A Study of Perceptual Motor Load as Affected by Combined Manual and Decision Task Characteristics

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This paper presents an experimental study of Perceptual Motor Load (PML) in a Combined Manual and Decision Task (CMDT). The purpose of this study was to compare Michon's scoring method of measuring PML with a new scoring method as affected by a two-stage CMDT under different work-load conditions. The dual task approach, using the simple task of foot tapping as the secondary task, was applied to obtain the quantitative measurement of PML. The experiment consisted of four major conditions, comprised of one of two activations, i.e., either unimanual or bimanual paired with each of the two stimulative repetitions, i.e., either random or sequential. Under each of the four experimental conditions, a central composite design was applied. The design included three levels of information load, three levels of time lag, and three levels of probability distribution of emergency signal occurrences. Twenty male subjects participated in the experiments. No significant difference between the results of both scoring methods was found; however, the new scoring method can contribute a better measure of PML in terms of correlation coefficients between the scores and the performance times.

The significant increase of mental involvement in most industrial situations has subjected the worker to a greater amount of mental stress and strain, thus causing the imposition of what is called Perceptual Motor Load (PML). This may induce

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failure in the proper functioning of work mechanisms and may even trigger a nervous breakdown in the human being. Hence, it is necessary to measure PML to determine if the task requirements are well matched with a worker's mental capability. A method of measuring PML was established by Michon (1964, 1966) and Michon and Van Doorne (1967) using the dual task method. However, his scoring method did not sufficiently take into account statistical characteristics of PML as affected by the primary task.

Many industrial control tasks can be described as Combined Manual and Decision Tasks (CMDT) (Sadosky, 1968; Thomas et al., 1974; Raouf and Mehra, 1974; Raouf and Khare, 1975; Raouf and Sethi, 1976; Raouf and Arora, 1980; Raouf and Abada, 1982). As the trend towards the centralized control of industrial systems continues, such tasks are becoming increasingly more common and important. Raouf et al. (1984) applied Michon's scoring method to CMDT and found that information load and activation were highly significant factors affecting PML. In the absence of well-tested methods for calculating PML caused by various levels of CMDT, Raouf et al. (1985) developed a new scoring method for obtaining PML Index (PMLI) for CMDT. A high correlation was found between PMLI and performance time. The purpose of this study was to compare both scoring methods as affected by a two-stage CMDT under different work-load conditions.

METHODS

Experimental set-up. The equipment used for this study consisted of the following main units:

(a) Two-stage CMDT Simulator.
(b) Pedal.
(c) Grass Model 7 Polygraph.
(d) PDP 11/03 Minicomputer.

Primary task. The primary task, in which PML was measured, is basically a two-stage signal-response unit and a simulation of a semi-automatic punch press machine commonly used in the steel fabrication industry. A layout of the equipment is shown in Fig. 1. The panel is mounted on the top of a box which houses the electronic circuits, the programmed chips required to control the levels of information load, and a potentiometer to control the duration of the time lag (range 500 to 4,000 ms). The box is fixed on the top of an adjustable stand. A more detailed description of the equipment is given in Raouf and Abada (1982) and Raouf et al. (1984). The time which elapsed between the occurrence of the stimulus and the completion of the response is recorded in milliseconds on a time measuring and recording unit. The output of the unit is a punched tape which is converted into data on a magnetic disk of a PDP 11/03 minicomputer for analysis.

The task was comprised of the following steps:
Fig. 1. Layout of two-stage CMDT simulator.

(a) Subject presses the 'start' button in order to start the cycle, sitting upright in front of the simulator facing and aligning his body with the center of the control panel.

(b) After a time lag (1.0, 1.5, or 2.0 s), one or two of the lights in the first stage (either side A or B, or both) light up; the subject then moves his index finger(s) from the initial position to activate (press) the associated response button(s), and brings his finger(s) back to the same position; left hand and/or right hand are used to activate side A and/or B buttons, respectively.

