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Neurophysiological Correlates of Performance and Fatigue in Study of Mental Workload

By

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A thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy

Department of Rehabilitation Sciences
The Hong Kong Polytechnic University
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September, 2006

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I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it produces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

Ada Wing-sze Leung

September, 2006

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ABSTRACT

Rest break schedule is a commonly used strategy to alleviate fatigue at work. However, previous studies examining rest break schedule on low demanding work task, particularly data entry, have revealed inconsistent results. These could be attributable to the task was of low demand on mental effort and the behavioral variables were not sensitive enough to reveal the anticipated differences. Based on the energetical approach proposed by Gaillard (1993) and Hockey (1997), the combination of neurophysiological variables such as energy regulation, mental effort and subjective fatigue feeling may offer new insights into the problem.

This study explores the relationships between common behavioral variables and neurophysiological correlates in a 6-hour data entry task under two rest break schedules (longer and less frequent versus shorter and more frequent). The behavioral variables were task performance, subjective fatigue, and eye blink rate. The neurophysiological correlates were brain activities in terms of the spectral powers of electrocephalogram (EEG) wavebands, and mental effort in terms of heart rate variability (HRV). The study was divided into two phases. Phase I was a validation of the Chinese version of the Swedish Occupational Fatigue Inventory (SOFI-C) for measuring subjective fatigue in this study. Phase II conducted the work-simulated experiment by which both the behavioral and neurophysiological results were obtained.

In Phase I, the Swedish Occupational Fatigue Inventory was translated and the content validity evaluated with respect to its five subscales describing fatigue. The Chinese version was field-tested among 104 sedentary workers. Exploratory factor analysis revealed a five-factor solution, which was comparable to that of the original English version. Cronbach's alphas for the five factors were between 0.88 and 0.95. Test-retest reliability was satisfactory, with intraclass correlations (ICC) ranging from 0.69 to 0.83. The results indicate that the SOFI-C was valid and reliable for use in this study.

In Phase II, 40 university students (20 females and 20 males) with a mean age of 20.9 ± 1.3 years were randomly assigned to a longer and less frequent rest break (LM) or shorter and more frequent rest break (SM) schedule. The experimental task consisted of two 3-hour blocks with a 1-hour break in-between. The LM schedule consisted of three 50-minute sessions with 10-minute rest breaks between each. The SM schedule consisted of five 30-minute sessions with 5-minute rest breaks between each. Participants were to type two-digit numbers at maximal speed and accuracy. The fatigue of the participants was assessed using the SOFI-C at the beginning and end of the morning and afternoon sessions. The spectral power of different EEG wavebands at the left frontal (F_3), right frontal (F_4), left occipital (O_1), and right occipital (O_2) areas, the HRV (0.1 Hz component), and eye blink rate were captured at the end of each session.

The LM subjects were found to show the highest speed by end of the morning session, and the SM subjects by end of the afternoon session. No significant differences in error rates were revealed. Both groups showed significant increases in SOFI-C scores across time on all subscales except the Physical Exertion subscale. There were, however, no significant differences between the two schedules. The spectral power of alpha activities at F_4 was significantly higher in the LM than in the SM group throughout the task ($p < 0.05$). For both groups, the heart rate variability

which reflected mental effort did not vary across time and differ between schedules. Eye blink rates remained steady throughout the task sessions for both groups.

For the LM subjects, the speed of data entry correlated positively with beta activities ($r = 0.59$) at F_3 at end of the morning, but negatively with delta activities ($r = -0.64$) at F_4 in midafternoon. In the SM schedule, the speed correlated only with alpha activities ($r = 0.64$ to 0.70) at O_1 at the end of the afternoon.

The SOFI-C scores correlated with EEG spectral powers in different ways. For the LM group, the Physical Discomfort and Sleepiness subscales obtained at the end of the morning session correlated negatively with alpha and beta activities ($r = -0.53$ to -0.64) at O_1 and O_2 at midmorning. As scores continued to increase by end of the afternoon, they correlated positively with the delta and theta activities ($r = 0.53$ to 0.70) at F_3 in the middle and end of the afternoon. In contrast, for the SM group, the Physical Discomfort subscale obtained at the end of the morning correlated positively with theta, alpha, and beta activities ($r = 0.59$ to 0.69) at O_1 only in the middle of the morning session. Delta activities, which correlated positively with Physical Discomfort and Lack of Motivation at F_3 at the end of morning session, became negatively correlated with Sleepiness and Lack of Energy ($r = -0.53$ to -0.54) at O_1 at the end of the afternoon.

The results of this study indicate that the two different rest schedules were likely to impose different levels of mental load and processing on individual subjects. At the group level, lower alpha activities throughout the SM group suggested that a higher mental demand might have been imposed on the subjects of this group. At the individual subject level, subjects generally found the task to be more demanding after the midway point of the morning sessions. The errors they committed typing were associated with an increase in mental processing (increase fast wave) in the SM and a

decrease in mental effort (increased heart rate variability) in the LM groups. The SM subjects who were more actively engaged and performed better in the data entry task elicited an earlier fatigue state than did the LM subjects. Nonetheless, the SM subjects continued to show a significant increase in their typing speed in the afternoon, whereas the LM subjects did not.

Behavioral and neurophysiological variables are found to be useful for demonstrating the differential effects of long (10 minutes) versus short (5 minutes) rest breaks on facilitating an individual's performance on a data entry task. The findings reveal the inadequacy of using merely behavioral variables for studying mental workloads, particularly on tasks that demand a low level of information processing. The results further support the importance of addressing mental load, cognitive processes, and energetic state simultaneously. The implications of the differences in performance and mental workload patterns between the two rest schedules are also discussed.

The present study has several implications. First, the use of neurophysiological correlates would be useful for revealing the underlying fatigue phenomenon associated with prolonged engagement in low information processing tasks like data entry. Second, effectiveness of the rest schedule was found not only dependent on the task content but also on how long the task has to be performed. Third, solely subjective fatigue rating would not be adequate for revealing the fatigue phenomenon across time and correlation of physiological data with subjective fatigue offers new insights into the phenomenon. Lastly, the results obtained shed light on the theoretical model for explaining prolonged task engagement which can be applied in future research.

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CHAPTER I

INTRODUCTION

This chapter provides an overview of the present research study on mental load and cognitive processes associated with low-level information processing. It begins by outlining the statement of purpose, which summarizes the objectives of the present study. This is followed by a section on the background and justification of the study. The chapter ends with an introduction to the content and organization of the dissertation.

Statement of Purpose

The purpose of this study was to examine how mental load and cognitive processes are associated with prolonged engagement on data entry tasks as well as the extent to which they can be modulated by different work/rest schedules. The study's objectives were (a) to validate a Chinese version of the Swedish Occupational Fatigue Inventory (SOFI) for use in measuring subjective fatigue in Chinese subjects; (b) to examine patterns of task performance throughout two different task schedules of prolonged data entry and to compare the changes obtained in this study to those of previous studies; (c) to explore the strength of the relationship between conventional outcome variables, such as subjective fatigue and task performance, and neurophysiological measures throughout the prolonged task; and (d) to establish a model of information processing and its application to prolonged low-level tasks such as data entry, as well as the effects of a rest break schedule.

Background and Justification of the Study

Over the past decade, workload has been extensively studied in the field of ergonomics. Most investigations conducted have concerned tasks that require participants to engage in a high level of cognitive processing, such as driving, piloting, and shift duties in truck driving and nursing work (e.g. Hankins & Wilson, 1998; Hartley et al., 1994; Neri et al., 2002; Okogbaa, Shell, & Filipusic, 1994). In an attempt to minimize the effect of workload on workers, these studies have largely focused on optimizing the human-machine interface or alleviating fatigue associated with the tasks. The former promotes a worker-machinery fit, enhances an efficient task operation, and reduces workers' discomfort on task, while the latter helps alleviate mental fatigue and improves task performance. Nevertheless, these findings do not apply to tasks that demand a low level of cognitive processing, such as sedentary office work. Moreover, it is unfortunate that many of the findings related to low-demand tasks have been far from consistent. For example, frequent microbreaks have been shown to relieve musculoskeletal discomfort at visual display terminal (VDT) tasks (Balci & Aghazadeh, 2003). However, frequent breaks have been found to interrupt task performance, and workers generally dislike too frequent breaks (Henning et al., 1997). Apart from this, there have still been no definite suggestions as to the optimal duration of rest breaks, probably because of varied experimental findings in the past (Galinsky et al., 2000; Henning et al., 1989). Hence, a detailed investigation is still needed.

Using a VDT to enter data is a common but important task in the workplace. On one hand, it requires the participant to engage in a low level of cognitive processing. On the other hand, prolonged exposure to such a task has been found to be harmful to health due to its monotonous and repetitive nature (Bergqvist, 1984;

Grandjean, 1984). Since earlier studies have demonstrated that performing sedentary work tasks like data entry for a considerable period of time exaggerates symptoms such as musculoskeletal discomfort, eye strain, visual fatigue, and mood disturbance (Carter & Banister, 1994; Pickett & Lees, 1991; Schleifer et al., 1990), much attention has been paid to developing ergonomically designed workstations.

