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Interactive Model of Subsidiary Behaviors, Work Performance and Autonomic Nerve Activity during Visual Display Terminal Work

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Abstract: Interactive Model of Subsidiary Behaviors, Work Performance and Autonomic Nerve Activity during Visual Display Terminal Work: Toshimasa TAKANISHI, *et al*. Department of Occupational and Environmental Health, Nagoya City University Graduate School of Medical Sciences—Objectives: The aims of the study were to investigate the systematic classification of subsidiary behaviors during visual display terminal (VDT) work and discuss the interpretation of these behaviors through an interactive model of subsidiary behaviors, work performance and autonomic nerve activity. **Methods:** Twelve university students were instructed to perform continuous 120-min English transcription tasks in a sedentary posture. Data on subsidiary behaviors, work performance (mean keystroke and mean error rates), and autonomic nervous system balance (log-transformed low frequency (LF) / high frequency (HF) ratio) were recorded every 5 min during VDT work. **Results:** The subsidiary behaviors were categorized into 3 qualitatively independent factors: distractive behaviors against monotony (DBM), sleepiness-related behaviors (SRB), and habitual behaviors (HB). A cross-correlation analysis indicated that an increase of DBM, which is considered as a sign of workers' attempt to escape from monotonous task operations, was related to a decline in performance. A decrease in the LF/HF ratio was followed by SRB after 5 min passed ($r=-0.57$, $p<0.05$), eventually leading to a restriction of the deterioration in performance. An increase of DBM was predictive of an increase in errors ($r=0.54$, $p<0.05$), and a significant negative correlation ($r=-0.46$, $p<0.05$) between HB and autonomic nerve activity at 10 min after the appearance of HB was observed. **Conclusion:** It emerged from the results that the factor structure of subsidiary behaviors consists of 3 mutually independent factors. The interactive model suggests that subsidiary behaviors are possibly precursory signs of errors and changes in autonomic nervous system balance.
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Key words: Cross-correlation, Ergonomics, Fatigue, Subsidiary behaviors, VDT, Work performance

Tasks such as data entry that require constant vigilance or involve repetitive and monotonous work, can cause a decline in arousal level, leading to a decline in work performance and an increase in errors[1–4]. Previous studies[5–16] support the notion that subsidiary behaviors, which are not directly relevant to the task would be useful indices as behavioral responses, as well as physiological and psychological responses.

Kishida[7, 10] defined subsidiary behaviors as those that aid in escaping from monotony, repetitive tasks, or a perpetually constrained posture. Substitution activities[17], substitute or redirected activities[18], superstitious conduct[19], non-specific activities[20], subsidiary activities[20], additional activities[11], collateral activities[13], and behavioral activities[21], all express a concept identical to Kishida's[7, 10].

The appearance of subsidiary behaviors allows workers to escape from the monotony of work or prevent a decline in work performance[22, 23]. In addition, their appearance indicates a decline in a worker's arousal level[21, 24, 25]. Subsidiary behaviors appear in different patterns, depending on task demands, length of work time, work situations, or motivation[26]. However, many previous studies used cumulative frequencies of each subsidiary behavior during work. Some studies that aimed to

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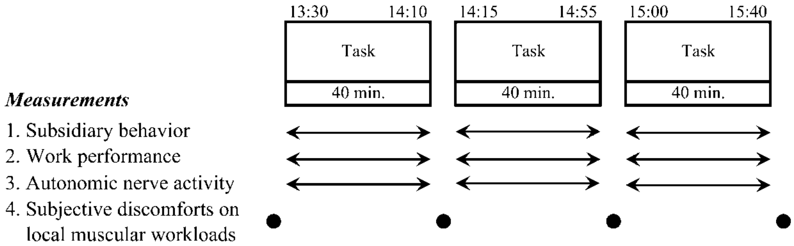

Fig. 1. Experimental procedure.

