Evaluation of Mental Strain by Palm Sweating during Short-term Memory Task

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Abstract. This paper reports on the investigation of palm sweating during short-term memory tasks and testing the availability of the amount of palm sweating for an index evaluating mental strain. Six male subjects performed sets of thirty tasks with digit strings ranging from 4 to 9 digits at random order. The correctness of recalled answer, subjective difficulty for mental stress and palm sweating at each task were recorded. The amount of palm sweating (PS) was measured using hygrometry with a ventilated capsule attached on the left palm. Correct answer rates suddenly decreased over 7 digits. Subjective difficulty tended to increase with an increase in string-length. PS tended to decrease exponentially with the repetition of tasks at each string-length, and the exponential regression curve was fitted between PS and order in tasks at each string-length. Estimated PSs were obtained at 1st, 15th and 30th tasks from the regression curves. Estimated PS at 1st task tended to increase in proportion to string-length. Each estimated PS at both 15th and 30th tasks had a threshold for increasing. Also, estimated PS increased in proportion to the string-length at no less than the threshold. The thresholds were 5 digits at 15th and 6 digits at 30th task. These present findings suggest that PS is an index available for measuring mental strain. Also, this index describes the level quantitatively in adaptation for mental stress.

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Keywords: palm sweating, mental stress, mental strain, short-term memory task, hygrometry

Introduction

In order to optimize various mental stress encountered in all phases of human life, the methods are necessary to evaluate mental strains (see Appendix). However, the indices measuring mental strains precisely are not yet established. For evaluating mental strain, synthetic evaluation is necessary from three viewable

points of subjective ratings, physiological responses and behavioral responses. Also, the observation of physiological responses is an effective method for objectively evaluating inner strains, mental efforts and fatigue in humans. The evaluation of physiological responses has advantages such as testing subjects without skills, avoiding to be controlled intentionally and continuous recording (Ohsuga et al., 1993).

Many investigators have studied various physiological responses; e.g. heart rate variability (HRV; Sayers, 1973; Hyndman and Gregory, 1975), event related potentials (ERP; Haider et al., 1964; Groves and Eason, 1969), skin temperatures (Umemura et al., 1989), and pupil diameter (Kahneman and Beatty, 1966) as indices for measuring mental efforts. A lot of papers have reported changes of the indices during various mental works, but few cases have made the quantitative relationships between mental stress and the indices clear.

Palm sweating has been observed during mental arithmetics in many studies as one of the indices. However, most of them have been the results of electrodermal activities (EDA) or the number of active sweat glands (PSI). There are not many reports on the amount of palm sweating during mental work. The amount of palm sweating is measured by means of hygrometry with a ventilated capsule quantitatively and continuously.

Iwase et al. (1988) found a positive correlation between the amount of palm sweating and integrated burst in skin sympathetic nerve activities. This finding suggested that a part of sympathetic nerve activities could be supported by palm sweating. Kahneman and Beatty (1966) observed the pupil diameters during short-term memory tasks with digit strings. The short-term memory task loads subject with memorizing presented digit-string and recalling it correctly after retention for a few seconds. They reported the pupillary dilation in proportion to increase in memorized string-lengths. It is considered that pupil diameter dilates by an activation in the sympathetic nerve system and contracts by an activation in the parasympathetic nerve system. If the

sympathetic nerve activity changes by mental stress such as short-term memory task, the amount of palm sweating will change with it. If there is a clear relation between mental stress and the amount of palm sweating, the effects of the mental stress on the sympathetic nerve activity will be supported by the amount of palm sweating. Therefore it is possible that the degree of mental strain is quantified with it. In this study, palm sweating was investigated by hygrometry during short-term memory tasks. Also, the availability in the amount of palm sweating was tested as an index of mental strain by observing the relation between mental stress and the amount of palm sweating.

Methods

Six healthy males (aged 26 ~ 40 yrs.) participated as subjects. Experiments were between 10:00 and 15:00, and all subjects had abstained from eating over two hours. The experimental room was closed, and the temperature and relative humidity in the room were 22°C (20~23°C) and 43% (37~48%). Subjects sat on a stool in this room and attended to tasks using a personal computer (Apple, LC475).

