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An attempt at mental load quantification in some mental tasks

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The aim of this study was to indirectly quantify mental load in counting backward tasks (assessed on Borg's scale), by use of fitted regression line between Fitts' tapping task difficulty indices (bits) and the ratings of their difficulty, on the same scale. Starting a minute before the tasks, as well as during the task, subjects' cardiac R-R intervals were countinuosly recorded. A good regression fit was obtained between the task difficulties in Fitts' tapping (bits) and their ratings ($y = 1.36+1.87x$; $r = 0.78$). By the use of this regression, the estimates of mental load were transformed into equivalents of bits. Fitts' tapping tasks were also performed together with the three mental tasks, as primary and secondary tasks, respectively. Generally, the validity of mental load quantification was indirectly supported by rather high and significant correlations between mental load equivalents in bits, on the one hand, and the ratings, residual mental capacity and cardiac parameters, on the other hand.

One of the problems when dealing with mental load is that it is often difficult, if not impossible, to quantify it at the input. It means that predictions of changes in dependent variables are unreliable. A number of authors recommended the use of different techniques for mental load assessment at the output, such as efficiency (time and error), residual mental capacity, subjective ratings of task difficulty, and changes in physiological variables, such as EEG, sinus arrhythmia, etc.

Efficiency, as the dependent variable, has its shortcomings, because time and/or errors depend on nature of the tasks, its complexity and the skills of subjects. Similarly, changes in physiological variables will depend on perceived task difficulty, which in a way, includes all major task characteristics. Together with this, various others extraneous variables may also have effects on physiological changes. Use of residual mental capacity for load assessment in various primary tasks, although theoretically rather elegant and straightforward technique, has several major applicational drawbacks, such as interference of primary and secondary tasks, as well as subjects' focus on the instructions how to do the tasks.

Subjective ratings of task load have shortcomings as well: the technique is subjective and cannot be controlled, therefore, its reliability cannot be assessed. On the other hand, this technique has, at least theoreticaly, some advantages, because it may incorporate various aspects of the task difficulty, such as perceptual, motor or mental.

In many studies various techniques were used simultanously in mental load assessment, where different authors, using different tasks, obtained various results.

Borg (1972., 1973., 1978.), for example, used a semy-descriptive scale for task difficulty assessment, which ranged from zero, meaning *'without load'*, to 20, meaning *'extreme load'*. He obtained high correlations between mental and physical workload, on the one hand, and subjective ratings on the scale, on the other hand. He also found high correlations between pulse rate and the ratings of task difficulty, as well as between the task workload and pulse rate.

In the series of the experiments Manenica (1994) used numerical and perceptual tasks, which were performed by two groups of subjects differing in anxiety level, under unpaced and computer-paced working conditions. There were five different levels of difficulty in numerical and three levels in perceptual tasks. For the workload assessment, he used subjective ratings on Borg's scale, heart rate variability parameters, and secondary task (finger tapping) technique. The results showed a high degree of agreement amongst the parameters of the three techniques, where subjective ratings were the most sensitive in differentiation of the load difficulty between the low and high anxiety groups, as well as between the two pacing situations. Secondary task parameters, however, indicated a smaller residual mental capacity in the high anxiety group, which fitted well with other parameters of the workload assessment. The sinus arrythmia parameters, were not very sensitive in

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differentiating the workload, apart from pacing stress. In this study, as well as in the study of Manenica and Krošnjar (1990), subjective assessment technique was found to be more sensitive to various 'hidden stressors', such as pacing stress, differences in residual mental capacity, as well as the task difficulty levels.

It ought to be said that different studies in this area have not come up with the same results, some of them being even contradictory. This may be due to differences in physical component in the tasks used, as well as in the levels of emotional or motivational engagement in the task. Therefore, various parameters (especially cardiac) may differ from task to task, or even within the same task in different time points.

The aim of this investigation was to try to quantify mental load in counting backward tasks by use of known quantities in some other tasks, expressed in bits, i.e. Fitts' tapping tasks. Subjective ratings of task difficulties in mental tasks and Fitts' tapping tasks will serve as a link between the two kinds of tasks.