interpret subsidiary behaviors classified them systematically by focusing on their physiological and/or psychological aspects. For example, Hirose *et al*.[25] classified these behaviors into 13 categories (e.g., those that ease strain or stiffness, induce eye or mouth movements, avert constant contact with a somewhat hard surface, cause changes in posture, and have a low arousal level); Rogé *et al*.[21] classified them into 4 categories (self-centered gestures, non-verbal activities, ludic activities, and postural adjustment); Cosnier[27] classified them into 3 categories (comfort movements, auto-centered gestures, handling objects and play activities); and Delvolvé *et al*.[11] classified them into 3 categories as additional activities (accessory activities such as postural readjustments, auto-manipulative gestures, verbal and non-verbal activities). In these activities, Rogé *et al*.[21] and Hirose *et al*.[25] used subsidiary behaviors as an index of arousal level. However, they did not refer to the reliability of classification of subsidiary behaviors and a consensus on them has not yet been arrived at. No studies have reported an interpretation of temporal changes between autonomic nerve activity, work performance and subsidiary behaviors. If these relationships are clearly identified, they could provide effective countermeasures not only for reducing worker's workloads, but also for establishing a safety management system for monitoring work with visual display terminals (VDTs).

In the present study, we attempted to classify subsidiary behaviors during VDT work by factor analysis. We built an interactive model to show the relationships among work performance, autonomic nerve activity and subsidiary behaviors, and discuss the interpretation of the classified subsidiary behaviors in terms of behavioral science and its validity.

Subjects and Methods

Subjects

Twelve healthy university students (6 males, 6 females; mean age 21.2 ± 1.0), participated in the study, and they were compensated at a rate of 9,000 JPY per half day. They were given a detailed explanation of the experiment. All participants had no previous history of musculoskeletal disorders, had normal vision either with or without glasses, and could type on a keyboard with both hands. They were instructed to sleep well and refrain from consuming alcohol the night before the experiment. This study was approved by the Human Research Ethics Committee of Nagoya City University Graduate School of Medical Sciences.

Procedure

In the present study, participants were required to perform a 120 min task in a continuous sedentary posture. Subjective discomfort on local muscular workloads was measured every 40 min during the 120 min, so the task was divided into three 40 min sessions (Fig. 1).

The experiment time was fixed between 13:00 and 16:00 to avoid a temporal effect such as within-day fluctuations in the appearance of subsidiary behaviors, which are more frequent in the afternoon than in the morning[26].

Participants were instructed to perform English transcription tasks. They transcribed English words shown on the left half of the computer screen onto the right half of the screen. The words were randomly extracted from a medical term database. Participants were instructed to perform these tasks as quickly and as accurately as possible. They were allowed to practice keyboard typing for 1 day prior to the experiment.

Participants adjusted the height of their desks and chairs based on ergonomic guidelines[28]. The temperature was controlled at 25°C with 60% humidity. They used a 19" thin film transistor (TFT) display with a 1,280 × 1,024 resolution, and all participants performed their tasks independently.

Measurements

We used the following three measurements with the exception of subjective discomforts on local muscular workloads for the analysis.

a) Subsidiary behaviors

In previous studies[7, 8, 10, 16], subsidiary behaviors were obtained by counting the movements of each body part. Our preliminary test indicated that it was appropriate for sedentary VDT work to use the following twenty-eight items: combinations of body parts (head, neck/shoulders, trunk, lower back/hip, arms, legs) and their movements (scratch, touch/rub, move, pat/knead), and 4 other items, which were yawn, rub eye(s), take a short break, and sigh. Participants' subsidiary behaviors were video recorded during the work, and the digital data were analyzed at 5 sec intervals. Prior to the experiments, observers recording the subsidiary behaviors were well trained to reach valid levels of inter- and intra-observer consistency.

b) Work performance

Mean keystroke rate and mean error rate were calculated every 5 min with log analysis software integrated into the program for English transcription tasks. These rates were used as indices of performance and errors.

c) Autonomic nerve activity

Each participant's heart rate was measured throughout the experiment using Holter electrocardiogram recorders (Active Tracer AC301, GMS Inc., Tokyo, Japan). After a power spectral analysis of R-R intervals (MemCalc System, Suwa Trust Co., Ltd., Tokyo, Japan), the high frequency (HF, 0.15–0.4 Hz) and low frequency (LF, 0.04–0.15 Hz) components were extracted. Because the high LF/HF ratio reflects the enhancement of sympathetic nerve activity and the low LF/HF ratio indicates dominant parasympathetic nerve activity[29, 30], we used the log-transformed LF/HF ratio as an index of autonomic nervous system balance.

