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Continuous Subjective Workload Assessment Technique

Ameersing Luximon[1] and Ravindra S. Goonetilleke[2]
Human Performance Laboratory
Department of Industrial Engineering and Engineering management
Hong Kong University of Science and Technology
Clear Water Bay, Kowloon, Hong Kong
Email:[1] ieshyam@ust.hk and [2] ravindra@ust.hk

Despite the wide usage of the Subjective Workload Assessment Technique (SWAT), it has two main problems: it is not so sensitive at low mental workload and it requires a card sorting procedure that is time consuming. This paper suggests improvements to the original SWAT scale. The card sorting procedure has been replaced by a pair-wise comparison procedure similar to that of the National Aeronautics and Space Administration - Task Load Index (NASA-TLX). In addition, a continuous scale is used instead of the discrete SWAT scale. This Continuous SWAT scale (C-SWAT) has been compared experimentally with the original SWAT scale using simple arithmetic tasks. Results show that the "new" procedure takes significantly less time than the original card sorting procedure. The results also seem to indicate that C-SWAT is sensitive at low mental workloads. At medium mental workloads, the SWAT and C-SWAT scales give similar results.

INTRODUCTION

The purpose of subjective workload assessment techniques is to assess the operator cognitive load. Advantages of subjective measures include their ease of use, general non intrusiveness, low cost, high face validity, and known sensitivity to workload variations (Reid and Nygren, 1988). Two of the common subjective workload assessment techniques are SWAT and NASA-TLX (Hendy et al. 1993). In SWAT, conjoint analysis is used to obtain a scale having interval properties. SWAT is composed of ratings for time load, mental effort load, and psychological stress load (Reid and Nygren, 1988) as opposed to NASA-TLX which has six dimensions (Hart and Staveland, 1988).

Even though the SWAT scale has been used extensively, it is insensitive when the workload is low (Hart and Staveland, 1988). Sensitivity has been defined as the ability of a measure to discriminate statistically between different load conditions (Wierwille and Connor, 1983). The sensitivity of the SWAT scale could be improved by adding more levels to each of its three scales (Nygren, 1991). However, the addition of more levels would make the card sorting task prohibitively difficult, error prone, and time consuming. This paper is an attempt to improve on the card sorting procedure. A procedure similar to the pair-wise comparisons of NASA-TLX is used. In addition, the discrete SWAT scale has been replaced by a continuous scale for improved discrimination.

Simple arithmetic tasks have been shown to simulate low mental workload tasks (Humphrey and Kramer, 1994). Hence, the effectiveness of the C-SWAT scale has been verified using simple arithmetic tasks.

METHODOLOGY

Subjects

Fifteen students from the Hong Kong University of Science and Technology participated in the study.

Procedure

After completing the informed consent form, each of the subjects was given information about the objectives and procedure of the experiment. For the SWAT card sorting procedure, the subject was asked to sort 27 cards in increasing order of mental workload (Reid and Nygren, 1988). For the C-SWAT pair-wise comparison procedure (Figure 1), the subjects were asked to select one of the two dimensions of workload that they felt was more critical to them. Each subject did both the card sorting and pair-wise comparison procedures and the time taken for each was recorded. The procedure done first was randomly assigned.

After the initial SWAT and C-SWAT procedures, each of the subjects completed a set of arithmetic tasks. In this experiment, 3 operations (addition, subtraction, and multiplication) and 2 operands were used. The type of operation and the operands determined the task difficulty (or workload). The number of digits in the first and second operand ranged from 1 to 4 (i.e. 1, 2, 3, or 4). The tasks were presented to the subject through an interface designed in visual C++ (Version 5). The task presentation was completely randomized and counter-balanced. The time taken to complete the arithmetic tasks were recorded in a computer file. Errors were also recorded. After completing each task, the subject's estimate of the mental workload was assessed using the 3 dimensions of the continuous C-SWAT and the discrete SWAT scale. Here again, the first assessment was randomly assigned.

The dependent variables were Time to complete each task, Errors, SWAT score and C-SWAT score.

Please tick one of the two dimensions of workload that you think is more important to you.

Mental Effort Load ❒/ Time Load ❒
Time Load ❒/ Psychological Stress Load ❒
Psychological Stress Load ❒/ Mental Effort Load ❒

Figure 1. The pair-wise comparison procedure.

