables (Pandolf, 1972 and 1978; Carton and Rhodes, 1985). The majority of studies which support the influence of heart rate on perception of effort have been correlational in nature (Mihevic, 1981), and consequently the relationship has not been investigated in cause and effect terms (Pandolf, 1972). Therefore, while heart rate and RPE may be highly correlated, at no point has it been implied that the two variables are causally related (Carton and Rhodes, 1985).

The research cited has demonstrated that the linear relationship of heart rate and perceived exertion across several exercise intensities is strong. However, the independence of heart rate and perceptual responses with pharmacological and environmental manipulations suggests that heart rate is not a major input for perceived exertion. It must be remembered that RPE and heart rate responses were originally tested recording the heart rate response of healthy young males to steadily increasing exercise intensity. The linear relationship between the two variables was therefore virtually inherent during progressive exercise under neutral conditions. Furthermore, heart rate and RPE are probably indirectly related through their common dependence upon physical strain (Carton and Rhodes, 1985).

Due to the nature of the work task, this study sought only Overall and Central RPE. With frequency being a critical task characteristic, the investigators felt that Central factors should be contrasted with the Overall (general gestalt) ratings.

METHODS

Utilising 15 male volunteer subjects (agė 21.3 years), this study investigated psychophysical responses to a lifting task at three different frequencies, namely 5, 10, and 15 lifts per minute, with the total task duration being 15 min. Heart rate (HR) and differentiated Ratings of Perceived Exertion (RPE Overall and Central) were recorded. The tasks were analysed using NIOSH and LIFTRISK.

Table I: Subject characteristics

	AGE (yrs)	STATURE (cm)	MASS (kg)	GRIP STRENGTH(N)	RESTING HR (bpm)
MEAN	21	175.7	75.8	488.1	80.1
SD	1.07	3.77	8.83	66.0	12.6

In an attempt to reduce subject variability, subjects were between 20 and 25 years of age and between 1.7 and 1.8m in height. Stature, mass, grip strength and resting HR were recorded at the original data collection. Subject characteristics are reported in Table I.

Data were collected at three test sessions spanning a period of ten days, with at least one, but not more than three days interval between each session.

There seems to be a growing consensus that there is no ideal way to lift, with morphology and task requirements interacting to varying degrees. Subjects were therefore instructed that a "free" lifting action was required, but they were asked to lift as symmetrically as possible in order to eliminate twisting. Subjects were required to lift a box weighing 10 kg from a pallet (150mm high) onto a table 800mm high) at regular intervals for all three tasks. The duration of each task was 15 min. The difficulty of extrapolation to, for example, an 8 hour shift from such a short period is recognised, but practical considerations and the inherent high risks of the tasks precluded prolonged testing sessions. Task requirements were held constant except for frequency of lift, which was as follows:

Condition 1 : 5 lifts.min^{-1} (1 lift every 12s)

Condition 2 : 10 lifts.min^{-1} (1 lift every 6s)

Condition 3 : 15 lifts.min^{-1} (1 lift every 4s)

These frequencies were chosen as it was felt that they would reflect the range encountered in 'real life' industrial settings.

The order of lifting frequency was randomly assigned. Lift-rate was controlled by means of a pre-recorded tape indicating the appropriate moment at which to lift. Data were collected during the last 10 seconds of minutes 2, 4, 6, 8, 10, 12, 14 and 15 of each task, with HR, RPE Overall and RPE Central being recorded. Recovery HR was recorded at minutes 1, 2 and 3 following termination of the work task.

Related students t-tests were computed to determine whether there were significant differences between the conditions for HR, RPE Overall and RPE Central. One independent variable regression analyses were then computed to examine possible correlations between HR and RPE.

The three conditions were also subjected to NIOSH and LIFTRISK analysis.

RESULTS AND DISCUSSION

NIOSH analysis of the conditions yielded the following results:

Condition 1:

Action limit (AL)	- 4.5 kg
Maximal permissable Limit (MPL)	- 13.5 kg (present situation acceptable)

Condition 2:
MPL - 2.25 kg
- 6.75 kg
(present mass too high).
Frequency was the 'worst factor' identified.