Analysis

The appearance of 28 subsidiary behaviors was recorded on a nominal scale (binary data: yes/no) every 5 s; then, an interval scale (0–7 times/5 min) was formed based on the cumulative frequency of the binary data every 5 min. During the experiment, 22 of the 28 coded subsidiary behaviors were actually observed (see notes in Table 1 for details). An exploratory factor analysis (principal factor method with promax rotation) was conducted based on the results. Eleven items were eliminated because of a communality value of less than 0.20 and a factor loading value of less than 0.35; then, factor analysis using the principal factor method was conducted to re-extract factors. A scree plot was used to determine the optimal number of factors. It revealed that 3 factors with eigenvalues over 1.0 should be retained. Promax rotation was repeated and Cronbach's coefficients were then calculated for internal consistency. The mean frequency of the subsidiary behaviors of each factor group was calculated every 5 min to make the data temporal. Mean keystroke rate, mean error rate, and the log-transformed LF/HF ratio were also calculated every 5 min for future temporal analysis.

The frequencies of subsidiary behaviors in each factor group were analyzed by two-way analysis of variance (ANOVA) with repeated measures to identify the independency and fluctuation of the above 3 factors. Furthermore, a cross-correlation analysis, which examined the strength of correlations and time lags among temporal data, was conducted to identify the temporal associations among frequency of subsidiary behaviors during work, autonomic nerve activity (LF/HF ratio), and work performance. Because a previous study[25] demonstrated that some subsidiary behaviors could act as predictive factors of a decline in arousal level, and that the arousal level could result in high frequencies of some subsidiary behaviors, we obtained cross-correlation coefficients in 5 phases, calling the time-lag point with no phase difference "lag 0" and covering 5-min time lags up to 10 min before and after "lag 0" (from "lag –2" to "lag +2"). For developing an interactive model of subsidiary behaviors, work performance and autonomic nerve activity, the maximum coefficient in each cross-correlation was adopted. All statistical analyses were performed with SPSS version 14 for Windows (SPSS Inc., Chicago, IL, USA).

Results

Table 1 shows the results of factor analysis of the subsidiary behaviors observed in this study. The first factor, defined as "distractive behaviors against monotony (DBM)," comprised "move trunk (e.g. stretch out one's back)," "move leg(s) (e.g. stretch out one's legs or cross one's ankles)," "take a short break," and "move lower back (e.g. twist one's waist)" (Cronbach's alpha=0.846). The second factor, interpreted as "sleepiness-related behaviors (SRB)," comprised "scratch head," "rub eye(s)," "yawn," and "sigh" (Cronbach's alpha=0.739). The third factor, interpreted as "habitual behaviors (HB)," comprised "touch head (mainly face)" and "touch arm(s)" (Cronbach's alpha=0.238). Inter-factor correlations were all less than 0.30, which showed the mutual independence of the 3 factors.

Figure 2(A) shows the temporal changes in the frequency of subsidiary behaviors in each factor group. DBM increased in frequency as the work progressed and were seen a maximum of 7 to 8 times per 5 min. Frequencies of SRB and HB also increased with time and were a maximum of 3 times per 5 min and 1 to 2 times per 5 min, respectively. The results of two-way ANOVA with repeated measures indicated that the 3 factors were independent of one another and had different fluctuation patterns with condition (p=0.04), time (p=0.02), and condition × time (p=0.02).

Though the LF/HF ratio seemed to increase with time during the first and third sessions, and decrease in the second session, no significant differences were found in the LF/HF ratio, and similarly, neither in mean keystroke rate nor mean error rate (Fig. 2B–C).