Research findings in the past have established some guidelines to promote worker-to-workstation fit (Hermenau, 1999). Proper posture at the workstation includes hip, knee, and ankle joints flexed to 90 degrees; feet firmly on floor; shoulder girdle over hip girdle; and head over shoulders to achieve the three natural spinal curves (Eastman, 1983, 1986). The suggested viewing distance has been established at 51-76 cm (Pinsky, 1987). Wrist rests have been recommended for keyboard operation. A document holder attached to the screen allows lateral eye gaze as opposed to repetitive neck flexion and extension to look at work on a desktop surface. A footrest may be used either to support the feet of a short worker or to change leg position during prolonged sitting. Illumination of the workstation is recommended at between 500 and 700 nm (Picone, 1999). The overall brightness of the environment should be three times brighter than the screen background (Godnig & Hacunda, 1991). On top of this, an ergonomically well-designed chair is necessary, because it is the most flexible and adjustable tool in fitting any mismatch that the worker may have at the workstation. The chair should have the features of a five-point base; curved seat edge; easily adjustable seat height, armrest height, and backrest inclination; ample space for the buttocks; and comfortable upholstery fabric (Chaffin & Andersson, 1984; Eastman, 1983, 1986). The worker is also advised to adjust the backrest or use a lumbar cushion or seat wedge to achieve proper lumbosacral support. In addition to these guidelines, training workshops can be provided to workers to enhance their awareness (Hermenau, 1999). The benefits of task composition have also been studied, and detailed job analysis and risk assessment tools have been developed to guide the evaluation of the worker-to-workstation fit (Nachreiner, 1999; NOISH, 1999). Although in some cases the ergonomically optimized workstation design has reduced musculoskeletal problems and eye discomfort (Sauter, 1991), task duration has been found to have a negative impact on task engagement (Evans, 1985; Ignatius et al., 1993; Rechichi, De Moja, & Scullica, 1996).

The schedule of rest breaks is another major factor for study in this area. Rest breaks can be described in terms of frequency and duration of the rest period for the task. Research in this area has turned up equivocal findings on the effects of different rest break schedules on work performance (e.g., Balci & Aghazadeh, 2003, 2004; Gao et al., 1990; Lundberg et al., 1993). For instance, Henning et al. (1989) reported that self-adjusted microbreaks were not effective for promoting fatigue recovery. Balci and Aghazadeh (2003, 2004) instead suggested that a schedule of 15 minutes of task work followed by microbreaks was effective for relieving eye strain and discomfort in the neck and lower back as well as chest pain, and for improving task performance. Kopardekar and Mital (1994) opined that a reason for the less-than-satisfactory effects of microbreaks is that they interrupt task reengagement following a microbreak. As a result, microbreaks apparently lead to a decrement of performance. Arguments on behalf of the positive effects of rest breaks have also been inconsistent. Floru, Cail, and Elias (1985) found that a 40-minute work segment followed by a 5-minute break schedule was efficient for eliminating performance decrements that would normally occur. However, Henning et al. (1989) did not obtain any performance improvement after their subjects were given a 10-minute break within a 40-minute data entry task. Instead, they observed a decrement of total keystrokes after the rest break. In addition, Kopardekar and Mital (1994) revealed no significant difference in errors between a task schedule of a 30-minute task plus a 5-minute break, and a task schedule of a 60-minute task plus a 10-minute break. This implies that more frequent rest breaks might not be better than less frequent rest breaks in preventing performance decrement. There could be two reasons for these equivocal findings. First, the tasks used in these studies were largely different in their content and cognitive demands, which could make interpretation of the effects of the work/rest schedules difficult. For instance, Kopardekar and Mital (1994) used a directory assistance operator's task in their experiment, their subjects being required to enter data such as phone number, name, and address. Balci and Aghazadeh's (2003) data entry task required subjects to key in alphanumeric characters such as last name, first name, and phone number. In Henning et al.'s (1989) study, the subjects were only asked to enter numerical data of 3 to 13 characters in length. As a result, the difficulty level and the task demands have varied greatly among these experiments. Second, the measurement variables employed in previous studies have been inadequate to explain the comprehensive processes taking place at low levels of information processing. It appears that most studies attempting to investigate the effect of rest breaks have based their results largely on behavioral findings, such as task performance, subjective discomfort ratings, and eye strain (Balci & Aghazadeh, 2003, 2004; Henning et al., 1989, 1997; Kopardekar & Mital, 1994). However, it is known that concomitants of fatigue, such as increased muscle tension and discomfort, often reflect secondary consequences of the person's compensatory efforts, which have to be analyzed through physiological investigation (Craig & Cooper, 1992).

In the area of cognitive ergonomics, theoretical models have been developed for analyzing the workloads involved in high levels of information processing. For instance, Hockey (1997) proposed modulation of the mental effort in tasks that require high levels of cognitive demand. A review of the literature shows that a coexisting model has been developed for describing the mental loads associated with energy regulation and cognitive function in human information processing. Of all the studies on data entry tasks, Floru, Cail and Elias (1985) is one of two that have examined the brain activities of participants when performing data entry tasks. Their study attempted to investigate changes in task performance with physiological indices of arousal using an electroencephalogram throughout a continuous 2-hour data entry performance. In their study, the spectral power of the electroencephalogram – a physiological variable – was found not to correlate with emotion and subjective fatigue. Instead, they found that the spectral power accompanied a rebound in the performance at around 60 minutes of work. Later, Floru and Cail (1987) replicated the same experimental procedure and incorporated an additional schedule with a 5-minute break after a 40-minute engagement in the data entry task. They found that with the rest break, task performance progressively increased, and the intensive mental activity revealed by the spectral powers was associated with enhancement of performance. Their findings suggest that rest breaks might play a role in mediating energy regulation as well as overall task performance across time. However, Floru and Cail's (1987) study involved only a single rest break throughout a 2-hour data entry task. As a result, their findings do not adequately explain the effects of rest breaks on prolonged data entry. In addition, their study did not examine the relationship of the behavioral variables, such as task performance and subject fatigue, to the spectral power of the electroencephalogram in their rest break schedule. According to models of information processing described by Hockey (1997) and Gaillard (1993), it is plausible that performance-based behavior is related to internal energy regulation and mental effort involvement. Therefore, the effects of rest breaks on the task might also influence energy regulation and its association with subjective feelings. To further explore this phenomenon, the present study was designed so that the duration of the entire data entry task was extended to 6 hours, and two different but systematic work/rest schedules were incorporated. Its purpose was to use both behavioral variables and their neurophysiological correlates to investigate how rest breaks influence information processing at low task demands and which work/rest schedule benefits the alleviation of fatigue in low levels of information processing. To this end, the present study compared the patterns of performance-based behavioral results between the two schedules and examined the neurophysiological correlates associated with each of the behavioral variables in each of the two work/rest schedules. The results of the study are applicable to the establishment of appropriate work/rest schedules for low-level information processing tasks like data entry. The findings are also beneficial to the enrichment of models and theories that describe prolonged low-level information processing and to the refinement of research methodology in studying mental workloads associated with low levels of information processing.

Organization of Chapters

The chapters in this dissertation are organized according to the measurement variables adopted in the study. Performance-based variables on subjective fatigue, task performance, and eye blink rate will be presented, followed by chapters describing the neurophysiological correlates with each of the performance-based variables. Method, measurement regimen, results, and discussion relevant to each cluster of variables form the content of each chapter. A general chapter on research design and method appears at the beginning, whilst general discussion and conclusion chapters will appear at the end of the dissertation.

Altogether this dissertation consists of nine chapters. Chapter II is the literature review, which gives a detailed account of the models on human information processing relevant to the study of data entry. The concepts of energy, mental effort, and cognitive processes are clarified. The ways in which performance-based variables can be measured are explained. The potential effects of rest breaks on mental workloads and possible mechanisms are explored.

Chapter III describes the process by which the Chinese version of the Swedish Occupational Fatigue Inventory (SOFI-C) was developed and validated. This instrument was used for the major performance-based variables used in the study. The chapter begins with the method of the study followed by its results, and reports its content and construct validity for use in measuring fatigue in Chinese subjects.

Chapter IV is a general method chapter that describes the basic design of this study. It includes the selection criteria of the subjects, the data entry task, the schedule of measurements, and the equipment and materials used in Chapters V to VIII.

Chapter V describes in detail the measurement schedules and instrumentation of three performance-based variables: subjective fatigue (SOFI-C), task performance, and eye blink rate. The results of changes in these three performance-based variables throughout the prolonged experimental task are reported. The differences obtained from the two rest break schedules are presented, and the results compared with the findings of other studies.

Chapters VI and VII report further analysis of the association of the conventional variables – SOFI-C and task performance – with all other neurophysiological and behavioral variables throughout the prolonged data entry task.

These chapters describe the detail measurement regimen of the neurophysiological variables used in the study, namely, electroencephalogram and heart rate variability. The method of data management and analysis of these two variables are presented. The relationship between the neurophysiological variables as measures of cognitive demand and mental workload and performance-based variables are also presented. The main observations on these relationships are then summarized.

Chapter VIII presents the general discussion of this study. The content relates the present findings to those revealed in other studies. The relevancy of the models developed by Hockey (1997) and Gaillard (1993) for describing low-level information processing are discussed, and the need for enrichment of these models is also highlighted.

