

Tapping task as an index of mental workload in a time sharing task¹

KAZUMITSU SHINOHARA

Graduate School of Human Sciences, Osaka University, 1–2 Yamadaoka, Suita, Osaka 565-0871, Japan

TOSHIAKI MIURA

Graduate School of Human Sciences, Osaka University, 1–2 Yamadaoka, Suita, Osaka 565-0871, Japan

SHINNOSUKE USUI

Graduate School of Human Sciences, Osaka University, 1–2, Yamadaoka, Suita, Osaka 565-0871, Japan

Abstract: The sensitivity of tapping task to mental workload was investigated. Thirteen subjects were asked to produce 3 s intervals continuously while performing a time sharing task. The time sharing task was designed to manipulate a demand to allocate an attentional resource to one target and a demand to switch the target to which an attentional resource was mainly allocated. Results showed that produced intervals became shorter and more variable as the time sharing task became more demanding. The subjective workload assessment by the NASA Task Load Index (NASA-TLX) indicated that subjects experienced an increasing workload as the demand of the time sharing task increased. Two sub scales of the NASA-TLX, "effort" and "mental demand," were rated higher than other sub scales. These results suggest that the tapping task is sensitive not only to the motor output load but also to the central processing load.

Key words: mental workload, interval production, tapping task, attentional resource

Assessing mental workload is important for developing a complex system, especially when human operators must control the system in a multitask environment. Many measures for assessing mental workload has been developed and they are classified into three types: (i) performance-based assessment, (ii) subjective workload assessment, and (iii) physiological workload assessment (Eggemeier, Wilson, Kramer, & Damos, 1991). In the performance-based assessment, a secondary task is performed with a primary task. It is assumed that the variation of mental workload is reflected to per-

formance of the secondary task. In the present study, a sensitivity of the tapping task as a secondary task was investigated.

In the time perception literature, it has been reported that perceived duration of the interval is shortened when a non-temporal task is performed in the interval to be estimated (e.g. Hicks, Miller & Kinsbourne, 1976; Brown, 1985). When subjects were asked to produce an interval, a produced interval is likely to be longer as a function of processing demand of non-temporal task (e.g. Fortin & Breton, 1995; Fortin & Rousseau, 1987; Fortin, Rousseau, Bourque & Kirouac, 1993).

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These previous studies indicate that time estimation and interval production can be used as a secondary task to measure mental workload.

In fact, time estimation and interval production have been used in some mental workload studies. For example, time estimation and interval production were adopted to assess mental workload in driving a car (Brown, Simmonds & Tickner, 1967) and operating aircraft simulators (Casali & Wierwille, 1983; Zakay & Shub, 1998). When an interval that subjects experienced as performing a primary task was estimated by the prospective time estimation paradigm², the duration of the interval was likely to be underestimated as the primary task became more demanding. When interval production was combined with a primary task, the produced interval increased as the primary task became more demanding. The prospective time estimation is suggested to be sensitive to perceptual load (Eggemeier et al., 1991), while the interval production was suggested to be sensitive to motor output load (Eggemeier, 1988).

In the present study, the primary task was the time sharing task in which subjects were required to monitor several targets moving horizontally and to control them by changing the direction of movement. The secondary task was a tapping task that required subjects to produce a series of regular responses using their finger. Two kinds of task demands were manipulated: one was the speed of the targets related to the demand on allocating attentional resource to one target, and the other was the number of targets related to the demand on switching the target to which an attentional resource was mainly allocated. The purpose of this study was to examine the sensitivity of the tapping task to these task demands.

Experiment

Method

Subjects. Thirteen undergraduates and graduates (10 males and 3 females) of the department of

psychology of Osaka University, Japan volunteered to participate in the experiment.

Apparatus. A PC-AT compatible computer was used to control the experiment. In order to measure produced intervals, the internal system timer of the computer was used via application programming interface of the operation system (Microsoft Windows 95). Stimulus was presented on a SVGA display monitor (SONY CPD-17sf2, Tokyo, Japan), which was placed approximately 60 cm from the subject. A 106-key type keyboard was used for the response both for the primary task and for the tapping task.