Table 1. Factor analysis of subsidiary behaviors

Subsidiary behavior	Factor 1	Factor 2	Factor 3
Factor 1 distractive behaviors against monotony (DBM) (α=0.846)			
Move trunk	**0.884**	0.088	–0.184
Move leg(s)	**0.815**	0.021	0.143
Take a short break	**0.766**	–0.051	–0.053
Move lower back	**0.723**	–0.059	0.002
Move arm(s)	**0.401**	–0.028	0.381
Factor 2 sleepiness-related behaviors (SRB) (α=0.739)			
Scratch head	0.065	**0.776**	–0.066
Rub eye(s)	–0.080	**0.773**	0.018
Yawn	0.007	**0.720**	–0.195
Sigh	–0.013	**0.590**	0.356
Factor 3 habitual behaviors (HB) (α=0.238)			
Touch head (mainly face)	–0.016	–0.149	**0.580**
Touch arm(s)	–0.070	0.054	**0.580**
Inter-factor correlations			
Factor 1 distractive behaviors against monotony (DBM)	—	0.042	0.287
Factor 2 sleepiness-related behaviors (SRB)		—	0.286
Factor 3 habitual behaviors (HB)			—

Method of factor extraction: exploratory factor analysis (principal factor method with promax rotation). Variance and proportion of variance are not shown because of the use of oblique rotation. Twenty-two of 28 subsidiary behaviors were observed. The 22 items were as follows: scratch head, touch head, <u>move head</u>, <u>scratch neck/shoulders</u>, <u>touch neck/shoulders</u>, <u>move neck/shoulders</u>, <u>scratch trunk</u>, <u>touch trunk</u>, move trunk, <u>scratch lower back, touch lower back</u>, move lower back, <u>scratch arm(s)</u>, touch arm(s), move arm(s), <u>scratch leg(s), touch leg(s)</u>, move leg(s), yawn, rub eye(s), take a short break and sigh. The above 11 items with underlines were eliminated because of a communality value of less than 0.20 and a factor loading value of less than 0.35.

The results of the cross-correlation analyses are shown in Table 2. DBM and HB showed the highest negative cross-correlations with performance (mean keystroke rate) at "lag 0" (r=–0.66 ± 0.20 and –0.41 ± 0.20, respectively). In contrast, the cross-correlation coefficient for SRB was highest at "lag +1", demonstrating a positive cross-correlation with performance (0.63 ± 0.21). The cross-correlation coefficient for DBM was highest at "lag +1," showing a significant positive cross-correlation with error (mean error rate) (0.54 ± 0.21), whereas there were no significant cross-correlations between the other 2 factors and error at any time lag. Autonomic nerve activity (LF/HF ratio) showed a significant cross-correlation with DBM at "lag –2", SRB at "lag –1" and with HB at "lag +2"; the cross-correlation coefficients were 0.44 ± 0.21, –0.57 ± 0.21 and –0.46 ± 0.21, respectively. Although there was a significant negative cross-correlation between autonomic nerve activity and performance at "lag –2" (–0.58 ± 0.21), no cross-correlations were observed between autonomic nerve activity and error at any time lag.

Based on the cross-correlation coefficients obtained, an interactive model was constructed to show the interrelation between subsidiary behaviors, work performance and autonomic nerve activity (Fig. 3). The coefficients used in the model were the largest of the 5 coefficients calculated for the 5 time lags. According to the model, DBM is a predictive factor for the increase in error (mean error rate). DBM and HB showed a negative cross-correlation with performance (mean keystroke rate) without any phase difference. Furthermore, the increase in the frequency of HB was predictive of a decline in the LF/HF ratio. The decline in the LF/HF ratio in turn was predictive of an increase in the frequency of SRB, which was then used to predict a rise in performance.

Discussion

Factor structure of subsidiary behaviors and its reliability

Some previous studies evaluated subsidiary behaviors by examining the number of body parts that moved during task operations or events such as naps and chatting[5–16]. Scientists have distinguished some categories such as postural movements, verbal and non-verbal activities[11, 21, 23, 25, 27]. However, none of these classifications have been verified for reliability. Moreover, few studies have employed an evidence-based classification of subsidiary behaviors with the characteristics of VDT work. Therefore, in the present