Chapter IX is the conclusion of the study. It provides a description of the study's limitations and suggestions for future research in the area. The chapter is followed by the reference list and appendices.

CHAPTER II

LITERATURE REVIEW

This chapter begins with an introduction of the study of mental workload in human information processing. The cognitive-energetical theory proposed by Hockey (1997) and the energetical regulation model proposed by Gaillard (1993) that guides the present study are further elaborated. Different models that conceptualize the factors mediating information processing are also explained. The methods for measuring the behavioral and neurophysiological variables involved in the data analysis and results interpretation are described as well. This chapter concludes with the stipulations of this study.

Study of Mental Workload

Workload is defined as the tuning between the demands of the task and the work environment, and the capacity of the operator to meet those demands (Gaillard, 1993; Gopher & Donchin, 1986; Kantowitz & Casper, 1988). The total workload can be regarded as the combination of the mental, physical, and emotional load of the work. Physical workload dominates in tasks that demand tremendous physical strength, while emotional workload describes the stress and mental strain that result from participating in high mentally demanding tasks. Mental workload describes the objective workload imposed by the task (e.g., pacing or cognitive processing) or the subjective ratings of the operator with regard to the demands of the task (Gaillard & Wientjes, 1994). A literature review of the concept of mental workload suggests that it is multidimensional in nature, and is defined as the relationship between the task demands and the capacity of the operator to process information in a task situation

(Gaillard, 1993; Kantowitz, 1988; O'Donnell & Eggemeier, 1986). Processing capacity depends on the availability of the processing modules, attentional resources, and the state of the individual (Gaillard, 1993). For instance, the more complex a task is, the more mental process an operator has to invest and the higher the level of alertness the operator has to maintain (Veltman & Gaillard, 1996). The complexity of a task is related to the processing strategies of the operator and the demands of the information processing involved in the task (Wickens & Hollands, 2000). Some clerical positions, such as secretarial and accounts receivable, light-industrial assignments, such as technical assembly, and certain types of inspection and quality control have been designated as having high information processing demands. These tasks are characterized by the requirement of at least a minimal level of judgment and decision making. Other clerical positions, such as filing and data entry, have been designated as having low information processing demands (Finkelman, 1994). These tasks are characterized as lacking judgment and decision-making requirements.

Engagement in tasks with a high mental workload tends to induce mental fatigue in the operator more quickly than engagement in tasks with low information processing demands (Matthews et al., 2000). Mental fatigue can be commonly defined as a gradual and cumulative process that manifests itself as a decrement in performance (Okogoaa, Shell, & Filipusic, 1994). Sometimes, mental fatigue and performance decline in work situations can be fatal, particularly in the transportation industry. Because of this, piloting and driving are the two work tasks that have attracted the most research in this area (Brown, 1994; Cabon et al., 1993; Neri et al., 2002). In measuring mental workload, those studies that focus on high mentally demanding tasks, such as truck driving, flight operation, arithmetic problem solving, proofreading, and even simple computer operation, often employ a combination of behavioral and physiological measures (Ahsberg, Gamberale, & Gustafsson, 2000; Hankins & Wilson, 1998; Hartley et al., 1994; Okogoaa, Shell, & Filipusic, 1994; Sterman, Mann, & Kaiser, 1992; Veltman & Gaillard, 1998). Task performance and subjective fatigue ratings are the behavioral measures commonly used in workload studies (Wickens & Hollands, 2000). Some studies use eye blink rate to reflect workload (Van Orden et al., 2001). It has been shown that eye blink rate declines as workload and the cognitive demand of the task increase (Brookings, Wilson, & Swain, 1996; Fogarty & Stern, 1989; Hankins & Wilson, 1998; Veltman & Gaillard, 1998). Others have reported that eye blink rate is related to visual fatigue in visual display terminal (VDT) tasks (Kaneko & Sakamoto, 2001). Although behavioral measures may reflect the mental workload and the capacity of the individual on the task, they have previously been commented upon as being inadequate for revealing the underlying processes, especially the state of the individual (Veltman & Gaillard, 1996). One complicating process is that operators will try to keep their performance at an acceptable level even if they feel fatigue on the task (Veltman & Gaillard, 1996). This is probably because individuals can adapt to increasing task demands by exerting additional effort to maintain a constant level of performance (Veltman & Gaillard, 1996). Such underlying processes, such as exertion of additional effort, call for quantification using physiological indicators such as cardiac, respiratory, brain, and hormonal measures (Hankins & Wilson, 1998). The mechanism underlying the regulation of an operator's performance on task has been modeled in Hockey's cognitive energetical framework.

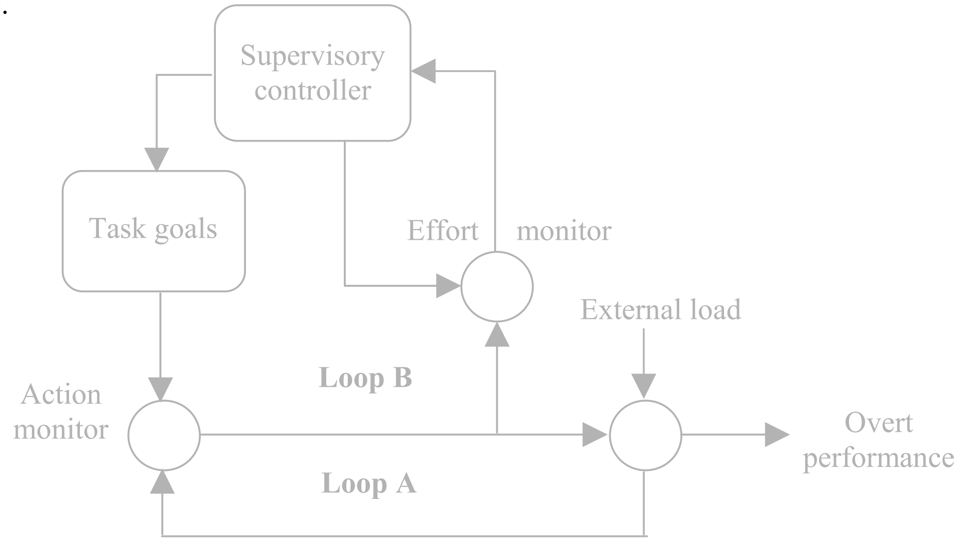
Hockey's Cognitive Energetical Framework

The thesis of the cognitive energetical framework is that maintenance of performance stability under demanding conditions is an active process under the control of the individual, which requires the management of cognitive resources through mobilization of mental effort (Hockey, 1997). Hockey (1997) proposed a compensatory control model to depict the regulation of performance that accounts for the different patterns of effects of performance observed under high workloads (Figure 2.1).

Loop A represents what is often called "automatic" control in Figure 2.1 (Hockey, 1997). The task demand at this level is often a well-learned skill that an individual can easily execute without any active regulation or effort. Hence, this loop best represents the performance of routine activities, such as writing a signature, and automatic processing, which is fast and relatively effortless (Shiffrin & Schneider, 1977). In contrast, Loop B represents controlled and effortful processing. Controlled processing requires serial search that demands attention and voluntary control (Shiffrin & Schneider, 1977). When task performance is executed via this loop, performance is thought to adjust according to the target task goal. Any adjustment depends on the task demand and difficulty as perceived by the individual. This is a major component difference between Loops A and B, in which the latter involves awareness of resource deployment.

According to Hockey's (1997) model, the amount of effort an individual puts into a task is sensitive to the increase in the control demands under the automatic task condition. Processing is shifted from automatic (Loop A) to effortful (Loop B) if the task demand is too high for execution. The maintenance of effort henceforth has been termed the *supervisory controller*. In the cognitive energetical framework, such involvement of effort is said to be compensatory in order to maintain the task performance at a certain task goal. Unlike Kahneman (1973), Hockey (1997) argued that effort does not automatically increase to meet new task demands but is adjusted according to the individual’s perception of the change in task load. An important implication of the two-level model is that there is probably only one kind of effort but two levels or settings. This means the control system requires two separate levels of the effort monitor, a lower and an upper set-point. The lower set-point is a default for a given task environment (the working effort budget), based on the anticipated resource needs of the task, level of skill, and so on (Hockey, 1997). Increases in demands below this level are not felt as effortful, and control of performance appears automatic (Loop A). The performance within Loop A henceforth is quite stable. The upper set-point represents an operational maximum for effort expenditure. The difference in magnitude between the two set-points constitutes a reserve for meeting any additional demands and/or unpredictable changes in the demands/resources balance as a result of engaging in the task (Hockey, 1997). The performance within Loop B henceforth is more motivational in origin and varied when compared with that of Loop A. Motivation is proposed as a function of individual differences in the perceived value of task goals, the response to challenge, the capacity for sustained work, and tolerance of aversive states associated with a high mental workload (Hockey, 1997). It is also likely to change more under the influence of short-term factors such as fatigue (Holding, 1983) and prevailing affective states (Ellis & Ashbrook, 1988; Wiethoff & Hockey, 1996).

Figure 2.1. Compensatory control model of performance. Loop A represents routine regulatory activity, and Loop B effort-based control. (Extracted from Hockey (1997), pp. 79).