Hypothesis

Although the task difficulty of the tasks which are different in the nature, such as Fitts' tapping (perceptual-motor task) and counting backward from a given number (mental task), can be assessed only subjectively, the same scale should be used to obtain the equivalents of the task difficulties.

Based on regression line between the task load in Fitts' tapping, expressed in bits, and the subjective difficulty ratings of the same tasks, the task difficulty equivalents of the counting backward tasks could be transformed into bits by the use of their subjective ratings. A good relationship could also be expected between the Fitts' tapping tasks load (bits) and efficiency in the task (number of hits), as well as the subjectiveratings. Furthermore, when used as primary and secondary tasks, with the increase in the task load of Fitts' tapping, a deterioration in the efficiency of the secondary tasks could be expected. Apart from this, the degree of deterioration would depend on the level of difficulty of secondary task, while the efficiency in the primary task should stay relatively stable.

Taking into account the results of some studies where sinus arrhythmia parameters were used, it could be expected that subjectively equivalent task loads of Fitts' tapping and mental tasks would have approximately similar magnitudes of sinus arrhythmia parameters.

METHOD

This investigation started with a pilot experiment, which included ratings of relative difficulty of some mental tasks by paired comparison method. Fifty subjects compared in pairs the difficulty of counting backward by three, seven, nine, eleven, thirteen and seventeen, which relative difficulty was expressed in z-values. Three numbers (three, nine, and thirteen) were chosen for the main experiment because of their position on z-scale, i.e. they were far enough from each other, and they did not represent major problem for the subjects.

The main experiments included a group of subjects, 18 to 20 years old, who performed six Fitts' tapping tasks, ranging in difficulty from one to six bits. The tasks included alternative hitting of two identical targets at the time, which widths were 0.5, 1.0, 2.0, and 4.0 cm, while the distances from each other (amplitudes) were 4.0, 8.0, and 16.0 cm. Various combinations of the target widths and amplitudes gave the tasks various levels of difficulty.

By use of Fitts' (1954) formula, the task difficulties were computed on the basis of two known elements, target width and amplitude.

$$ID = \log_2 (2A/W),$$

where,

ID = index of difficulty (bits)

W = target width (cm)

A = amplitude (cm).

In every experimental situation subject performed Fitts' tapping for one minute, during which he was not allowed to do more than four target misses (errors). If the subject made more than four errors, he had to repeat that task.

Each subject performed the six Fitts' tapping tasks four times, i.e. as a single, and as the primary task, simultaneously with counting backwards by three, by nine, and by thirteen. Apart from being performed as secondary task with Fitts' tapping, the mental tasks were also performed as single tasks.

When doing primary and secondary tasks simultaneously, the subject was asked to concentrate on the primary task, and to do the secondary as much as the working on the primary would allow him.

In every experimental situation the number of target hits of Fitts' tapping was recorded and the number of counts in mental tasks. During all experimental sessions, as well as prior to the beginning, subjects' R-R intervals were continuously recorded and registered using three electrodes, which were connected to a computerised polygraph system. At the end of every experimental situation subjects rated the difficulty of the completed task on Borg's scale.

RESULTS AND DISCUSSION

High correlations were found between the task load in Fitts' tapping when performed on its own, and the subjective ratings of the task difficulty (r=0.78), as well as between the difficulty of counting backward tasks expressed in z-values and their subjective ratings (r=0.75).

The relationship for Fitts' tapping is shown in Figure 1., which was used for the transformation of mental task difficulty into equivalents of bits, by the use of formula:

EB = (DA-1.36)/1.87, where EB = equivalents in bits, and DA = difficulty assessment. The transformed values of the mental tasks difficulties are shown in Table 1.

The correlations between the efficiency in Fitts' tapping task and mental task, on the one hand, and subjective ratings of the difficulty on the other, were –0.72 and –0.75, respectively.

One of the indications that efficiency results in Fitts' tapping tasks are reliable could be seen *via* high correlation with the task difficulty in bits (r=-0.94).