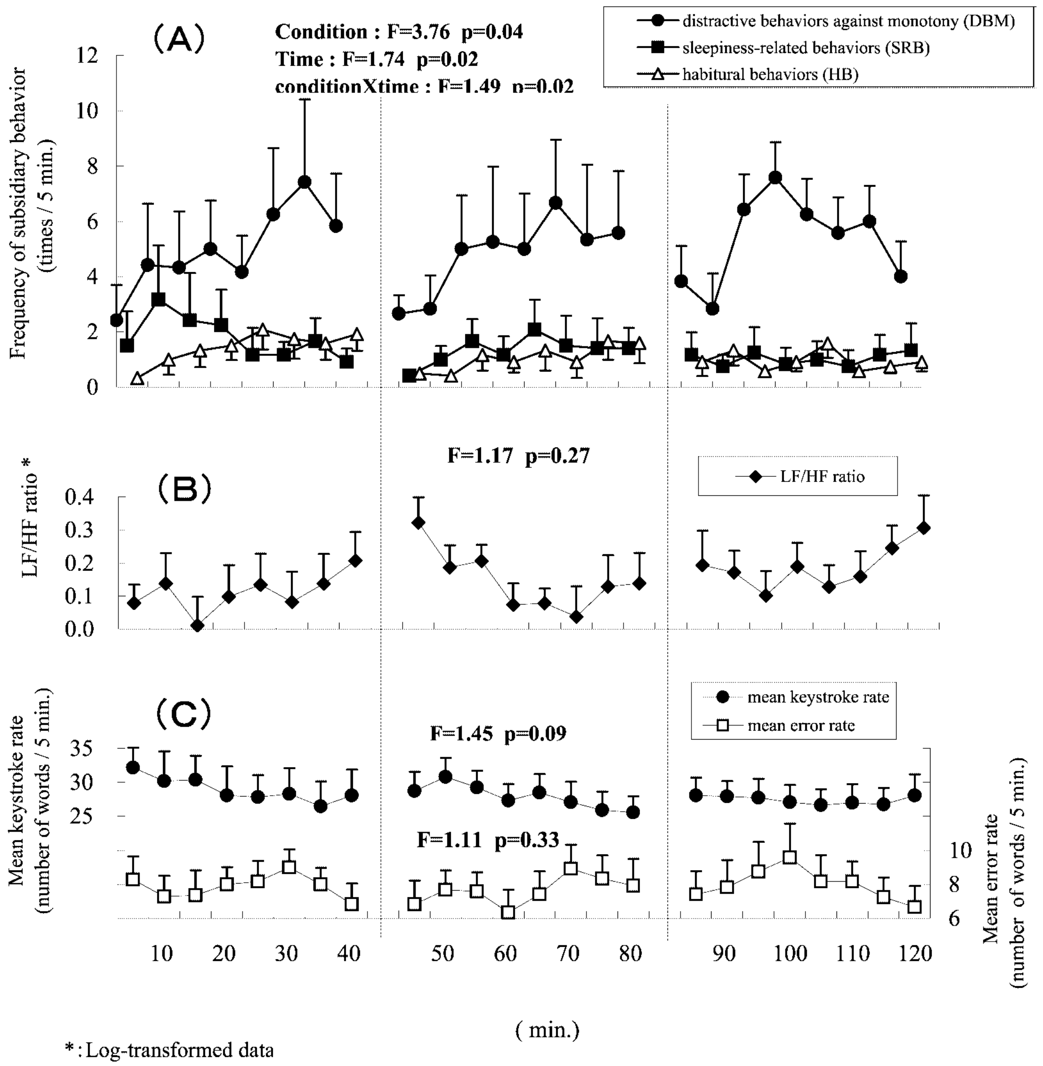

Fig. 2. Temporal changes in frequency of subsidiary behaviors of each factor (A), the LF/HF ratio (B), and mean keystroke rate and mean error rate (C).

study, we attempted to classify subsidiary behaviors observed during VDT work and verify the reliability of this classification. Factor analysis was conducted on the participants' subsidiary behaviors and 3 factors were identified. Physical movements and voluntary rest (move trunk or lower leg(s), take a short break, etc.) were categorized into one group as the first factor. Because a change in work posture, which increases in frequency during continuous work, is a compensatory activity[7–9], it indicates a worker's self-defense response to the regularity and monotony of the work. It might be appropriate to regard the subsidiary behaviors included in the first factor as DBM. These behaviors corresponded to postural adjustments according to Rogé *et al.*[21], comfort movements according to Cosnier[27], and postural readjustments according to Delvolvé *et al.*[11].