The Hockey model is a compensatory control model that describes single-task performance, but it becomes less comprehensive for describing the mechanism underlying a dual task. In the performance of a single task such as driving – a high mental workload condition – Loop B of the model is expected to be activated because the demand of the task is so high that it should overstep the low set-point of the effort monitor. Since individuals participating in this kind of task are aware of performance and safety, they need to continuously invest mental effort so as to maintain the performance at a specific level of safety. Under this circumstance, the investment in mental effort becomes an intensive and compensatory process that is regarded as a valid indicator reflecting the mental workload associated with performance of the task.

In contrast, for tasks of low workload demand, such as filing and typing, the relationship between mental effort (Loop B), mental workload, and performance are less obvious. One reason is that simple and repetitive clerical tasks do not require active and continuous decision making for the task to be executed at a fairly low level of effort below the low set-point of the effort monitor. Nonetheless, the execution process might not be fully automatic. The main reason is that the stimuli (or content of the task) tend to vary across time. For instance, an individual may have to organize different files and type different words and digits. The task procedures require the operator to attend to each piece of information despite the familiarily of the information to the operator. Several factors may lead to a shift from low to high effortful task conditions, such as motivation of the individual, a higher level of perceived task goals, and better tolerance of fatigue. In the case of fatigue, the operator needs to invest more effort if he/she wants to maintain the task performance at a steady level. This act triggers the effortful processing. There are individual differences in the shift between the two levels even when the task remains the same. The evaluation of mental workload on prolonged low-demanding tasks not only requires examination of the underlying physiological changes but also the association of factors within the context of the framework, such as the relationship between performance and effort.

Concepts of Mental Effort and Resources

Hockey's cognitive energetical framework stresses the role of mental effort – an energy-based construct in performing an information-processing task. Mental effort is the primary energetical drive of active information processing. Other literature on human factors emphasizes the processing modules responsible for information processing (Allport, 1989; Wickens & Hollands, 2000). These processing modules usually refer to different specialized cognitive subsystems, such as sensory processing and perception, that constitute an individual's resources in processing a task (Matthews et al., 2000).

Resources

Performance of a task with specific content requires specialized cognitive functions (Matthews et al., 2000). Wickens and Hollands (2000) outlined the different cognitive functions that could be involved in processing information: sensory processing, perception, decision making, and response execution. Sensory processing refers to the initial perceptual processes that transform neural outputs from the senses into abstract codes that represent characteristics of the objects. These characteristics can be in the form of color, size, or distance. Following recognition of the stimuli, the relevant decision-making process may recruit long-term memory or working memory for producing the appropriate response. It is obvious that the recruitment of different cognitive subsystems is task and response specific. Nevertheless, the energy that fuels the subsystems comes from a single pool of attentional resources (Wicken & Hollands, 2000). The efficiency of processing the information available to the operator depends on the extent to which sufficient resources are allocated. The more energetical resources that are delivered to the cognitive subsystems, the better the performance. In reality, resources tend to be limited in most tasks. In particular, the pool of resources will deplete quickly under a high workload situation or deplete gradually during prolonged information processing (Parasuraman et al., 1987). According to Hockey (1997), effort increases the delivery of the energetical resources to the cognitive subsystem.

Mental Effort

Kahneman (1973) and Moray (1967) proposed that resources are equivalent to attention and all the related processing capacities of an individual. Based on their theory, resources can be flexibly allocated to more than one task at a time and up to the point that all attentional resources have been allocated. This theory equates effort with the level of resource allocated to the task, which is somewhat similar to what Hockey (1997) adopted in defining the term *effort* within the cognitive energetical framework. What this means is that with more effort, more resources can be allocated to the task and better performance will result.

Despite Hockey's (1997) use of the term *effort* instead of *mental effort*, it is generally believed that the term *effort* refers to mental effort. The reason is that in his model, the term *effort* has been used to denote a drive on the central resources of the individual. For instance, Hockey's (1997) cognitive energetical framework describes self-regulation and cognitive control. These connotations vary greatly and are similar to those of others who have adopted the term *mental effort* (e.g., Gaillard & Wientjes, 1994; Muraven & Baumeister, 2000).

While Hockey (1997) proposed the two-level compensatory control model for guiding the mechanism of resource allocation, Mulder (1986) argued for the existence of a computational mechanism and an energetical mechanism to support the processing of resources. According to Mulder, performance of controlled processing requires the registration of information, which denotes sensory input, and the motor response, which denotes task output, from the computational mechanism. Effort is an element in the energetical mechanism, which is regarded as the executive system that coordinates the input and output processes. Based on his model, Mulder further assumed there to be two forms of effort, one that is activated whenever a task requires attention-demanding controlled processing, and the other when the individual has to change the current energetical resource state into another state. His assumptions cohere with those of Pribram and McGuinness (1975). Mulder has discussed the distinction between the two forms of effort, in which the former is related to the difficulty of the task and the latter to the control of state. However, both types of effort have physiological concomitants. It has been hypothesized that the physiological changes observed during the performance of attention-demanding tasks reflect the mobilization of computational mechanisms required to carry out the task (Mulder, 1986). The more central the physiological indices, the closer they reveal something about the nature of the resources. From this point of view, peripheral measures such as pupil dilation and heart rate variability can only indicate that resources are mobilized and effort is invested for the control of state. In contrast, the central indices are more specific for revealing the investment of effort for a particular function (Mulder, 1986). For example, brain imaging allows the examination of activations in specific cortical structures. Theoretically, however, it is sometimes difficult to differentiate between the two types of effort. One could argue that there is probably only one type of effort, because if an individual has to carry out a difficult mental task, he/she has to also simultaneously change the present state in the direction that is optimal for the task (Hockey, Coles, & Gaillard, 1986).

Hockey's (1997) model consists of only one effort but a two-level effort system. The aim is to provide a possible solution to the theoretical problem of separating the two efforts (Hockey, 1997). These two effort levels could represent differences in both task difficulty and processing state. In the former situation, the individual determines whether or not to set a higher set-point of effort to meet the task demand at the very beginning of engagement. In the latter situation, the individual has to push for a higher level of effort to avoid performance decline as the result of fatigue or other detrimental incidence. The former situation describes a coping with regard to the demand of controlled processing, and the latter to compensatory control. Relating effort to both task difficulty (amount of controlled processing required) and compensatory control has also been outlined in some other models (Humphreys & Revelle, 1984; Sanders, 1983).

Base on Hockey’s (1997) model, the meaning of effort obtained from whichever measurements, peripheral or central, is dependent on which parameters, task difficulty, or processing state the experiment manipulates. For example, if task difficulty is under experimentation, then effort is likely to reflect differences in terms of the demands on controlled processing. In the present study, the duration and frequency of rest breaks was the sole difference between the two experimental groups. Such a difference in rest breaks was intended to manipulate the processing state of the subjects. As a result, the physiological measurements used to denote changes or association in the present study most probably explain the differences in processing state at different points of time. It is necessary to further elaborate details of the processing state and energy by drawing models of the regulation of energetical states in human information processing.

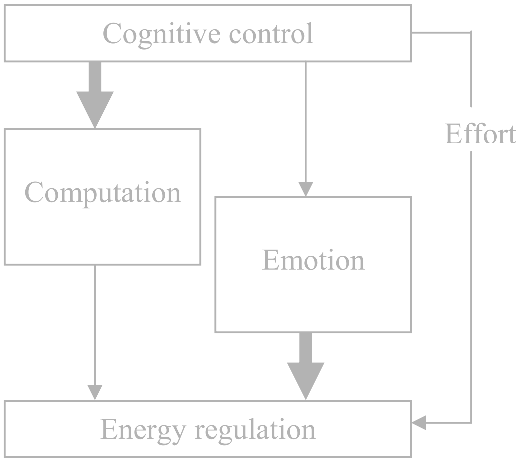
Gaillard’s Model of Information Processing and Energetical Regulation

In a typical model of information processing, the quality and quantity of task output from any input of task demand depends on an individual’s central computational processing, which is influenced by higher cognitive processes on one hand and energetic states on the other (Figure 2.2) (Gaillard, 1993). The central computational processing operates on formal and logical rules generated from an individual’s cognitive processes and hence produces overt behaviors. The mental resources required for supporting the processing of information originate from the brain, and their dissipation is determined by the individual’s energetical state. Under normal circumstances, energy is dissipated sufficiently to maintain the individual’s activation and performance on task. The energy dissipating level from this point on is optimized for driving the cognitive processes for matching the task demands and maximizing the performance on task. The investment of resources, cognitive processing, and task performance from this point is under equilibrium and in an automatic state. In some circumstances after engaging in a task for a substantial period of time, the energetical resources ready for use may become depleted. As a result, an individual might need to recruit extra resources from his/her reserve to maintain the cognitive processing and hence performance. It has been suggested that this process is mediated by mental effort. According to Gaillard (1993), the only way in which the individual's energetical state can be influenced directly is by mobilizing extra energy through mental effort. This is a trying-harder action under voluntary control and largely depends on one's motivation to attain particular goals. Both Gaillard (1993) and Hockey (1997) shared the same viewpoint that mental effort is mobilized to meet task demands. In addition to Hockey, Gaillard has elaborated on mental effort in more detail.