(c) After another time lag (0.5, 1.0, or 1.5 s) and according to the response made in the first stage, one of the lights in the second stage appears sequentially. The subject then moves his index finger(s) from the initial position and activates the associated response button. Eight lights are associated with each side A and B. With the occurrence of two lights appearing simultaneously, one from side A and the other from side B, the subject has to activate the appropriate buttons using both hands concurrently.

(d) In order to complete the cycle, the subject activates the appropriate
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'the program complete' button(s). The cycle is repeated.

(e) After repeating the above sequence for a certain length of time (30 cycles), the 'end of cycle light' appears.

In case of an emergency, indicated by continuous flashing of all lights of the second stage on the panel, the subject has to activate the 'emergency stop' button as soon as possible and then the 'program cancel' button(s). Activating the 'program cancel' button(s) allows him to start the cycle again. In all circumstances whereby the subject commits an error, he has to respond immediately to correct the error.

Secondary task. The simple task of foot tapping was used as the secondary task to obtain the quantitative measurement of PML. The subject was asked to tap a pedal by foot as regularly as possible at a constant rate of about one or two taps per second during the performance of the primary task. The pedal had a micro-switch and electric circuit to send a pulse to the PDP 11/03 minicomputer placed in an adjacent room through the polygraph's pen driver in order to monitor the tapping intervals.

PML Index (PMLI) developed by RAOUF et al. (1985) was defined as follows:

\[
PML \text{ Index} = \frac{\text{Loaded Standardized Tapping Irregularity Index}}{\text{Basic Standardized Tapping Irregularity Index}} - 1
\]

where \( t \) = length of interval between two successive taps.

\( T \) = total period of measurement, during which \( N \) intervals are produced.

\( N \) = number of intervals produced in time—\( T \):

\[
C.V.(t_i) = \sqrt{\text{variance}(t_i)/(T/N)^2}
\]

\( R = \text{covariance}(t_i, t_{i+1})/\text{variance}(t_i) \)

Subscript \( i \) = rank order of interval \( t \).

Subscript 0 = index of data related to Basic Tapping Irregularity Index.

Subscript 1 = index of data related to Loaded Tapping Irregularity Index.

Here, basic standardized tapping irregularity index was calculated only when the secondary task was performed. Therefore, each subject was asked to perform the secondary task alone before, during, and after the experiment.

PML Score (PMLS) developed by MICHON (1966) was calculated as follows:

\[
PML \text{ Score} = \frac{\text{Loaded Tapping Level}}{\text{Basic Tapping Level}} - 1
\]
Subjects. Twenty male students (all right-handed), between 20 and 30 years of age, performed the experiments. All the subjects were in good physical condition and were interested in the study.

EXPERIMENTAL DESIGN

Independent variables. The levels of independent variables studied are as follows:

(a) Information Load \((H)\) in bits:

<table>
<thead>
<tr>
<th>Levels</th>
<th>No. of stimuli ((N))</th>
<th>(H) (bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>H2</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>H3</td>
<td>16</td>
<td>4</td>
</tr>
</tbody>
</table>

\(H = \log_{2} N\), where \(N\) = number of equally likely alternatives in case of random varied stimuli.

(b) Time Lag \((TL)\) in seconds:

<table>
<thead>
<tr>
<th>Levels</th>
<th>TL in 1st stage</th>
<th>TL in 2nd stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL1</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>TL2</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>TL3</td>
<td>2.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

(c) Probability distribution of Emergency Signal \((ES)\) occurrences:

<table>
<thead>
<tr>
<th>Levels</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES1</td>
<td>0.00 (normal operation)</td>
</tr>
<tr>
<td>ES2</td>
<td>0.03</td>
</tr>
<tr>
<td>ES3</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Dependent variable. The dependent variable in this investigation was Performance Time \((PT)\) which is the time that has elapsed between the occurrence of the stimulus and the completion of the responses in the second stage.

Experimental conditions. The experiments consisted of the following four...
major studies:
(a) Unimanual activation and random input.
(b) Unimanual activation and sequential input.
(c) Bimanual activations and random input.
(d) Bimanual activations and sequential input.