The second factor included scratch head, rub eye(s), sigh, and yawn, which were classified as "non-verbal activities that can be observed on the face" by Rogé *et al.*[21] and termed SRB by Hirose *et al.*[25], who reported that the decline in arousal level caused by monotonous work induces such activities.

Subsidiary behaviors in the third factor termed HB (play with hair, scratch cheeks, run hands over arms) corresponded to ludic activities according to Rogé *et al.*[21] and auto-manipulative gestures[11]. However, Kishida[10] reported that there were also individual differences in the occurrence of activities such as touching head (fixing hair), which were included in the third factor in this study.

There was no discrepancy between previous studies and the present study for the structure of the 3 factors. The results of ANOVA as well as the low correlations

Table 2. Results of cross-correlation analysis

	Performance (mean keystroke rate)				
	Lag –2	Lag –1	Lag 0	Lag +1	Lag+2
Distractive behaviors against monotony (DBM)	–0.19	**–0.53***	**–0.66***	–0.13	0.07
Sleepiness-related behaviors (SRB)	–0.08	0.05	0.29	**0.63***	**0.51***
Habitual behaviors (HB)	–0.02	–0.27	**–0.41***	–0.08	0.31
	Error (mean error rate)				
	Lag –2	Lag –1	Lag 0	Lag +1	Lag +2
Distractive behaviors against monotony (DBM)	–0.15	–0.03	**0.46***	**0.54***	0.10
Sleepiness-related behaviors (SRB)	0.19	0.02	–0.11	–0.12	–0.25
Habitual behaviors (HB)	0.10	0.11	0.08	0.34	0.14
	Autonomic nerve activity (LF/HF ratio)				
	Lag –2	Lag –1	Lag 0	Lag +1	Lag +2
Distractive behaviors against monotony (DBM)	**0.44***	0.21	–0.25	–0.38	–0.07
Sleepiness-related behaviors (SRB)	–0.34	**–0.57***	**–0.52***	**–0.44***	0.05
Habitual behaviors (HB)	0.32	–0.10	–0.23	**–0.42***	**–0.46***
Mean keystroke rate	**–0.58***	–0.29	–0.09	0.28	0.27
Mean error rate	0.21	–0.05	–0.39	–0.34	–0.13

*: Significant cross-correlation $p<0.05$. 1 Lag=5 min.