Condition 3:
frequency too high for NIOSH analysis.

LIFTRISK analysis was as follows:

Condition 1: task inherent risk 3.74, and with an average worker the overall situational risk was 5.54, which is "high risk". Stooping was the 'highest risk'

Condition 2: task inherent risk of 4.34 and overall situational risk of 5.82. Frequency was the 'highest risk' factor identified.

Condition 3: task inherent risk of 4.97 and overall situational risk of 6.17, which is "very high risk". Frequency was the 'highest risk' factor identified.

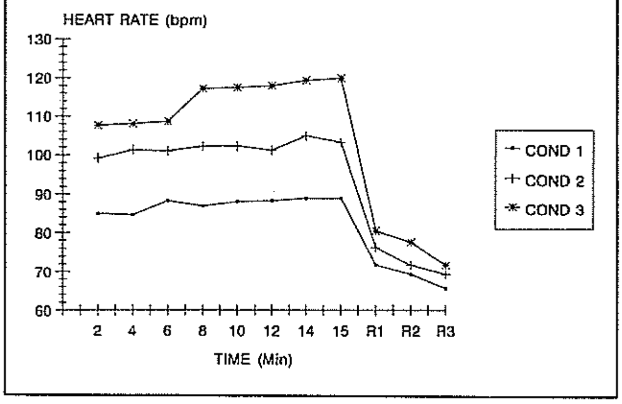

Figure 1: Work and recovery heart rate responses for conditions 1, 2 & 3.

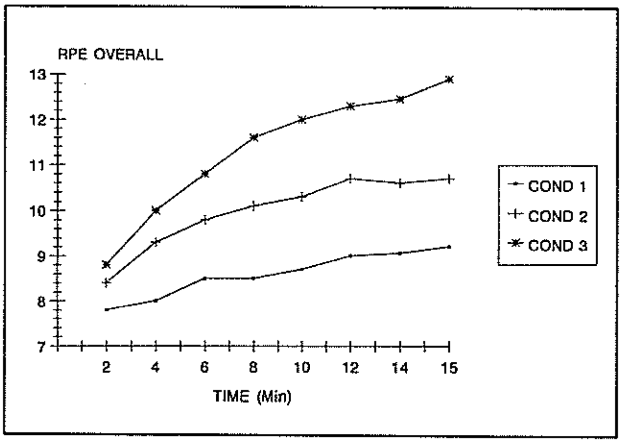

Figure 2: RPE Overall responses for conditions 1, 2 & 3.

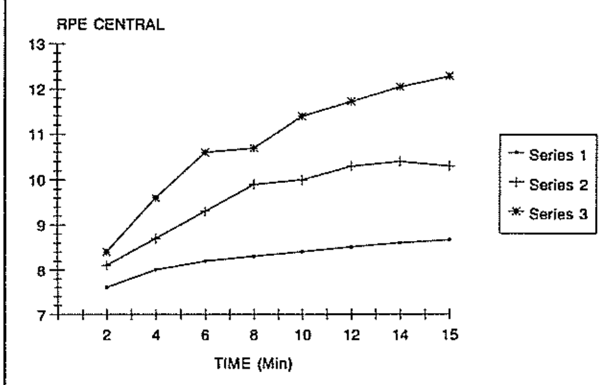

Figure 3: RPE Central responses for conditions 1, 2 & 3.

Table II: Means and standard deviations for heart rate, RPE Overall, and RPE Central (*represents a significant difference).

	CONDITION 1 MEAN (SD)	CONDITION 2 MEAN (SD)	CONDITION 3 MEAN (SD)
HR (bpm^{-1}.)	87.5 (13.4)	101.8 (15.5)*	114.5 (11.7)*
RPE OVERALL	8.6 (2.26)	10.0 (1.87)*	10.9 (1.43)*
RPE CENTRAL	8.2 (1.95)	9.6 (1.62)*	10.9 (1.43)*