Here, random input corresponds to the stimulative repetitions being varied randomly. On the other hand, sequential input occurs to the stimulative repetitions being varied in the form of sequential dependencies. Ten subjects, out of the twenty, participated in experiments (a) and (b).

The other ten subjects participated in experiments (c) and (d). Each subject was given a sufficient practice period for both the primary and secondary task before running the experiments. Under each of the four experimental conditions, a three-level and three-variable Box-Behnken design (BOX and BEHNKEN, 1960) was applied. In this design, there were 15 experimental points, 3 of which were the center points. Therefore, 450 data points (15 experimental conditions, 3 replications, and 10 subjects) were obtained in each major experiment.

RESULTS

The analysis of the experimental data was done on the IBM 3031 computer. The individual values of PMLI and PMLS were calculated on the basis of 90 second run-periods in each of the 45 experimental conditions. Correlations between PT and PMLI, and PT and PMLS were investigated. The result of Pearson correlation coefficients is shown in Table 1. PT vs. PMLI for unimanual activation and random input condition and PT vs. PMLI for bimanual activations and sequential input condition are represented in Figs. 2 and 3, respectively.

Under the condition of unimanual activation and random input, it was observed that there is a correlation between PT and PMLI. Also, a high correlation was found for bimanual activations and sequential input. However, in the case of unimanual activation and sequential input, a correlation was found only between PT and PMLS. In two conditions, i.e., unimanual activation and sequential input, and bimanual activations and random input, negative correlations were observed between both PT and PMLI, and PT and PMLS. No significant difference between

<table>
<thead>
<tr>
<th>Conditions</th>
<th>PT vs. PMLI</th>
<th>PT vs. PMLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unimanual activation and random input</td>
<td>0.09475*</td>
<td>0.09030</td>
</tr>
<tr>
<td>Unimanual activation and sequential input</td>
<td>−0.01156</td>
<td>−0.11201*</td>
</tr>
<tr>
<td>Bimanual activations and random input</td>
<td>−0.02544</td>
<td>−0.00768</td>
</tr>
<tr>
<td>Bimanual activations and sequential input</td>
<td>0.22628**</td>
<td>0.1700**</td>
</tr>
</tbody>
</table>

** indicates significance at 1% level of significance.
* indicates significance at 5% level of significance.
the results of both scoring methods (i.e. PMLI and PMLS) was found ($\alpha=0.01$).

DISCUSSION

Although the concept of PML as defined by Michon is not universally accepted, a measure of worker's mental capacity has to be developed. The present study is a step in that direction. For this study an industrial task was simulated in the laboratory. For measuring PMLI, foot tapping was used in place of finger tapping used by Michon, thus freeing both the hands of the worker to perform the task.

Our results show that as the performance time increases, PMLI tends to
increase under two conditions, i.e. unimanual activation and random input and bimanual activations and sequential input. This suggests that workers perform slower when they are required to use their mental capacity to a fuller extent. Negative correlations for bimanual activations and random input are perhaps due to worker's heavy concentration on task performance and thus overloading his mental capacity.

To have a better understanding of the PML, further investigations using psychological as well as physiological measures are envisaged.
CONCLUSION

Within the constraints of this experiment, the following conclusions can be made:

(a) In two conditions, i.e., unimanual activation and random input, and bimanual activations and sequential input, PMLI is a better measure of PML in terms of correlation coefficients between PMLI and performance time.

(b) As the performance time increases, PMLI tends to increase in two of the above conditions, i.e., unimanual activation and random input, and bimanual activations and sequential input.

(c) In unimanual activation and sequential input condition, PMLS is a better measure. In this case, as the performance time increases, PMLS tends to decrease.

(d) In all conditions, there is no significant difference between PMLI and Michon’s PMLS ($\alpha = 0.01$).

PMLI can provide a more satisfactory index for measuring the operator's “spare mental capacity” in a two-stage CMDT. These findings are likely to be useful in designing man-machine systems as performance time and human mental capacity both are considered at the same time.

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