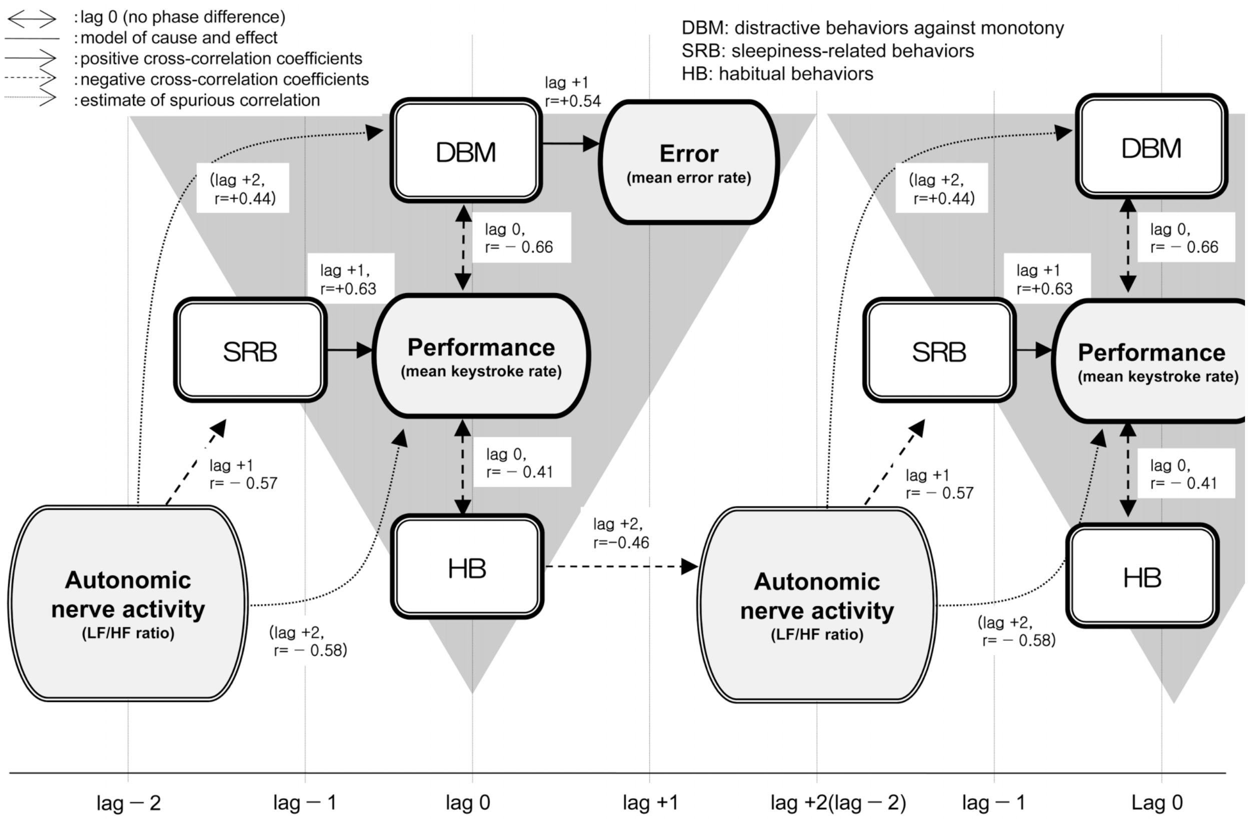

Fig. 3. Interactive model of relationships between subsidiary behaviors, work performance and autonomic nerve activity lag 0: 0 min (no phase difference), lag ± 1: ± 5 min, lag ± 2: ± 10 min.

among them show the independence of each factor, suggesting that integration of data by factor group makes the occurrence patterns of subsidiary behaviors more distinctive and enables us to interpret the behaviors in terms of the participants' internal states. The reliability of each factor was analyzed using Cronbach's alpha coefficient. DBM and SRB proved to have sufficient reliability, but HB showed low internal consistency. Some previous studies reported that "habits" might occur as characteristic activities that could be considered subsidiary behaviors and that there might be a temporal fluctuation in their appearance associated with task progression[10, 31]. For example, Hirose *et al*.[25] reported individual differences in the tendency for subsidiary behaviors to appear. However, some researchers now claim that ludic activities, such as playing with hair as reported by Rogé *et al*.[21], are not related with workers' arousal levels. Such evidence suggests that although HB occurs as subsidiary behaviors, their type and frequency might be largely dependent on individual differences, and that the suitability of HB as behavioral indices should be limited.

Behavioral interpretation of the 3 factors using an interactive model

We attempted to interpret subsidiary behaviors from the viewpoint of behavioral science by developing an interactive model. In the model, we associated the decline in work performance with the appearance of subsidiary behaviors as behavioral indices, and then added an interpretation of their temporal changes to elucidate the mechanism of appearance of these subsidiary behaviors. According to the model, the decline in performance and DBM and HB appeared at the same time, with large correlation coefficients at "lag 0," suggesting that these subsidiary behaviors occur in synchrony with declining performance. Our findings also support previous results[26] suggesting subsidiary behaviors might act as a factor that interferes with performance. An increase in the frequency of DBM was followed by an increase in errors, indicating that the appearance of these behaviors could be a predictive factor of an increase in errors. DBM, such as "take a short break" and "move trunk," could also be a sign of decline in performance and may be useful as an index for error prevention.

While it is assumed that the repetitive/monotonous features of work cause a decrease in the LF/HF ratio, the increase in frequency of SRB such as "yawn" and "rub eye(s)" helps lead to recovery of performance. However, there has been no consensus about the physiological mechanism concerning these subsidiary behaviors and autonomic nerve activity. Some previous studies reported that yawning and sighing precede a decline in activity of the cerebral cortex, whereas others found that when people feel a decline in alertness, they yawn and sigh to escape from it[26, 32]. In this study, although yawning and autonomic nerve activity were considered to complement and affect each other, the appearance of SRB led to recovery of performance. This result is in agreement with the study reported by Hirose *et al*.[25], which assumed that an increase in the appearance of HB might promote a drop in arousal level, eventually leading to a decline in performance. Thus, the increase in the frequency of HB such as "touch head" and "touch arm(s)" can be predictive of a decrease in arousal level, if the LF/HF ratio is considered to be related to arousal level.