Results and Analysis

The overall mental workload score was used in all subsequent analyses. For the SWAT scale, conjoint analysis was used to produce overall workload values between 0 to 100 (Reid and Nygren, 1988). For the C-SWAT scale, an overall workload level was obtained using weightings similar to NASA-TLX (Hart and Staveland, 1988).

All statistical tests were carried out using the SAS statistical package. A t-test showed a significantly lower time for the C-SWAT pair-wise comparison procedure ($t(14)=9.097$, $p< 0.05$). The mean time for the pair-wise comparison task was 22.08 seconds, as opposed to 476.49 seconds for the card sorting procedure.

Correlation (Table 1) and factor analyses showed that SWAT and C-SWAT are closely related (R^2 = 0.66). Correlation analysis for each operation (Tables 2-4) showed that there is a relatively high correlation between SWAT and C-SWAT for multiplication (R^2=0.72), but relatively low for addition (R^2=0.28) and subtraction (R^2=0.44). The factor analysis with varimax rotation showed the emergence of three factors that could explain 95% of the variation. The first factor (explains 61.4% of variance) is loaded by the mental workload measures of SWAT (factor loading = 0.91) and C-SWAT (factor loading = 0.91). The second factor (explains 21.5% of variance) is loaded by Time (factor loading = 0.93), and the third factor (explains 12.4% of variance) is loaded with the Error measure (factor loading =0.99).

Table 1. Overall Correlations

	SWAT	C-SWAT	Error	Time
SWAT	1	0.81	0.28	0.57
C-SWAT	0.81	1	0.25	0.58
Error	0.28	0.25	1	0.25
Time	0.57	0.58	0.25	1

Table 2. Correlations for multiplication

	SWAT	C-SWAT	Error	Time
SWAT	1	0.85	0.31	0.59
C-SWAT	0.85	1	0.23	0.50
Error	0.31	0.23	1	0.27
Time	0.59	0.50	0.27	1

Table 3. Correlations for addition

	SWAT	C-SWAT	Error	Time
SWAT	1	0.53	0.15	0.24
C-SWAT	0.53	1	0.29	0.22
Error	0.15	0.29	1	0.10
Time	0.24	0.22	0.10	1

Table 4. Correlations for subtraction

	SWAT	C-SWAT	Error	Time
SWAT	1	0.66	0	0.21
C-SWAT	0.66	1	0	0.38
Error	0	0	1	0
Time	0.21	0.38	0	1

A 3 (Operations) * 4 (First operand) * 4 (Second operand) analysis of variance was performed using task completion time (Time), computation error (Error), C-SWAT score, and SWAT score as dependent variables. For the Error measure, only the main effects were significant at the $p<0.05$ level. For the Time measure, all the main effects and all the interactions were significant at $p<0.05$. For the mental workload measures of SWAT and C-SWAT, all the main effects and the interactions of "Operation*First operand" and "Operation*Second operand" were significant at $p< 0.05$. The *post-hoc* Student-Newman Keuls (SNK) tests are shown in Figure 2. It could be seen that multiplication took more time to complete, had significantly more errors, and imposed significantly higher mental workload. Similar effects were seen for the higher number of digits in the first and second operand.

	Operation	First Operand	Second Operand
SWAT	x - +	4 3 2 1	4 3 2 1
C-SWAT	x - +	4 3 2 1	4 3 2 1
Error	x - +	4 3 2 1	4 3 2 1
Time	x + -	4 3 2 1	4 3 2 1

Figure 2. SNK comparison of means

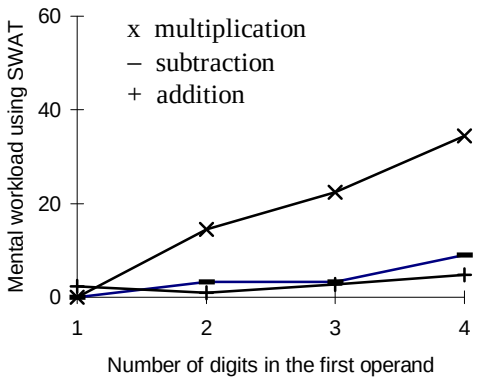

Figure 3. SWAT rating versus number of digits in first operand for each operation