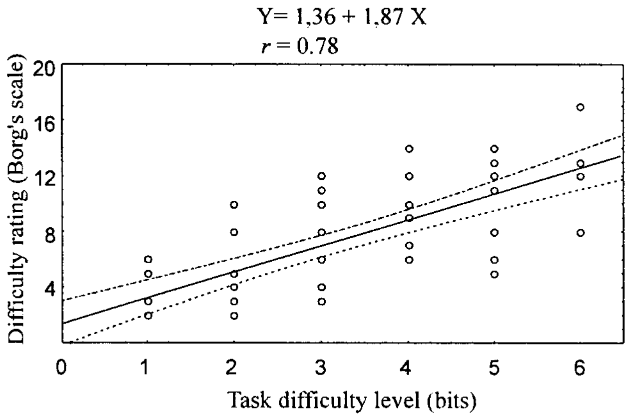

Figure 1. Relationship between the task difficulty of Fitts' tapping and its subjective ratings on Borg's scale

Table 1

Difficulty ratings of mental tasks transformed into equivalents of bits

Counting backward by	z-values	Equivalents in bits
3	-2.34	2.2
11	-0.95	2.8
9	-0.39	4.4
7	-0.15	4.7
13	1.66	6.5
17	2.18	7.1

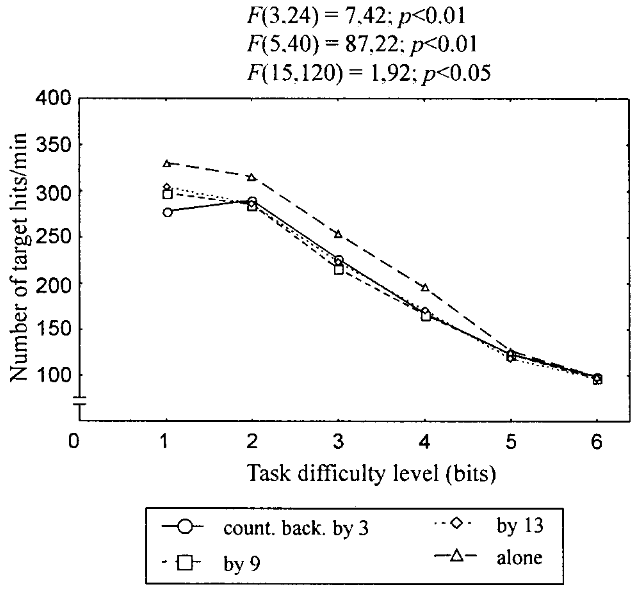

Figure 2. Efficiency in Fitts' tapping tasks, when performed alone and simultaneously with counting backward by 3, 9 and 13

A significant correlation was also found between subjective ratings of task difficulty and cardiac R-R intervals, which indicates that both variables similarly reflect the task difficulty (r=0.33).

Figure 2 shows the changes in efficiency in Fitts' tapping (number of target hits) in relation to the task difficulty when the task was performed on its own, and as the primary task, with the three mental tasks as secondary tasks. Apart from the changes in efficiency due to the changes in complexity level of the task, there is a significant difference in efficiency between the situations when the task was performed as single, and when performed as the primary task, up to the level of four bits of difficulty. The efficiency in Fitts' tapping, when performed as the primary task, dropped *en bloc* for about 17%, regardless of the secondary task difficulty. This indicates that the subjects were concentrated on performing the primary task during simultaneous performance of mental tasks, which resulted in reliable results. The changes in efficiency that took place due to the Fitts' tapping task difficulty were congruent, which is seen in cross-correlations amongst the four situations, ranging from 0.89 to 0.97.

As it was expected, the efficiency in the three mental tasks when used as secondary tasks simultaneously with Fitts' tapping deteriorated as the primary task difficulty increased (Figure 3). At the same time significant differences in the efficiency amongst secondary tasks occurred due to the differences in their difficulty. The slopes of their efficiency curves are not the same, the steepest being for counting by three and the flattest for counting by 13. This means that simpler secondary task was more sensitive to changes in the primary task load.