Tasks. The primary task was a time sharing task developed by Goldstein and Dorfman (1978). Subjects were presented rectangular frames on the computer screen. The size of a frame was approximately 191 mm long and 27 mm high (18.0 deg by 2.6 deg). Each frame contained a target moving at a uniform speed to the right or left. Subjects could reverse the direction of movement of the target by pressing the corresponding buttons assigned to each frame. Subjects were instructed to keep the moving targets in the frames and to prevent the targets from reaching both ends of the frames. When a target approached either end of the frame, subjects had to change the direction of the movement of the target by pressing the button corresponding to the frame.

Goldstein and Dorfman (1978) changed the number of frames and the speed of targets to manipulate load stress and speed stress, respectively. Also, in the present study, the number of frames varied from one to three. It was assumed that the more frames subjects had to monitor, the more switching of attention between frames was required. The target moved at one of three levels of speed: low (6.38 deg/s), medium (12.24 deg/s), and high (17.56 deg/s). It was assumed that manipulating the speed of target varied the demand to allocate an attentional resource to one target. When the targets moved faster, subjects were required to monitor them more carefully and to make responses to reverse the direction of movement

² In the prospective time estimation paradigm, subjects are informed that they will be asked to judge duration of the interval prior to the beginning of task.

more frequently than when the target moved slowly. In this case greater attentional resources would have to be allocated to the target. As a result, demand on allocating attention to one target increased.

The secondary task was the tapping task. Subjects were asked to produce approximately 3 s intervals by pressing “z” key of the keyboard by the index finger of their left hand. Subjects were also instructed to make an effort to keep the rate of interval production constant over the experiment.

Subjective workload assessment. To assess a subjective mental workload in the present experiment, six scales in the Japanese version (Miyake & Kumashiro, 1993) of the NASA-TLX (Hart et al., 1988) were used. These scales were: (i) “mental demand,” (ii) “physical demand,” (iii) “temporal demand,” (iv) “performance,” (v) “effort,” and (vi) “frustration level.” In addition, subjects rated the overall workload on the scale that Haga and Mizukami, 1996) used. These seven subjective mental workload scales were presented on a sheet of paper with each of the scale titles followed by a 12-cm line marked with the appropriate end-point descriptors. Subjects marked the appropriate point on each line to indicate the extent of their experienced workload. The distance of the marks from the left end of each scale was measured for the raw rating (from 0 “very low” to 100 “very high”).

Procedure. Subjects were tested individually. After instruction, subjects practiced the tapping task and the time sharing task separately for 30 s. Although subjects were instructed to produce 3 s intervals, no feedback on duration of produced interval was provided. Subjects were encouraged to minimize variation of produced intervals rather than to adjust produced interval to 3 s. Produced intervals in the practice were treated as in the control condition. The experiment session consisted of nine sub-sessions in three blocks. In each sub-session, subjects experienced one of nine possible combinations of the number of frames condition and the target speed condition. In one block,

subjects performed 40 s of the concurrent performance of the time sharing task and the tapping task.

At the beginning of each block, subjects were asked to start tapping after the warning signal. The frames were presented and the time sharing task began. The default location of the target ranged from 69 mm to 127 mm from the left end of a frame and it was varied among trials at random. The subject monitored the targets and pressed keys to reverse the direction of movement of the target by using the index finger of their right hand. Subjects had to select the corresponding key assigned to the frame which reversed the movement of the target. The “8” key of the 10-key board was assigned to the top frame of the target, the “5” to the middle frame of the target and the “2” to the bottom frame of the target, respectively. After completing each block of three trials, subjects were asked to complete seven measures of the NASA-TLX to assess subjective workload. The total duration of the experiment was approximately 1 h.

Results

Primary task performance. The number of targets that reached either end of the frame was treated as the error of the primary task. Figure 1 indicates that the number of errors that occurred in each block. A two-way repeated

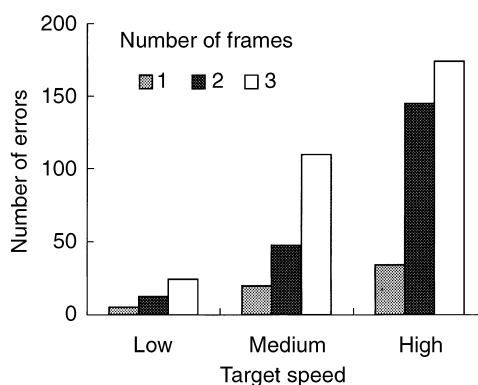


Figure 1. Number of errors of the primary task as a function of the number of frames and the speed of targets.