According to Hirose *et al*.[25], yawning and sighing are predictive of a drop in arousal level, and behaviors such as changing posture increase after the arousal level drops by some degree. They also reported that an increase in frequency of subsidiary behaviors and a drop in performance occur at the same time. Our results were in accordance with theirs, i.e., an increase in the appearance of DBM and HB occurred in synchrony with a drop in performance. However, we also obtained evidence to support a mutually interacting process between subsidiary behaviors, work performance and autonomic nerve activity using cross-correlation analysis.

Limitations

In the present study, participants performed English transcription tasks for 120 min in which they typed words as quickly and as accurately as possible. The task time was experimentally set as one continuous operation time based on the conditions used in previous studies, and English transcription was employed because of its monotonous nature. The length of a task is one of the most important factors for the appearance of subsidiary behaviors[26], and there are within-day fluctuations in the appearance of such behaviors[26]. Moreover, the appearance of subsidiary behaviors is affected by other factors such as in-house communication, psychosocial factors, work characteristics, and physical environment. However, because this study was conducted in a laboratory and the effects of factors generally existing in a real workplace were not taken into account, the interpretation of the results is limited. Kishida[26] also reported that workers' motivations cannot be ignored for good work performance. In fact, in some studies, more rewards were promised for better performance to control participants' motivations. This was not adopted in the present study for fear that it might become a confounding factor. It is generally difficult to examine the effect of motivation in a laboratory study. Informal communication, one of the important subsidiary behaviors[26], is also difficult to control in a laboratory environment. Although spontaneous communication exists everywhere in real workplaces, it is almost impossible to control and reproduce it experimentally. Participants in the present study did the task independently under non-verbal conditions. Moreover, participants were instructed to perform these tasks as quickly and as accurately as possible. Thus, attention should be paid to the differences between laboratory conditions and those of the real workplace.

Secondly, we recruited 12 young male and female students for our study, but differences in gender, age, and cultural factors might also affect task operations. Further research is needed to clarify these issues.

Lastly, there remains room for argument about some statistical aspects. Since the theory of factor analysis is built on independent samples from multivariate normal distributions, it is not often applied to the analysis of time series data. Regarding such data, there have been some instances in recent years of the application of a dynamic factor analysis model[33, 34]. In the present study, however, we could not adopt this approach because there was insufficient time series data, as there were only 24 time points. Accordingly, we were obliged to adopt a traditional exploratory factor analysis, regarding our data as frequency data which were extracted randomly and independently without any consideration of time factors as variables, even though accuracy in factor model distinction and factor extraction deteriorates. If we were to obtain sufficient samples from longer hours of VDT work, the distinction of factor structures might improve.

Practical implication

VDT work is one of the most important operations in offices today, and includes a variety of tasks such as data checks, text correction, and data coding. Recently, it has become more complex with the introduction of the shift-work system, and some workers engage in long VDT operations with 24-h monitoring and data input. There are also quite a few VDT operations that consider security paramount, such as instrument monitoring at chemical or nuclear power plants and radar monitoring at air traffic control towers. Because of these situations, practical safety control measures have been explored in VDT workplaces where long working hours and safety are both required. Recently, subsidiary behaviors as a behavioral index have drawn attention as a measure for risk communication[21, 25].

This study showed a possible interpretation for each subsidiary behavior in terms of behavioral science by qualitatively classifying the observed subsidiary behaviors into 3 categories. With an interactive model constructed based on cross-correlation coefficients and time lag data, we demonstrated the interrelation between subsidiary behaviors, work performance and autonomic nerve activity during VDT work. It is hoped that a practical application of behavioral indices to actual workplaces will help provide effective tools for safety management systems with a new aspect to risk communication measures.

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