Subjects performed tasks after resting for forty minutes. The task was a sequence of thirty short-term memory tasks using random digit strings ranging from 4 to 9 digits (6 conditions). Each condition consisted of five different digit strings of the same length. They were extracted from the table of random numbers, and the digit strings and orders of presentations were different for each subject. They were presented to the subjects in the center of CRT for intervals that decided according to their lengths by means of programmed software (Apple, HyperCard). Each interval for the presentation was decided by $(0.516\text{sec}) \times (\text{the length of digit strings})$ that Komatsubara and Yokomizo (1989) established according to the time for an eye movement and an instantaneous inference. Subjects input memorized digit strings to the keyboard by clicking the mouse after 10 seconds for retention. The keyboard was made in display using the software program. The subject evaluated the subjective difficulty for each task immediately after recall. Short pauses in which palm sweating recovered to the base level were made in between all tasks. One session of thirty tasks took about thirty minutes.

The emotional states of the subjects were examined using questionnaires before and after short-term memory tasks. The questionnaire consisted of seventy items that Terashita et al. (1992) abstracted from all emotional states. These emotional items were abstracted and classified to assess the various emotional states of daily life, and they were composed of fatigue and drowsiness, general activation, passive comfort, joy, refreshment, tense, disgust, worry, and depression. Sub-

jects assessed their emotional states for each item using five-grade scales that had "do not quite feel" and "feel clearly" at both ends.

Recalled digit strings were automatically recorded by the software program, and they were distinguished as right or wrong. Subjects evaluated their subjective difficulties of mental stress at each task according to four-grade scale (not difficult / slightly difficult / difficult / very difficult). The presentations of the questions and recordings of answers were also carried out automatically by software.

Palm sweating was continuously recorded using hygrometry with a ventilated capsule and humidity sensors (Fig.1). Dry N₂ gas flowed at 2.5 l/min through the capsule (diameter: 23mm, area: 415.5mm²) that was attached on left palm, and the humidity of gas that had passed through it was measured using a humidity sensor (VAISALA, HMM-20). Fig.2 shows the examples of palm sweating recorded by hygrometry. They had risen like spikes at presentations of digit strings (▲ in Fig.2), and slowly returned to base line after recalls of them. In order to measure the amount of palm sweating (hereinafter called PS), the output of humidity sensor was integrated and calibrated with the value gained by standard water poured into another same size capsule for calibration (unit: mg).

It is possible that palm sweating is caused by voluntary muscle contraction or deep breath (Maruyama et al., 1993). The input of recall was carried out by clicking the mouse. It was confirmed before the experiment that clickings of the mouse without memory tasks did not cause palm sweating. Also, the subjects were instructed not to change their postures or to breath deeply during tasks.

Fig. 1 Schematic drawing of hygrometry with a ventilated capsule and humidity sensors.

Fig. 2 Examples of palm sweating recorded by hygrometry. The triangular marks show the presentations of digit strings.

Results

Before and after the short-term memory tasks, the changes in mental strains and arousals were investigated using questionnaires. Four of the six subjects acknowledged their tenseness at the beginning of the tasks, and they reported an easing in tenseness after the tasks. No subjects had felt a decline in his arousal before and after the tasks. Thus short-term memory tasks did not cause the arousal levels to decline.

Fig.3 shows the mean correct answer rates for all subjects in the short-term memory tasks. They were about 100% at range from 4 to 7 digits, but recall errors increased over 7 digits. This tendency agreed with the results of Komatsubara and Yokomizo (1989) and Nakashima and Sato (1992), and it supported the Miller's theory that the limit in short-term memory was 7 ± 2 chunks (Miller, 1956). To investigate the change in performance with the repetition of tasks, the sequence of thirty tasks was divided into three blocks. Two-way ANOVA (analysis of variance) was used to test significant changes of correct answer rates between the three blocks and with the increase in string-lengths. ANOVA indicated a significant effect of increase in string-lengths ($F=64.42$, $P<0.01$), but the effect of repetition of tasks was not significant ($F=1.11$).