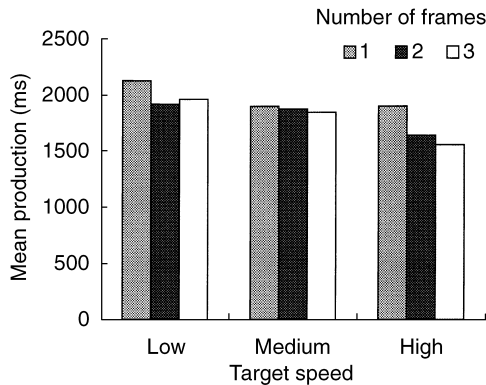


Figure 2. Mean produced intervals as a function of the number of frames and the speed of targets. Mean produced interval in the control condition was 2206 ms.

measure of ANOVA was used. The independent variables were the number of frames (one, two, or three) and the target speed (low, medium or high). The ANOVA indicated that the main effects were significant ($F_{s_{2,24}} > 69.98$, $p < 0.001$). The interaction was also significant ($F_{4,48} = 17.33$, $p < 0.001$). Simple main effect analysis revealed that when the speed of the targets was low, there was no significant difference in the number of frames condition ($F_{2,24} = 1.28$, ns).

Tapping task performance. Figure 2 indicates mean interval productions in each condition. The two-way repeated measures ANOVA indicated that the main effect of the target speed was significant ($F_{2,24} = 12.51$, $p < 0.001$), and the main effect of the number of frames condition was also significant ($F_{2,24} = 6.53$, $p < 0.006$). The interaction was not significant ($F_{4,48} = 1.79$, ns). Produced intervals decreased as the target speed increased and as more frames were presented. The mean produced interval in the control condition (2206 ms) was compared with mean produced intervals in experimental condition. The one-way ANOVA indicated that the main effect was significant ($F_{9,106} = 4.23$, $p < 0.001$), and the Tukey test showed that the intervals produced under control conditions were significantly longer than those in the experimental blocks ($p < 0.05$), except when

one frame was presented at the lowest target speed.

The standard deviations in each condition are shown in Figure 3. The two-ways repeated measures of ANOVA indicated that both the main effect of target speed and that of the number of frames were significant ($F_{s_{2,24}} > 7.14$, $p < 0.04$), suggesting that a variation of produced intervals increased as the primary task became more demanding. The interaction was also significant ($F_{4,48} = 2.70$, $p < 0.05$). Simple main effects analysis indicated that there was no significant difference among the number of frames condition when the target speed was high ($F_{2,24} = 0.76$, ns). When three frames were presented, no significant difference was found in the target speed condition ($F_{2,24} = 0.48$, ns).

Subjective mental workload. The original version of the NASA-TLX includes the process evaluating relative importance of the six subscales by each subject to calculate a weighted mean. Miyake and Kumashiro (1993) reported a high correlation ($r = 0.971$) between the weighted mean computed in the original NASA-TLX and the simple arithmetic mean ratings of the scales. Their results suggest that the mean ratings can be considered an appropriate subjective workload measure. Thus, in the present study this evaluation process was omitted. A simple arithmetic mean was computed across subscales of the NASA-TLX and it was treated as a subjective workload score.

Subjective workload scores for each condition (Figure 4) were submitted to the two-way repeated measures of ANOVA. The main effect of the target speed was significant ($F_{2,24} = 17.45$, $p < 0.001$), and the main effect of the frames was also significant ($F_{2,24} = 23.86$, $p < 0.001$). The interaction was not significant ($F_{4,48} = 0.60$, ns). Subjective workload increased as a function of the number of frames and the target speed. Subjective workload scores were highly correlated with the overall workload rating ($r = 0.916$).