Definition of Mental Effort

When the type of processing is attention-demanding and resources are limited, the individual has to mobilize extra energy to be able to perform the task, and such an act requires mental effort (Gaillard, 1993; Gaillard & Wientjes, 1994). According to Gaillard (1993), this type of processing is needed in a dynamic environment where the tasks cannot be executed by applying rules or procedures or on the basis of well-trained skills only. This type of processing is necessary in several situations, for instance: (a) when the processing required by the task is "knowledge based" and has to be done under cognitive control, or demands attention, such as decision making; (b) when the processing takes place in a multiple-task environment characterized by time sharing and allocation of attention to different tasks; or (c), when the operator has difficulty maintaining a task set due to sleep loss or fatigue; preventing distraction by irrelevant cues, such as emotion; or neglecting and showing a decline in task performance. The third situation is likely to happen in a prolonged task engagement. To further understanding, Gaillard (1993) provided a more in-depth model to illustrate explicitly the regulation of energy during information processing.

Figure 2.2. Schematic representation of the way in which the regulation of the energetical state is influenced by three levels of processing: cognitive control, computation, and emotion. The solid arrows indicate a strong influence, and the thin arrows little control. (Extracted from Gaillard (1993), pp. 993).



Gaillard (1993) and Gaillard and Wientjes (1994) described how the regulation of energy is influenced by three levels: cognitive control, computation, and emotion. Cognitive control plays a role in evaluating performance and guiding task execution under knowledge of results, that is, feedback from the task. For example, when an individual is under time pressure or is fatigued, he/she may decide to change the performance criteria (e.g., allowing more errors or investing extra mental effort to maintain the performance outcome). Cognitive control is also necessary when the individual changes his/her mind and adopts a different strategy at work. For example, a driver may decide to deviate from his driving plan or a secretary may need to change her typing strategy. Such concepts are in fact present in most human performance theories, but they may have different connotations: an upper mechanism that controls a lower mechanism (Broadbent, 1971), allocates processing resources (Kahneman, 1973), evaluates the task performance (Sanders, 1983), or monitors the state of the body (Hockey, 1986). Another concept of Gaillard's (1993) on the regulation of energy is the effects of computation and emotion. Although Hockey (1997) also mentioned the effects of motivation and subjective feelings on information processing, his interpretation largely focused on coping with work strain and the aftereffects of fatigue. According to Gaillard (1993), the influence of both computational and affective processing on the regulation of the energetical state is autonomic, and people are not able to control its influence voluntarily. The execution, and even the planning, of a task prompts the energy regulation to slowly change the bodily state into an optimal state (Gaillard, 1993; Gaillard & Wientjes, 1994). However, the impact of strong emotions on the energetical state is faster and much more violent (Gaillard, 1993). Affective processing differs from computational processing because it is not logical and does not follow formal rules (Gaillard, 1993). Therefore, it is not possible for individuals to stop or start the processing of affective information, and it is hardly possible to disregard the signals sent by an emotion (Gaillard, 1993). For instance, negative emotions such as feelings of fatigue or sleepiness often develop in prolonged task engagement regardless of whether the individual is engaging in a high workload or low workload task (Grandjean, 1988). It could be that the accumulation of a sensation of fatigue is faster and more pronounced in a high workload situation than in a low workload situation. But in both cases, such strong negative emotions often reach the individual's consciousness precedent to all other signals arising as the result of active control or computational processing (Frijda, 1986). These emotions continuously beg for attention, and mental effort is often required to neglect or neutralize these signals (Gaillard, 1993). In the present study, subjects were required to fully engage in a data entry task for 6 hours. Although the motivation of the subjects was controlled by providing a monetary reward, the development of negative emotions and feelings of fatigue were inevitable. Therefore, it was plausible that the subjects would develop subjective fatigue and negative emotions as time on task increased in the present study. According to Gaillard's (1993) model, it was likely that the amount of mental effort invested to mobilize energy at different points of time would be associated with the subjective feeling of fatigue. Nevertheless, the concept of energy and the energetical constructs needed to be revealed in more detail before a definite hypothesis could be made.

Concepts of Energy

A review of the literature on the concept of energy shows it to be rather diverse and complicated. One problem is that the energetical state is multidimensional, and different schools of thought offer a definition of energy based on their own assumptions (Hockey, Gaillard, & Coles, 1986). Another problem is that effort, activation, arousal, stress, fatigue, and resources are all regarded as energetical constructs in the computational models of behavior described by Hockey, Gaillard, and Coles (1986). However, it has been difficult to make definite distinctions among them because they all interact with information processing. The concept of stress, however, has an even larger variety of meanings, which originate from environmental factors such as noise, sleep loss, and drugs, or work-related factors such as pacing and time pressure (Gaillard, 1993). Nevertheless, stress was outside the scope of the present study because none of the above factors were being manipulated in the experiment, and therefore it is not discussed in detail here. It is generally accepted that arousal is identified with early processing (e.g., feature encoding and registration of sensory information); activation with motor response (e.g., preparation of task output); and effort with a central coordination process (Hockey, Gaillard, & Coles, 1986; Pribram & McGuinness, 1975). This interpretation is coherent with Mulder's (1986), who based his understanding of effort on the coordination between the input and output processes. Although this model also outlines processing states, it puts too much emphasis on tasks involving highly controlled processing. In addition, there are other conceptualizations regarding energy and processing states that are worth a brief illustration below.

Activation and Task Performance

It has been well established that the relationship between task performance and activation level follows an inverted U-curve (Gillard, 1993; Hebb, 1955). That is, each activity has its optimum at which the task can be performed best, while performance efficiency is low when the activation level is either too high or too low (Gaillard, 1993; Hebb, 1955). In addition, according to the arousal theory of performance, the activation level determines the state of the individual: Too low an activation level denotes a state of drowsiness and reduced arousal, whereas too high an activation level denotes a state of agitation and excitement (Duffy, 1962). When the actual state does not deviate very much from the optimal state, the individual is still able to perform the task but at a lower rate or less accurately (Gaillard, 1993). If the activation is too high, the individual is likely to experience high mental strain (Matthews et al., 2000). If the activation is low, the individual can decide to maintain the same performance level by mobilizing energy through extra mental effort. However, such an act has a high physiological cost (high sympathetic activation) (Hockey, 1997) and high psychological cost (high negative feeling) (Gaillard, 1993, 1994), and can only be maintained for a short period while inducing mental fatigue (Gaillard, 1993). This model differs from some information processing theories mentioned before (e.g. Kahneman, 1973; Sanders, 1983) in that it explains performance efficiency in terms of a deviation from an optimal energetical state rather than of shortages in resources. Nevertheless, this model further supplements the need to mobilize mental effort in the energetical mechanism outlined by Gaillard (1993) and Mulder (1986), particularly Gaillard (1993), who argued for the importance of mental effort under suboptimal conditions.

Posner's Attention Network

Attention can be defined as the ability to attend to and focus on tasks selectively varied over time (Metthews et al., 2000). Posner and Rothbart (1986) regarded attention as an operant form of energy that serves to improve information processing. Posner and Raichle (1997) proposed an attention network comprising three components, namely visual orientation, executive function, and vigilance, interacting with one other for successful performance of a task. Among the three elements, vigilance describes the processing state of the individual. According to Posner and Raichle (1997), vigilance refers to the maintenance of a state of alertness for executing the orientating and executive functions. In Posner's studies, however, the terms *alertness* and *arousal* are interchangeable (Posner & Raichle, 1997; Posner & Rothbart, 1986). This definition differs from those of others like Pribram and McGuinness (1975) and Mulder (1986), who have referred to arousal as the immediate physiological response of the orienting response, while alertness is the readiness of an executive response, such as a motor action. The orienting of visual attention in Posner's attention network depends upon a sequence of elementary mental operations that includes disengaging from the current focus of attention, shifting attention to the cued location, and amplifying the target (Posner & Raichle, 1997). For instance, the whole process applies to numerical data entry when the individual has to focus on a word and then shift his/her attention to each consecutive digit along with the execution of the typing action. Executive function comes into play when judgment and decision making have to be performed (Posner & Raichle, 1997). Unlike Gaillard's model of information processing (1993), Posner's attention network does not emphasize emotion (Hockey, Gaillard, & Coles, 1986). Rather, Posner's attention network gives a very detailed analysis of the elements involved for the engagement of a task (Posner & Rothbart, 1992; Posner & Tudela, 1997). Although Posner's attention network is built on a selective attention framework that depicts performance mostly on visual-spatial tasks (Posner & Raichle, 1997; Posner et al., 1984; Posner & Rothbart, 1986), its explanation of the vigilance network is consistent with that of Davis and Parasuraman (1982), who observed that attention is involved in the detection of novel and rare targets, and that a change in the attention level can influence task performance on a prolonged task. Another important element of Posner's work is the integration of attention with anatomical structures of the human brain (Posner, 1982). In fact, the understanding of the energetic and computational concepts in information processing has been documented in terms of neural systems and neural processes (Robbins, 1986). In this context, what Posner and Rothbart (1992) and Posner and Raichle (1997) have contributed is additional information on the locations responsible for task execution. For instance, Posner and Raichle (1997) reported that activation of the vigilance network is substantiated in the right frontal lobe, and activation of the visual orienting network is substantiated in the parietal lobe and the thalamus. These locations provide possible landmarks for interpretation of the neurocorrelates to be obtained in this study. Furthermore, Posner and Raichle (1997) found that the amount of activation is reduced as the task becomes automated with practice. They explained that as an individual becomes more practiced, feelings of effort and continuous attention diminish, and details of performance drop out of subjective experience (Posner & Raichle, 1997). This observation is important, because the task employed in the present study was a simple numerical data entry task in which a certain level of automaticity was suspected during prolonged engagement. Nevertheless, understanding how activation, mental effort, and subjective fatigue are interrelated in the neural system requires a more comprehensive review of the neurophysiological basis of energy.