Fig.4 shows the percentages of each level in subjective difficulties for short-term memory tasks. This figure also shows the index of subjective difficulties (hereinafter called SDI). SDI was defined in the following equation :

$$\text{SDI} = (0 \times P(\text{not difficult}) + 1 \times P(\text{slightly difficult}) + 2 \times P(\text{difficult}) + 3 \times P(\text{very difficult})) / 100$$

where

P (level of subjective difficulty) = percentage of the level of subjective difficulty(%).

Subjective difficulties tended to shift to more difficult with an increase in string-lengths. To investigate changes in subjective difficulties with the repetition of tasks and with the increase in string-lengths, SDI at each block were compared with ANOVA. ANOVA indicated a significant effect of increase in string-lengths ($F=154.40$, $P<0.01$), but the effect of repetition of tasks was not significant ($F=3.59$).

Samples of PSs of the six subjects at 4 and 8 digits are shown in Fig.5. They tended to decrease exponentially with the repetition of tasks at all string-lengths. Exponential regression curve was fitted between PS and order in tasks at each length for data of six subjects (Fig. 6). PS tended to increase with the increase in string-lengths. Also, the tendencies of declined degree in these six curves with the repetitions were different from each other.

To investigate the decrease in PS with the repetition of tasks, PSs were estimated at 1st, 15th and 30th tasks from each exponential curve. Fig.7 shows the estimated PSs. Estimated PSs at 1st task tended to increase in proportion to string-lengths. However, estimated PSs at 15th and 30th tended to level off at each string-length and increased over the lengths. Then the upper limit of length in range leveled off was defined for threshold of increase in estimated PS. It was clearly interpreted that the threshold of estimated PS was 5 digits at 15th task. However, the decision was difficult at 30th task. The segmented regression analysis that Fukuba and Koya (1985) applied to estimation of lactate threshold was to decide this sweating threshold. Using this analysis the decided threshold was 6 digits at 30th task. Therefore the thresholds tended to shift to longer

Fig. 3 The mean correct answer rates in each string-length.

digit strings with the repetition of tasks. Fitting regression lines between string-lengths and estimated PSs in range over each threshold showed that the three slopes were almost equal (1st task : 0.059 mg/digit, 15th task : 0.075 mg/digit, 30th task : 0.084 mg/digit).

Discussion

In this study, a linear correlation was investigated between estimated PS and the length of digit strings at the beginning of short-term memory tasks (Fig.7: $k=1st$). This finding suggests that PS can be applied to an index for evaluating mental strains during short-term memory tasks. Palm sweating is controlled by the sympathetic nerve system. Iwase et al. (1988) investigated skin sympathetic nerve activities (SSA) using microneurography and palm sweating with hygrometry simultaneously. They found a positive correlation between palm sweating and integrated burst in SSA during mental arithmetics. Therefore, it is supposed that the increase in estimated PS in proportion to string-length reflects the activities in sympathetic nerve system at initial short-term memory task. Kahneman and Beatty (1966) tested short-term memory tasks with digit strings rang-

ing from 3 to 7 digits by audio stimuli, and they investigated pupillary dilation in proportion to increase in memorized string-length. Their finding suggests that an increase in string-length of short-term memory tasks steps up the difference between the sympathetic nerve activities and parasympathetic nerve activities. The results of our experiment on PS at the initial task agrees with this finding by Kahneman and Beatty (1966).