The changes in the task difficulty ratings when Fitts' tapping was performed as a single, and as the primary task given with three mental tasks are shown in Figure 4. As can be seen, there is a marked difference between the difficulty ratings of Fitts' tapping task when performed alone and when performed with the secondary tasks. The estimates of the task difficulties are significantly higher when the two tasks were performed simultaneously. It seems that the subjects assessed the difficulties of the two cumulatively, which could be seen *via* the estimates when the tasks were done simultaneously. No differences were found amongst the three assessments, which slopes were similar to the Fitts' task when performed on its own. Thus, there was a difference in correlation between the task load difficulty assessments when Fitts' tapping was performed alone (0.78) and when performed with secondary tasks, where correlations ranged from 0.50 to 0.57.

It should be pointed out that there was no correlation between the subjective ratings of the task difficulty and the efficiency in secondary tasks. This also points toward the subjects' reliability in concentrating on performance of the primary task.

Cardiac parameters used were the means of R-R intervals and sddR parameter, which is standard deviation of the differences between successive R-R intervals. It represents internal variability, or homogeneity of the data. As it was mentioned earlier it was expected that R-R intervals would reflect changes in physical component of the tasks, while the sddR parameter would reflect changes in mental component of the tasks.

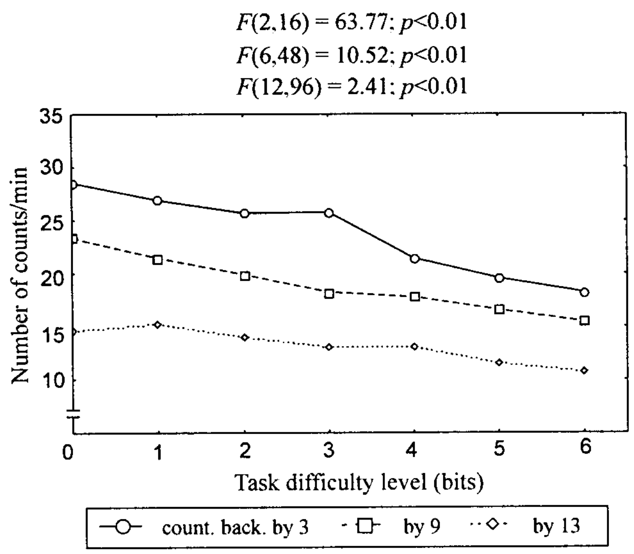

Figure 3. Efficiency in counting tasks when performed alone (level 0) and as the secondary tasks with Fitts' tapping

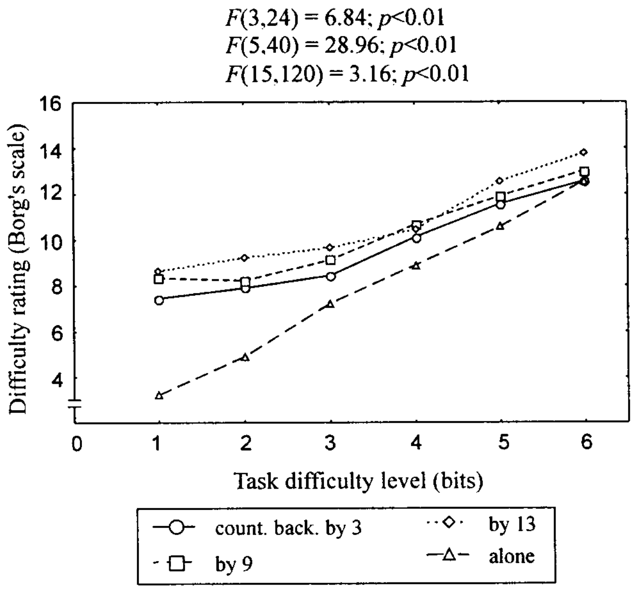

Figure 4. Changes in the ratings task difficulty of Fitts' tapping, when performed alone, and with secondary tasks