Figures 1-3 indicate that, as expected, HR, RPE Overall and RPE Central increased with lifting frequency. Table II shows that there were significant differences between successive frequencies for all data recorded, with the exception of RPE Overall between 5 and 10 lifts.min^{-1} (Conditions 1 and 2). These results are consistent with physiological and psychophysical expectations. Tables III-V indicate that there were no significant correlations between HR and either of the RPE measures for any of the conditions. As the Borg scale is based on a correlation between HR and RPE, with a linear relationship between the measures being a factor in the development of the scale, this finding is somewhat surprising. One explanation could be the nature of the task, with the Borg scale being constructed in an exercise mode of steadily increasing intensity. Figure 1 shows that there was only a slight increase in exercise heart rate for each of the three tasks, indicating a steady-state exercise modality. Figures 2-3 show more linear increases for RPE, and this may go some way towards explaining the low correlations. Also, it is possible that RPE data were either consciously or subconsciously suppressed, and this re-emphasizes the need for clear, easy to understand instructions. This is, of course, of critical importance in multicultural and multilingual industrial settings. Doubt has also previously been cast on placing too much emphasis on the HR and RPE relationship. The results of this study suggest that for MMH tasks involving relatively high lifting frequencies, caution should be exercised when evaluating a task from a psychophysical approach.

Table III: Correlation matrix for Heart rate, RPE Overall and RPE Central for condition 1.

	HEART RATE	RPE Overall	RPE Central
HEART RATE	1.00	0.47	0.49
RPE CENTRAL	0.47	1.00	0.96
RPE OVERALL	0.49	0.96	1.00

Table IV: Correlation matrix for Heart rate, RPE Overall and RPE Central for condition 2.

	HEART RATE	RPE Overall	RPE Central
HEART RATE	1.00	0.38	0.48
RPE CENTRAL	0.38	1.00	0.92
RPE OVERALL	0.48	0.92	1.00

Table V: Correlation matrix for Heart rate, RPE Overall and RPE Central for condition 3.

	HEART RATE	RPE Overall	RPE Central
HEART RATE	1.00	0.16	0.08
RPE CENTRAL	0.16	1.00	0.88
RPE OVERALL	0.08	0.88	1.00

RPE Central values were generally lower than Overall values, and this reflects the relatively low metabolic demands of the task. Also it is interesting to note that correlations were higher at lower lift frequencies, which suggests that other factor/s mediated in the processing of perceptual information, particularly when work intensity increased. Pandolf (1978) has noted that when a particular cue, e.g. strain in the exercising muscles, is accentuated by either elevated rate, concentration or value over others, it can dominate the overall rating and this has been supported by Olivier and Scott (1993), who contend that central factors do not play as important a role in the perception of exertion as was originally thought. The results of the present study seem to bear this out, and the mediating factor in the processing of perceptual information may have been the unreported local factors of discomfort in the working muscles. This is consistent with earlier findings by Charteris et al. (1987), who found that for a brick-stacking task at 12, 15 and 22 lifts.min^{-1}, the sensations of strain in the working muscles or joints may have affected the interplay of local and central factors in the reporting of overall RPE. Furthermore, although local factors were not accessed, perceived discomfort on completion of the task was. All subjects reported perceived discomfort in the arms and lower back, providing some support for mediation in the perception of exertion by local factors. Earlier we noted that some doubt exists as to the efficacy of a psychophysical approach to setting guidelines for lifting tasks, particularly at higher frequencies. With frequency in this case being an important task variable, it seemed reasonable to assume that the metabolic demands of the task would be adequately reflected by the self-report of central factors of RPE. This however was not the case, and the findings of this paper support the notion that caution should be exercised when evaluating tasks, or setting lifting standards at lift frequencies higher than 6 lifts.min^{-1}. It seems then that the interrelationships between subjective perceptual ratings and specific physiological responses to MMH tasks at higher frequencies are not as clearly defined as for less complex work tasks.

CONCLUSION

In conclusion, this study investigated the effect of frequency on psychophysical responses to three MMH tasks with inherent high risk characteristics. With low subject numbers precluding a firm conclusion, the results suggest that researchers should exercise caution when using RPE in self-determination of task limitations for MMH tasks of this nature. Nevertheless, RPE may be a useful tool as a supplement to physiological and biomechanical task analysis. If it is clearly understood and correctly applied, RPE could have practical relevance in Southern African industrial settings, where manual labour predominates.

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