HRV, ERP, skin temperature, etc. have been studied as the representative physiological indices for evaluating mental strains. Many studies have reported the changes in these indices during mental works, but quantitative relations among the indices, mental stress and mental strains have not been clear. Many indices of HRV have been studied. However, the changes in 0.1Hz component of the spectral analysis on cardiac intervals (0.1Hz HRV) are specially noted since Sayers (1973) suggested that 0.1Hz HRV declined during mental work. Many studies agree that such 0.1Hz HRV decreased by mental work. However, there were no agreements on the relation between 0.1Hz HRV and mental stress (Hyndman and Gregory, 1975; Vicente et al., 1987; Murata, 1992). Haider et al. (1964) and Groves and Eason (1969) suggested that the amplitude in ERP showed the attentional level, and also Kramer et al. (1985) and Ullsperger et al. (1988) found the relations between mental stress and the amplitudes. However, a negative opinion (Karlin, 1970) and the unknown parts still exist in this index, so future studies are expected in this field. The contraction and dilatation of peripheral skin veins are controlled by the sympathetic nerve system, thus it appears that the skin temperature will change during

Fig. 4 Percentages of subjective difficulties and SDI (Index of Subjective Difficulty) in short-term memory tasks. SDI was calculated from

$$SDI = (0 \times P(\text{not difficult}) + 1 \times P(\text{slightly difficult}) + 2 \times P(\text{difficult}) + 3 \times P(\text{very difficult})) / 100$$
 where $P(\text{level}) = \text{Percentage of each level (\%)}$.

Fig. 5 The sequences of PSs at 4 and 8 digits.
 (PS: the amount of palm sweating)

mental work. The skin temperatures of the forehead and fingertips were reported to decline during mental arithmetics (Umemura et al., 1989; Umemura et al., 1991). However, the relation between skin temperature and mental stress has not been clear either. The skin temperature is a thermo-regulatory response, thus the problem of this index is considered to be affected by environmental temperature and metabolism. In this study, clear relations were found among PS, mental stress, performances and subjective responses (Fig.3, 4 and 7). Therefore, PS will be suggested as an index available for measuring mental strains. However, we have to be aware that the voluntary muscle contractions or heterogeneous emotions during task would cause uninvited palm sweatings as noises. Supposing that the motor and emotional patterns in palm sweating are identified to exclude such noise, PS should be widely applicable as an index for mental strain.

The tendency of decline in PS was observed at the same string-length by the repetition of short-term memory tasks. Sakaguchi et al. (1988) called this decline an adaptation. However, it has not been asserted what adaptation means. In this study the presented sets of digit strings were extracted from random numbers, and

they were different for each subject. The correct answer rate and subjective difficulty did not show the changes with the repetition of tasks. Therefore, it would not be supposed that the presented digit strings became more memorable with repetition of tasks. Also, the decline in the arousal level would affect palm sweating (Niimi et al., 1968), but the significant decline with the repetition of tasks was not found on subjective ratings. It thus appears that PS has declined with unknown factors. Such factors must be unobserved with the performance and subjective difficulty. It is also possible that the factors include the habituation to experimental conditions, task methods, measuring equipments, etc..

In this study, the decline in PS with the repetition of tasks could be attributed to the fact that the threshold in estimated PS had shifted to heavier mental stress and that the slopes of the three regression lines were consistent (Fig.7). This result suggests that PS will quantitatively express the change in mental strain with an adaptation to the mental stress. The application of PS as an index of mental strain will be necessary to explicate the mechanism and patterns of decreasing palm sweating. In this experiment, the estimated PS has been used along with exponential regression curves as the criteria for the decline in palm sweating. However, another test must be performed using the actual measured amount of palm sweating to confirm whether the same results will be observed.

Fig. 6 Regression curves of PSs at each string-length. (PS: The amount of palm sweating)

Fig. 7 Estimated PSs at 1st, 15th, and 30th tasks in the sequence of short-term memory tasks. (PS: The amount of palm sweating)

Appendix: Definitions of mental, mental stress and mental strain

In this article, the definitions of mental, mental stress and mental strain conform to ISO 10075 (1991). These terms were defined as in the following sentences.

- mental: The expression referring to cognitive, informational, and emotional processes in the human being.
- mental stress: The total of all assessable influences impinging upon a human being from external sources and effecting it mentally.
- mental strain: The immediate effect of mental stress within the individual (not the long-term effect) depending on his/her individual habitual and actual preconditions, including individual coping styles.

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