Each of the ratings were averaged and listed in Table 1. A one-way repeated measure of ANOVA indicated that the main effect was significant ($F_{6,72} = 4.46$, $p < 0.001$), and a Tukey

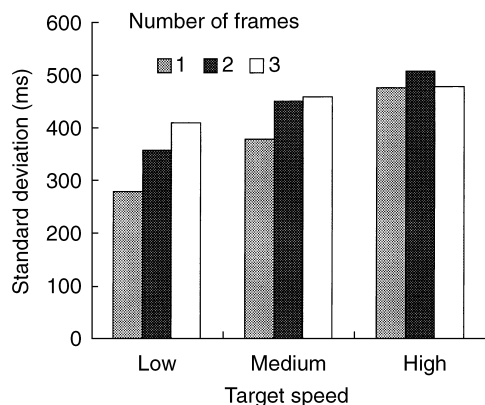


Figure 3. Standard deviation of produced intervals as a function of the number of frames and the speed of targets.

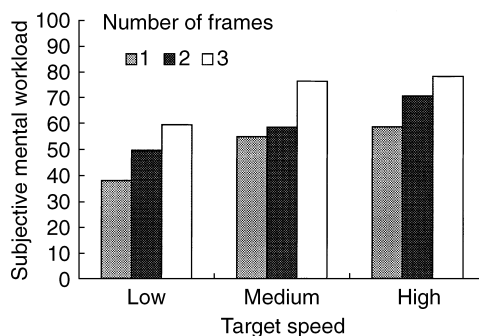


Figure 4. Mean subjective workload scores as a function of the number of frames and the speed of targets.

Table 1. Ratings of sub-scales of the NASA task load index and of overall workload

Target speed	No. frames	Sub-scales						Overall
		Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration level	
Low	1	36.3	30.9	30.0	38.2	55.1	37.9	42.8
	2	50.2	45.8	44.7	53.8	59.6	43.7	50.5
	3	60.3	54.2	55.5	62.9	72.2	51.4	60.2
Medium	1	57.1	52.4	48.8	53.5	66.7	50.2	57.1
	2	63.9	60.1	58.8	54.1	64.6	48.6	59.6
	3	79.6	75.8	80.3	72.8	83.5	65.7	77.6
High	1	53.8	60.6	63.5	61.8	63.5	47.9	61.8
	2	73.8	72.8	74.4	64.7	77.9	58.8	71.0
	3	82.1	79.7	81.9	72.7	82.2	69.9	81.9
	<i>M</i>	61.9	59.2	59.8	59.4	69.5	52.7	62.5
	<i>SD</i>	24.0	24.4	25.8	24.6	20.2	24.1	21.2

test revealed that the ratings of “effort” and “mental demand” were significantly higher than the ratings of “temporal demand,” “performance,” “physical demand” and “frustration level” ($p = 0.05$).

To examine the relation between the tapping task performance and the subjective mental workload assessment, the correlation among ratings of scales were computed. The correlation among the scales ranging from 0.495 to 0.790 were significant ($p < 0.01$). The correlation between each rating of scales and the mean and standard

deviation of produced interval was also analyzed. While the mean of produced intervals was significantly correlated only with the rating of “performance” ($r = 0.229, p < 0.013$), the standard deviation of intervals was significantly correlated with all scales ($r > 0.212, p < 0.022$).

Discussion

Performance of the primary time sharing task deteriorated as the number of frames increased and as the target speed increased. Subjective

workload scores increased as the primary task performance decreased. These results indicate that the demand of the primary task is manipulated successfully by the number of frames and the speed of targets.

The mean and the standard deviation of produced intervals varied with the number of frames and the speed of the targets. This suggests that performance of the tapping task reflects the demand of the primary task.

Motor output load and tapping

In the present experiment, as the number of frames increased, subjects were required to monitor more frames, by switching the direction of their attention, than when they were required to monitor one frame only. As the target speed increased, time to reach the end of the frame became shorter. Therefore, when several frames were presented or when the target speed was high, subjects had to schedule and to execute a strict sequence of button pressing responses. This scheduling and executing process of motor output depends on a common timing mechanism that was accessed in a range of motor and perceptual tasks (Keel & Ivry, 1991). Although there are separate mechanisms regulating the timing of each limb, these two mechanisms are integrated prior to motor execution (Helmuth & Ivry, 1996). Thus, it is expected that the primary task will interfere with the tapping task when the motor output load increased, as Eggemeier (1988) stated. This interference seems to derive from the sharing of the central timing mechanism between the primary task and the tapping task, which causes interference between tasks.