Neurophysiological Basis of Energy

Ascending Reticular Activating System

The neurophysiological basis of energy originates in the reticular formation, a subcortical structure responsible for the maintenance of alertness (Zomeren & Brouwer, 1994). The reticular formation exerts an excitatory influence on the whole brain by means of a nonspecific projecting system known as the ascending reticular activating system (ARAS) (Zomeren & Brouwer, 1994). The ARAS consists of the reticular formation plus non-specific afferents that arise from it, ascend through the intralaminar nuclei of the thalamus, and then fan out to various part of the brain, particularly the cortex (Zomeren & Brouwer, 1994). The activity of the reticular formation itself is mainly determined by sensory input. As the main afferent paths ascend through the brainstem and approach the thalamus, branches turn away from the mainstream and re-enter the reticular formation. In accordance with the special histological character of the formation, the effect of this sensory stimulation is not specific, but results in a pooling of excitatory effects (Zomeren & Brouwer, 1994). The ARAS then transmits this excitation through its diffuse projection system to the cortex. This implies that any sensory stimulation will affect the cortex in two ways: as a specific input (according to the input of the task demand) relayed through thalamic nuclei to direct the signals to particular a cortical area; and as a contribution in the nonspecific activating system to maintain alertness. In addition, Pribram and McGuinness (1975) and Sharpless and Jaspers (1956) mentioned functional differences between the upper end (upper half of the medulla oblongata) and the lower end (lower half of the medulla oblongata approaching the spinal cord) of the reticular formation. In the upper end, when the reticular formation enters the thalamus and fills the spaces between specific thalamic nuclei, an additional branch turns away to enter the hypothalamus, providing a link between alertness and viscero-autonomic phenomena, such as sympathetic activation (Pribram & McGuinness, 1975). This upper ARAS and the nonspecific thalamic projection mediate alertness and are responsible for changes in it. Zomere and Brouwer (1994) regarded this kind of activation as phasic activation, producing an elevated state. On the other hand, the lower half of the reticular formation is responsible for tonic activation, producing the background state (Zomeren & Brouwer, 1994). For instance, drowsiness provoked by too low-demanding task situations is explained in terms of decreased collateral sensory input in the lower half of the reticular formation (Sharpless & Jaspers, 1956).

Meaning of Alertness, Arousal, and Activation

The terminology of alertness, arousal, and activation has been confusing in theories of human information processing, probably because they refer to very similar ideas. Nonetheless, their meanings could be made more distinct by viewing them from a physiological perspective. According to Zomere and Brouwer (1994), the thresholds for reacting to environmental stimulation vary strongly with the background state of wakefulness, from Stage IV sleep to hyperalertness. The scale between these two extremes is called the level of alertness, which may be defined as a generalized state of receptivity to stimulation and preparedness to respond (Posner & Rafal, 1987). In the view of Zomere and Brouwer (1994) and Pribram and McGuinness (1975), alertness is a tonic activation to denote a background state. A sudden increase in alertness from attentional mechanism for processing of information, for example, is known as arousal (Zomere & Brouwer, 1994). This definition is consistent with Mulder (1986), who regarded arousal as the registration of information, an initial response to a novel stimulus, in his information processing theory. Furthermore, arousal is regarded as a phasic change to denote an elevated state for processing of incoming information (Zomere & Brouwer, 1994). This phasic change has various names depending on the discipline (Zomere & Brouwer, 1994). For instance, arousal can refer to activation from an electrophysiological perspective (Ursin, 1986), while to an orienting reaction from a psychological perspective (Posner & Raichle, 1997). According to Pribram and McGuinness (1975), arousal is controlled by two reciprocal systems that converge on the amygdala, a part of the limbic system responsible for generating emotion and feeling. Both these systems originate in the frontal cortex, converge on the amydgala, and finally influence hypothalamic structures related to arousal. Hence, emotions and subjective feelings can influence the arousal level of the individual involuntarily. The first of these systems has its cortical component in the dorsolateral frontal cortex and has a facilitating effect on arousal. The second system originates in the orbitofrontal cortex and represents an extensive inhibitory pathway. This reciprocal innervation allows a sensitive modulation of the arousal mechanism. In fact, the neural anatomical relationship between emotion and arousal has been documented in Kandel, Schwartz, and Jessell (2000). Although the neurophysiological perspective offers a distinctive meaning between alertness and arousal, the identification of whether the ARAS or the diffuse thalamic projection system or both are responsible for regulation of the state is confusing. It has been demonstrated that the ARAS and the diffuse thalamic projection system together bring about a particular state of the individual (Zomere & Brouwer, 1994). However, Stuss and Benson (1984, 1986) argued that the ARAS provides a tonic level of alertness, while the diffuse thalamic projection system provides phasic changes in alertness. Nevertheless, the differentiation of the neurophysiological basis between alertness and arousal is not the main issue in the present study. Rather, the modulation of arousal levels and the influence of rest breaks on the modulation and its neurocorrelates are the study’s main focus. Since mental effort has been shown to be involved in the mobilization of energy (Gaillard, 1993; Hockey, 1997; Hockey, Gaillard, & Coles, 1986), it should have a role to play in the neurophysiological mechanism associated with the ARAS.

Mental Effort and the Reticular Activating System

Under any circumstances, the ascending activating system continues to maintain alertness as long as an individual is awake. When the individual attends to a task, the cerebral cortex receives external stimulation and stimulates the ARAS to increase alertness and improve information processing to facilitate the performance (Grandjean, 1988). The individual is said to be aroused, and the level of arousal is apparently sustained by the reciprocal feedback mechanisms between the cortex, the ARAS, and the hypothalamus (Roscoe, 1992). The cerebral cortex delivers the signals to the ARAS through its descending fibers that run from the orbital and medial frontal cortex to the nuclei of the thalamus and the brainstem. In many respects, this descending system is the mirror image of the ARAS, and the descending fibers permit the higher levels of the cortex, which participate directly in information processing, to recruit the lower systems and modulate their work to elicit a sufficient level of arousal to support the cortical activities (Luria, 1973; Zomere & Brouwer, 1994). In this context, the internal drive of the individual to elevate his/her arousal state is perceived as mental effort (Hockey, Coles, & Gaillard, 1986). In the information processing theories mentioned previously, all authors have agreed that the psychological phenomena of mental effort investment originate from neurophysiological processes (Gaillard, 1993; Hockey, 1997; Mulder, 1986). But their definitions of mental effort vary, which is not desirable in the present study. In particular, Mulder (1986) has argued that there are two efforts, one for controlled processing and the other for maintaining the state; Gaillard (1993) has viewed the effort in meeting task demand or withstanding fatigue as extra mental effort; while Hockey (1997) has proposed one effort with two set points. In view of the neurophysiological basis, it appears that the state of the individual changes simultaneously with the task demands. This is because the cerebral cortex, the reticular activating system, and the hypothalamus are interconnected and operate under a reciprocal feedback mechanism. That is, the more mental effort a task demands, the higher the arousal level a person has to adjust for. In this way, it is practically difficult to separate the effort involved in meeting a particular task demand from that involved in elevating the state to the optimal level, as Mulder (1986) has considered. In addition, the use of mental effort in mobilizing extra energy as proposed by Gaillard (1993) could be conceptualized in two ways. First, in whatever situation, effort is needed to maintain alertness and mental effort, which describes the drive of the individual to utilize extra energy to meet a specific demand imposed by the task. Second, when an individual is engaging in a task at a certain level of effort, extra energy has to be invested through mental effort to maintain the performance against the detrimental effect of fatigue.

In the present study, it is more reasonable to stick to the one-effort principle as proposed by Hockey (1997). This is because the neurophysiolgical mechanism operates in such a way that any mental effort, whether it is primarily designated for meeting task demand or for elevating the state, is regulated concurrently under the reciprocal feedback mechanism. Under normal circumstances, when an individual engages in a task, his/her background state will be adjusted with regard to the demand of the task at the very beginning. This adjustment requires mental effort, and whether the amount of effort is high, requiring effortful controlled processing, or low, requiring routine automatic processing, depends on whether the effort requirement is over or under the lower set-point of the effort monitor, respectively (Hockey, 1997). As the task engagement progresses, the adjustment of mental effort continues and is likely to be influenced by emotion and/or fatigue (Hockey, 1997). In this study, since subjects were required to engage in a data entry task for a prolonged period, the adjustment of mental effort could readily be explained by the two set-points of the effort monitor: less mental effort was required after practice (below the lower set-point), and more mental effort was required to overcome performance decrement approaching fatigue (above the lower set-point).