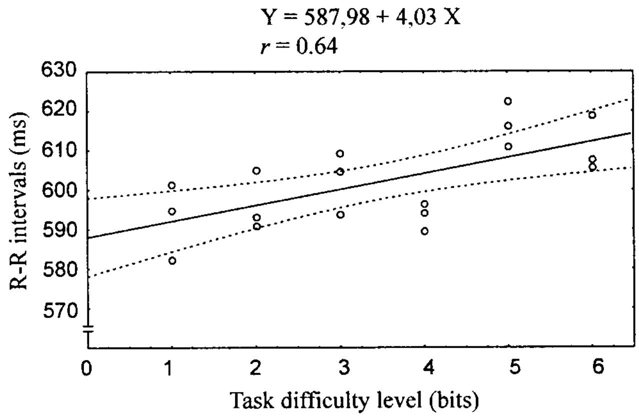

Figure 5. Relationship between the task difficulty of Fitts' tapping and cardiac R-R intervals

The obtained results suggest that at higher levels of the tapping task difficulty, where number of arm movements (hits) was much lower, there was an increase in R-R intervals (see Figure 5), which is in agreement with some earlier studies, where the tasks with significant physical components were used (Lee & Park, 1990).

The sddR parameter showed no consistent changes for any of three secondary tasks as a function of primary task difficulty change, although it differed with regard to the difficulty levels of secondary tasks (see Figure 6). This could mean that the subjects' strategy was to keep mental load of the tasks more or less subjectively constant, which was compensated by the fall in the performance of both, primary and secondary tasks.

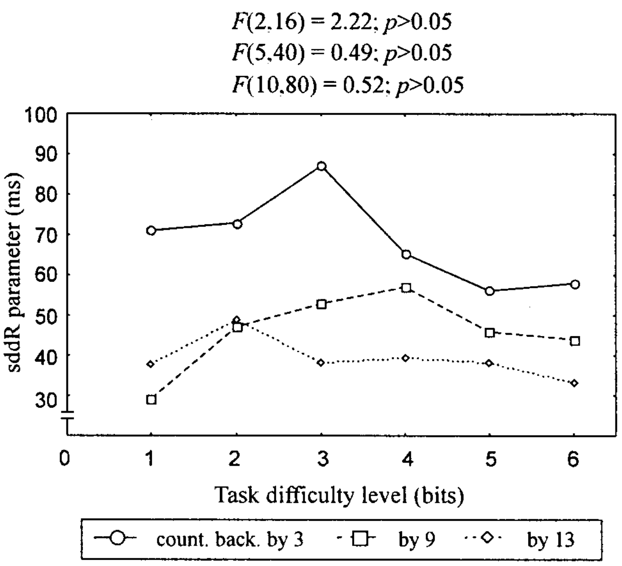

Figure 6. Changes of the cardiac sddR parameter during simultaneous performance of Fitts' tapping and counting backward tasks

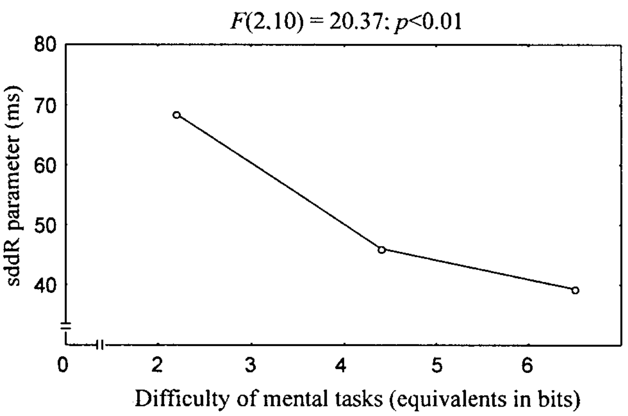

Figure 7. Difference in the level of sddR parameter for three counting backward tasks

Nevertheless, since the three secondary tasks *a priori* differed in difficulty the difference seems to have been reflected on sddR parameter in sense that it fell as the difficulty of the secondary tasks increased (see Figure 7).

As in some earlier studies, this investigation showed that R-R intervals (heart rate) may be used for the assessment of physical component of psychomotor tasks, while certain heart rate variability parameters, such as sddR may be used for differentiation amongst situations with different quantities of mental load.