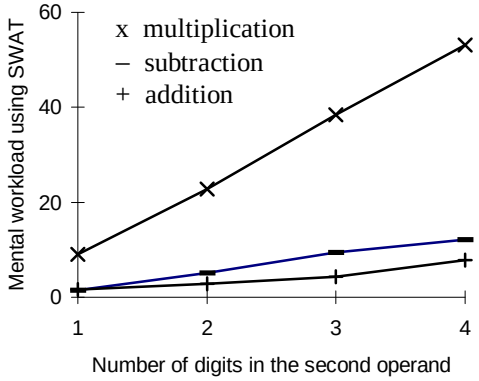

Figure 4. SWAT rating versus number of digits in second operand for each operation

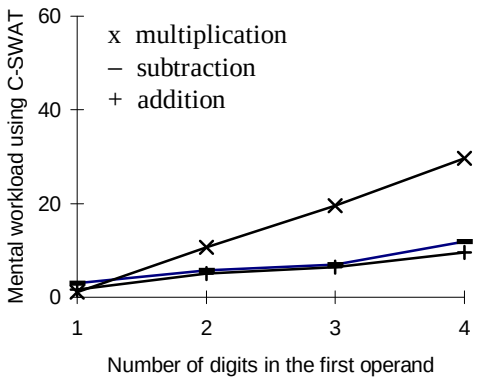

Figure 5. C-SWAT rating versus number of digits in first operand for each operation

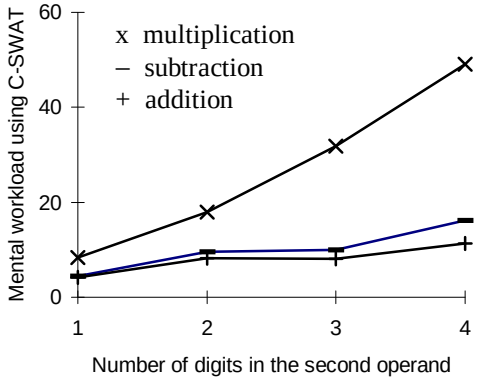

Figure 6. C-SWAT rating versus number of digits in second operand for each operation

The interaction plots of "Operation*First operand" and "Operation*Second operand" for the SWAT and C-SWAT scales are shown in Figures 3 to 6. The plots show that an increase in the number of digits results in a higher mental workload. The multiplication operation imposes a higher workload compared to the subtraction and addition operations as shown in Figure 2. The simple-effects analysis (Figure 7) showed that SWAT cannot discriminate between the number of digits for the addition operation even though significant differences were seen with C-SWAT and Time. Humphrey and Kramer (1994) have shown that there is a

significant change in the P300 component of Event Related Potential (ERP) when doing mental arithmetic tasks with addition and multiplication operations of single digit numbers. In addition, they found a significant change in the subjective rating of the two sub-scales (mental workload and effort) in NASA-TLX. The tasks performed here were similar and it is likely that there were differences in workload between the number of digits for the multiplication and addition operations.

	Operation					
	Multiplication (x)		Subtraction(–)		Addition (+)	
	First	Second	First	Second	First	Second
SWAT	4 3 2 1	4 3 2 1	4 3 2 1	4 3 1 2	4 3 1 2	4 3 2 1
C-SWAT	4 3 2 1	4 3 2 1	4 3 2 1	4 3 1 2	4 3 2 1	4 3 1 2
Time	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1

Figure 7. SNK comparisons of mean scores by operation. Error is not shown since the interaction terms were not significant at the $p < 0.05$ level

CONCLUSIONS

The main advantage of C-SWAT is that the time consuming sorting procedure in SWAT is replaced by a simple pair-wise comparison similar to the NASA-TLX (Hart and Staveland, 1988). The results show that the C-SWAT score is highly correlated with the SWAT score for multiplication operations or medium workload levels. However, this result does not seem to be true, especially for the addition task (i.e., low mental workload). The differences may be attributed to the low sensitivity of the SWAT scale at low workloads as seen by the SNK grouping for the addition task (Figure 7).

The C-SWAT scale has some disadvantages. Firstly, it may not have the interval property similar to NASA-TLX. In addition, the pair-wise comparison procedure results in only a limited range of weights (Nygren, 1991).

In this experiment, simple arithmetic tasks were used to determine the differences between SWAT and C-SWAT. Further validation may be needed with tasks of differing workload, to confirm the above findings.

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