Attention, Vigilance and Fatigue

Attention, which can be referred to as sustained attention in performance of a single task, is defined as the maintenance of a focus attention over a relatively long period of time, for example in industrial inspection, military target spotting, air traffic control and medical monitoring (Matthews et al., 2000). Vigilance has been a term used in a more restricted sense to denote a state of readiness (Mackworth, 1957). Therefore it has been mentioned that sustained attention and vigilance could be of similar concept and that vigilance tasks have came to be regarded as providing the fundamental paradigm for defining sustained attention as a behavioral category (Jerison, 1977). Signal detection task is a typical vigilance task in which an individual's sustained attention can be assessed by performance decrement in detecting signals (Matthews et al., 2000). Fatigue of the individual can result in performance break down. However, fatigue is not the sole reason for showing decline in attention or vigilance of individual. Although decline in performance of vigilance tasks could be explained by fatigue, it could also be related to attention decline as the result of environmental distraction. Generally, fatigue refers to feelings of tiredness and bodily discomfort associated with prolonged activity (Matthews et al., 2000). In many mental workload studies, like those addressing fatigue and work efficiency in driving tasks, objective indicator of mental fatigue is often declined in task performance (Okogbaa et al., 1994). Since data entry is a simple and monotonous low demanding task, it is not expected to observe prominent decrement in task performance. Instead, because of the prolonged performance of low level information processing, subjective feelings of fatigue would be more likely to increase which hinder energy regulation. Therefore, perceived fatigue feeling as revealed using the subjective fatigue rating is used as the indicator to reflect mental fatigue in this study.

Heart Rate Variability as a Measure of Mental Effort

Mental effort modulates heart rate regulation via the hypothalamus in the subcortical system, which integrates autonomic responses (Roscoe, 1992). The nucleus of the solitary tract, situated in the reticular formation, is a key component of the central autonomic network (Kandel, Schwartz, & Jessell, 2000). This nucleus receives signals from the hypothalamus and relays visceral afferents directly to regulate vagal motor control of the stomach and heart rate (Kandel, Schwartz, & Jessell, 2000). Other outputs from the nucleus of the solitary tract innervate neurons in the ventrolateral medullary reticular formation and control blood pressure (Kandel, Schwartz, & Jessell, 2000). Under normal circumstances, baroreflex in the aorta is responsible for blood pressure regulation. When blood pressure increases, the vascular walls expand and the firing rates of the baroreceptors, and thus of the aortic and the carotid nerves, rise, causing a drop in blood pressure, which results in a beat-to-beat change of heart rate (Roscoe, 1992). However, the investment of mental effort in the cortical and subcortical levels has been found to suppress cardiac baroreflex sensitivity (Berntson, Cacipoppo, & Fieldstone, 1996; Eckberg & Sleight, 1992; Steptoe, Fielman, & Evans, 1993). Furthermore, Mulder (1988) also showed that mental effort reduces the sensitivity of the baroreflex mechanism, resulting in reduced blood pressure control on the heart rate regulation in the peripheral nervous system, and reduced beat-to-beat change of heart rate.

Heart rate variability (HRV) is the beat-to-beat change of heart rate, the physiological meaning of which is best interpreted using spectral analysis (Jorna, 1992; Schellekens, 2000; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). The frequency spectrum of HRV can be divided into three bands: low band (0.02-0.06 Hz), mid band (0.07-0.14 Hz) and high band (0.15-0.5 Hz) (Jorna, 1992; Schellekens, 2000; Veltman & Gaillard, 1996). The total area under the curve of the spectrum indicates the total variance of the signal in the time domain (Jorna, 1992). The low and high bands are for body temperature and respiratory regulation respectively (Jorna, 1992). The mid band, ranging from 0.07 to 0.14 Hz, also called the 0.1 Hz component, is related to blood pressure regulation because its control mechanism causes a resonance in the veins with a frequency of about 0.1 Hz (Veltman & Gaillard, 1996). Since mental effort reduces the sensitivity of blood pressure regulation, the HRV will be less determined by changes in blood pressure during mental effort investment and result in a reduction of the power of the mid band (Veltman & Gaillard, 1996). Past studies have shown that the 0.1 Hz component is suppressed in mentally demanding tasks (Schellekens et al., 2000). Furthermore, it has been found that difficult tasks that demand more mental effort show a lower spectral power of 0.1 Hz HRV than do simple tasks (Aasman, Mulder, & Mulder, 1987; Sammer, 1998; Vicente, Thornton, & Moray, 1987).

Electroencephalogram as Measures of State and Cognitive Process

The electroencephalogram (EEG) is regarded as one of the most predicative and reliable physiological measures of arousal and vigilance (Davidson, Jackson, & Larson, 2000; Sterman & Mann, 1995; Wright & McGown, 2001). The EEG is generated by the inhibitory and excitatory postsynaptic potentials of cortical nerve cells. These potentials summate in the cortex and extend through the coverings of the brain (Fisch, 1991). This electrical activity of the brain is classified according to rhythms and is often decomposed into bands defined on the basis of lower and upper frequency boundaries (Davidson, Jackson, & Larson, 2000). The classic bands for adult EEG include delta (0 – 4 Hz), theta (5 – 7 Hz), alpha (8 – 12 Hz), and beta (13 – 30 Hz). The delta rhythms are slow waves that present mostly during sleep or in a very sleepy condition (Grandjean, 1988; Wright & McGown, 2001). The theta rhythms are slow, long period waves that present when alertness is reduced. The alpha rhythms are present during waking hours and are blocked by sensory impulses, so that a high alpha wave component indicates a relaxed condition and a reduced readiness to react to stimuli. A lower alpha component coupled with a higher beta component indicates a more alert state (Davidson, Jackson, & Larson, 2000; Grandjean, 1988). The beta rhythms represent irregular electrical activity of very low amplitude. This occurs after the receipt of a sensory stimulus, and is the expression of an interruption of the synchronized activities of neurons that make up the alpha rhythm. Synchronization is the simultaneous excitation of a large group of nerve cells. Desychronization between beta and alpha activities (high beta activity and low alpha activity) is a sign of a state of increased alertness and is also known as arousal reaction (Davidson, Jackson, & Larson, 2000; Grandjean, 1988). Awaking and taking alarm are examples of this (Grandjean, 1988).

The EEG has been used as a neurophysiological measure of cognitive workload during human/computer interaction (Gevins & Smith, 2003). The EEG parameters, that is, waveband intensity, magnitude, and site of activation, have been found to be useful indicators reflecting the impact of tasks on an individual's performance, such as exposure to a task, the cognitive processes required by the task, and the cognitive strategies involved in the task (Rappelsberger & Petsche, 1988). For instance, alpha activity is divided into slow and fast signals (Davidson, Jackson, & Larson, 2000). At frontal locations, the slow alpha band (average 9 Hz, range 8 – 10 Hz) is primarily associated with attentional processes (Gevins et al., 1997), and the fast alpha band (average 11 Hz, range 10 – 13 Hz) with semantic memory processes (Jausovec & Jausovec, 2000; Wilson, Swain, & Ullsperger, 1999). At occipitoparietal locations, the fast alpha is also related to variations in the cognitive content of the tasks being performed (Gevins et al., 1997). In addition, it has been demonstrated that changes in mental load are associated with changes in magnitude of the frontal theta waveband (Gevins & Smith, 2003; Klimesch, 1999; Klimesch, Schimke, & Schwaiger, 1994; Rugg & Dickens, 1982). The generating source of the frontal theta has been shown to be the anterior cingulate cortex (Gevins & Smith, 2003). The anterior cingulate cortex is part of an anterior brain network that is critical to attention control mechanisms and that is activated by the performance of complex cognitive tasks (Posner & Peterson, 1990; Posner & Rothbart, 1992). Hence, according to Gevins and Smith (2003), performance of tasks that require significant mental effort places high demands on frontal brain circuits involved with attention control. On the other hand, past studies have revealed that the alpha band tends to be attenuated in high load tasks relative to low load tasks. This inverse relationship between task difficulty and alpha band power has been observed in many studies in which task difficulty has been systematically manipulated (Galin et al., 1978; Gevins et al., 1997, 1998; Gevins & Smith, 1999; Gundel & Wilson, 1992). Hence, the magnitude of the alpha activity during cognitive tasks has been hypothesized to be inversely proportional to the fraction of cortical neurons recruited into a transient functional network for purposes of task performance (Gevins & Schaffer, 1980; Mulholland, 1995). In additional to signals in the theta and alpha bands, the slow wave activity in the delta band (< 3 Hz) and high frequency activity in the beta band (15 – 30 Hz) have also been reported to be sensitive to changes in effortful attention (McCallum, Cooper, & Pocock, 1988; Rockstroh et al., 1989; Sheer, 1989). In addition, Popovich and Hachaturyanz (1983) revealed specific patterns in power spectral changes during and after the performance of a prolonged information processing task. During the task, slow wave activity (delta, theta, and alpha) gradually increased across time. In contrast, at the end of the task, both slow wave (mainly theta) and fast wave (beta) activities increased. The former effect is probably related to the decline of arousal, whereas the latter is likely to result from subjects making an effort to maintain a high level of performance by overcoming the inhibition (Kiroy et al., 1996). Chan et al. (2003) further showed that mental fatigue after prolonged computer-based proofreading tasks result in overall suppression of the band wave activities and a simultaneous increase in both the theta and beta band activities. Furthermore, the EEG activities at occipital sites have been shown to reflect general arousal throughout prolonged engagement in tasks. For example, Wright and McGown (2001) showed that an intermittent sleepiness state during prolonged engagement in a mentally demanding task is reflected by a slow wave (delta) at occipital sites. Floru and Cail (1987) and Floru et al. (1985) used the EEG activities at occipital sites to comment on the arousal state during data entry performance. Lastly, specific EEG wavebands were found to correlate with task performance (Chouinard et al., 2003). For example, Gevins and Smith (2000) reported that practice-related increase in magnitude of frontal theta wavebands during a high-load task is positively correlated with an individual's intelligence. Moreover, the increase in beta and decrease of alpha activities are associated with heightened performance in working memory tasks (Gevins et al., 1998; Gevins & Smith, 2003; Klimesch, 1999; Wilson, Swain, & Ullsperger, 1999).