Although the previous studies (e.g. Eggemeier, 1988; Brown, 1997) have indicated that an increased task load lengthened produced intervals, the present results indicate an opposite trend; produced intervals increase as a function of task load. This could be caused by the experimental setting in which the primary task was performed by the right hand while the tapping task was performed by the left hand. Subjects had to produce responses for the primary task more frequently when the primary

task became more demanding. This right hand response sequence, which included many motor responses incompatible with the tapping sequence, could have accelerated the tapping performed by subject's left hand.

Sensitivity of the tapping task to mental workload

Although primary task performance can be used as an index of workload, it cannot measure workload appropriately when two tasks are so easy that processing capacity is reserved (Wickens, 1992). When a task becomes more difficult, subjects try to spend the reserved attentional resource in maintaining performance. As long as reserved resource remains, deterioration of task performance is minimized. In the present study, when the target speed was low, the number of frames did not have significant effect on errors of the primary task (Figure 1). When several frames were presented, subjects had to monitor frames by switching the direction of attention among frames. This result implies that in the low target speed condition, subjects succeeded in maintaining primary task performance by using the reserved attentional resource to cope with an increase in time sharing demands. However, even when the target speed was low, the mean and the standard deviation of produced intervals reflected the difference of workload, based on the number of frames (Figures 2 and 3). The present study revealed that the tapping task was so sensitive that the task could detect an increasing time sharing demand, even though decreased performance of the primary task was observed.

When the target speed was low, the standard deviation of intervals increased as a function of the number of frames. When the target speed was high, however, there was no difference in standard deviation among the number of frames. Also, when three frames were presented, the effect of target speed on standard deviation was not significant. These results suggest that the standard deviation is not sensitive to the mental workload produced by the heaviest demand. The tapping task seems to be useful as an index suitable for relatively low or medium levels of workload.

Subjective mental workload assessment

The subjective workload assessment indicated that "effort" and "mental demand" were of relative importance in the present time sharing task. Hart and Staveland (1988) stated that "effort" relates to the extent of how hard subjects have to work mentally and physically to accomplish their level of performance, and "mental demand" relates to the extent how much mental and perceptual activity subjects were required to use. The results imply that the present task imposes on subjects not only motor output load, but also load relating to mental demand. Haga and Mizukami (1996) showed that when subjective workload while performing a mental arithmetic task was assessed by the NASA-TLX, mental demand was highly weighted. A mental arithmetic task requires a general attentional resource (Wickens & Kessel, 1980; Reisberg, 1983; Brown, 1997). Thus, it is supposed that the present time sharing task requires an attentional resource which the mental arithmetic task also requires, and that the tapping task reflects the amount of attentional resource allocated to primary task performance. This interpretation is consistent with the findings of several previous studies (Brown, 1997; Shinohara, 1999) that an interval production task requires a central and general purpose processing resource.

Analysis of correlation between the assessments of subjective workload and the tapping task performance indicates that the standard deviation of intervals varied with the subjective measures of workload; on the other hand, the means of intervals did not correlate with most of the ratings of subjective workload. This result suggests that the standard deviation can reflect workload assessed by subjective measures. Yeh and Wickens (1988) suggested that a subjective workload measure directly reflects the effort of task performance and the number of concurrent tasks. As described above, effort and mental demand were given relatively high importance in the present task. Thus, the standard deviation of intervals, rather than the mean of intervals, is supposed to be good measure of physical or mental effort and the amount of mental activity required by the task.

Summary

In the present study, increased demand of the primary time sharing task was successfully detected by the tapping task, even when primary task performance did not reflect this increase of demand. Results of the dual task experiment indicated that the tapping task was sensitive to the motor output load, and the result of subjective workload assessment implied that the tapping task also reflected a central processing demand of the primary task. While several previous studies (e.g. Brown, 1997) have proposed that a central processing resource is required to perform the tapping task, some other studies (e.g. Eggemeier et al., 1991) indicated a sensitivity of tapping task to motor output load. However, analysis of the present study implies that the tapping task reflects both motor output load and central processing load. Further study is required to investigate sensitivity to central processing load and to motor output load separately.

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