One of the aims of this study was also to indirectly evaluate subjective assessment of the task difficulty as a method. The idea was that, if subjective method of evaluation is reliable and usable for various kinds of tasks, the

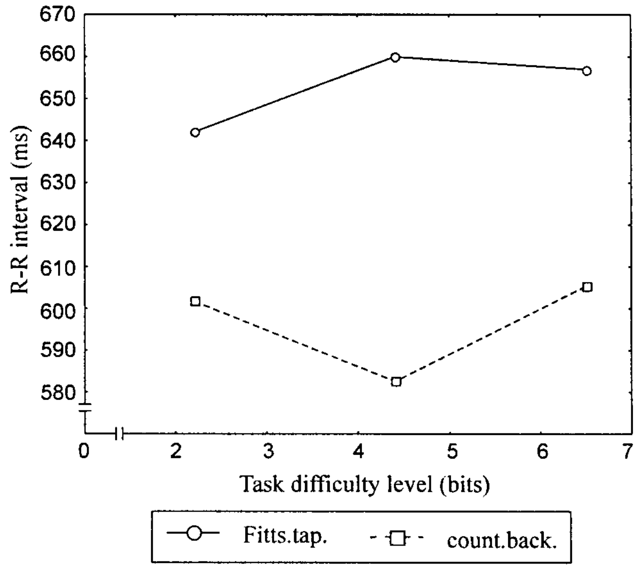

Figure 8. Comparison of means of the cardiac R-R intervals for equivalent values (bits) of mental and Fitts' tapping tasks

same estimates in different tasks could have similar levels of physiological variables. As mentioned at the beginning, the difficulties of the three mental tasks were transformed in to bits, where for the three obtained difficulty equivalents of mental tasks and Fitts' tapping task, the corresponding R-R intervals and the sddR parameters were compared.

The comparison of R-R intervals is shown in Figure 8., where marked differences are shown for the equivalent values expressed in bits for mental and Fitts' tapping tasks. Contrary to expectations, the R-R intervals showed higher values for Fitts' tapping, than for mental tasks equivalents, although the physical component was significantly higher in Fitts' tapping tasks. The explanation could be sought in the results of some other studies (Langewitz and Ruddel, 1989.), which suggested that mental load might have greater effects on cardiac parameters, than light physical component of psychomotor tasks.

For the same difficulty estimates, sddR parameters were also compared (see Figure 9), where the results showed no significant differences between the three difficulty estimates in mental and Fitts' tapping tasks, which is especially true for the medium and higher estimates. This points to the subjective assessment as an acceptable method for difficulty estimation of various tasks.

As has been claimed in various studies, and confirmed here, it could be concluded that sddR parameter reflects mental load component of the task, while subjective rat-

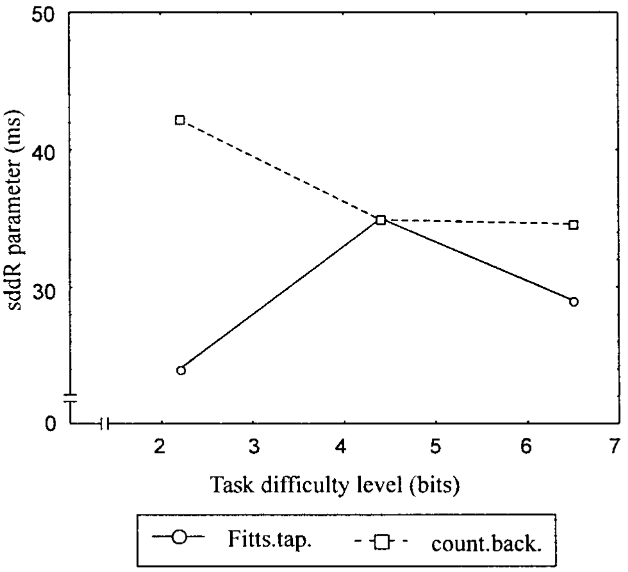

Figure 9. Comparison of the cardiac sddR parameters for equivalent values (bits) of mental and Fitts' tapping tasks

ings, when transformed to the same scale, may be used as a rather reliable and acceptable method of task load comparisons.

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