Effects of Prolonged Single Task Engagement

Vigilance

Vigilance, also known as sustained attention, refers to the maintenance of a focus of attention over a relatively long period of time (Davies & Parasuraman, 1982; Matthew et al., 2000). Posner and Raichle (1997) regarded vigilance as a state of alertness that is fundamental to all types of attentional processing, such as execution of the orientating and executive functions. Although earlier studies on vigilance were mostly built on typical signal detection paradigms in which participants were required to monitor displays over extended periods for the occasional occurrence of critical signals (Grier et al., 2003; Mackworth, 1950, 1969), vigilance itself represents tedious, monotonous, and understimulating situations (Warm, Dember, & Hancocok, 1996). According to the arousal or activation model of vigilance, the repetitious and monotonous aspects of sustained attention tasks reduce the level of stimulation needed by elements of the central nervous system (e.g., the ascending reticular formation and the diffuse thalamic projection system) to maintain wakefulness and alertness (Warm, Bember, & Honcocok, 1996). As a result, the level of arousal drops and task performance declines.

Monotony and uniformity are common to low-level information processing tasks, like data entry (Floru et al., 1985). Past studies have shown that engagement in a monotonous task for a long period of time is prone to vigilance decrement and developing feelings of general tiredness (Grandjean, 1988). Based on Rumelhart and Norman's (1982) schema activation model on copy-typing activity, data entry is mainly composed of keypress schemata and response activation. The former relates the perceived number to the specific key in the keypad, whereas the latter refers to the activation of hand and finger muscles in relation to the keypress schemata. After practice, such activation patterns become involuntary and resource-free, which greatly reduces one's effort in the engagement (Shallice & Burgess, 1993). In addition, a numerical data entry task has an advantage over other typing tasks in that it is simple (Fitts, 1962). Although individuals performing the task may need to process different information each time, the information is limited to variations of digits, and the required response is rather uniform (Floru et al., 1985). Therefore, it is inevitable that prolonged engagement of the task will induce arousal decrement.

Habituation

Habituation results when a repeated sensory event tends to lose its capacity to produce arousal rapidly. In a prolonged sedentary task engagement like data entry, the habituation is not from the task content but from the invariant requirements of the task, such as environmental monotony, the individual's relative immobility, the reduction of stimulus variety, and low intrinsic motivation that facilitates a "passive" deactivation through a diminution of the afferent input to the brain stem arousal system (Floru et al., 1985). According to Mackworth (1969), monotonous conditions of testing induce habituation of evoked responses and the arousal reaction. The resultant cortical inhibition spreads to inhibit cortical responses to relevant signals, thus accounting for the reduction of the non-specific, diffuse arousal (Floru et al., 1985). In addition, an active deactivation mechanism results, contributing to declining arousal during prolonged low information processing (Floru et al., 1985). In the mechanism, the repetitive, prolonged stimulations of the same functional (cortical) structures induce an active inhibition, thus reducing the selective, specific activation required by the attentional process (Floru et al., 1985).

Accumulation of Negative Emotion

Numerous previous studies have shown that prolonged engagement in computer-based tasks lead to bodily discomfort such as eye strain, musculoskeletal discomfort, headache, and low back pain (McLean et al., 2001; Nelson & Silverstein, 1998; Sauter, 1991). In addition, mental fatigue is likely to develop, especially when the task is carried out for a long period of time (Leung, Chan, & He, 2004; Leung et al, in press). All these problems not only affect an individual's physical health, but also contribute to the individual's negative feelings on the task (Finkelman, 1994). These negative feelings in turn hinder energetical regulation and mental effort investment (Gaillard, 1993), and hence degrade the efficiency of the information processing.

Possible Effects of Rest Breaks

Energy Recuperation

Theoretical Basis

According to Gaillard (1993), energy is dissipated sufficiently to maintain the individual activated and the performance on task in normal situations. This energy is optimized for utilizing the cognitive processes to maximize the performance on the task. However, after engaging in the task for a substantial period of time, the energetical resources deplete and extra resources have to be mobilized by mental effort. Dissipation of extra energetical resources for a prolonged period of time could lead to further energy depletion. The consequence of energy depletion is fatigue, which manifests as decrement of performance. Under this model, rest breaks remove the individual from the task and enable him/her to recuperate from the energy dissipation process. The reaccumulation of energetical resources enables the individual to reestablish optimized and automatic energy dissipation, cognitive processing, and the task performance cycle. This state lasts until the next cycle of increased mental effort, energy dissipation, fatigue, and rest break. Floru et al. (1985) and Floru and Cail (1987) demonstrated differences in the regulation of arousal on two data entry tasks with different rest schedules. In the data entry task without a rest break, their subjects showed a gradual decline in arousal levels. They then observed an EEG pattern accompanying a rebound of performance at around 45 to 60 minutes of task engagement, suggesting an auto-arousal phenomenon, which indicates that a compensatory effort intervenes in a mentally repetitive task (Floru et al., 1985). On the other hand, when a 5-minute rest break was incorporated after 40 minutes of the data entry task, they found that their subjects could restore the arousal level without showing a high fluctuation in EEG activities.

Biological Basis

Computational processing of information has been shown to rely on cellular function, and the interaction between computational and physiological control processes has to be analyzed at the cellular level (Beatty, 1986). In this context, energy is a necessity for neuron and cell activities. When processing information or when the information processing demands are high, the cells consume more glucose and oxygen and increase local cerebral metabolic activities. Energy is needed to synthesize neurotransmitter substances and other compounds related to the metabolic activities and the synaptic transmission (Beatty, 1986). Apart from this, some chemically defined arousal systems are found active during information processing (Robbins, 1997). These systems include the monoaminergic projections comprising cells utilizing noradrenaline, dopamine, serotonin (5-hydroxytryptamine, 5-HT), or histamine as neurotransmitters. Their diffuse anatomical natures have been found to be related to attentional processing, and they support non-specific forebrain processing (Robbins, 1997). Numerous past studies have demonstrated an increase in metabolic activities associated with particular brain functions, such as visual stimulation in the visual cortex (Phelps, Kuhl, & Mazziota, 1981). Under this model, rest breaks are believed to facilitate the restoration of neurotransmitter substances and other compounds necessary for metabolic activities (Beatty, 1986).

Task Interruption

The forementioned effects of rest breaks are facilitative. But practically speaking, many workers fear that frequent rest breaks will have a negative impact on their work or on their co-workers' perception of their efforts (McLean et al., 2001). Additionally, the regimentation of breaks may result in added stress due to frequent work interruption (McLean et al., 2001). Studies have reported that frequent rest breaks can seriously disrupt complex computer-based tasks with high cognitive demands and long cycle times (Henning et al., 1993). Moreover, Kopadekar and Mital (1994) have noted that adequate recovery during complex computer work may require more than a short rest break. In a field study of computer operation done by Henning et al. (1997), complicated task operations like navigating between multiple computer displays and concentrated reading were found susceptible to disruption by short rest breaks.

Summary of the Literature Review Leading to Research Questions

Prolonged engagement in a single, low-level information processing task demands a gradual consumption of energetical resources for supporting the execution of the cognitive subsystems. Compared to tasks with high processing demands, tasks with low processing demands, like data entry, require less, and less intensive, cognitive processing. Nevertheless, maintaining an adequate level of vigilance on the task is needed, but performance over a long period of time often leads to energy depletion and finally performance decrement. According to both Hockey (1997) and Gaillard (1993), performance decline can be compensated for by investing mental effort into mobilizing extra energetical resources that support the cognitive processes necessary for maintaining task performance. Such an act results in a high psychological cost (i.e., development of negative emotion) and a high physiological cost (i.e., increasing activities in the ascending reticular activating system and the relevant cortical areas). According to Gaillard (1993), emotions such as fatigue and general tiredness due to prolonged engagement in a task influence mental effort investment and energy regulation. Unlike high information processing, tasks demanding low information processing may result in a large variation of perceived workload and tiredness among the individuals performing the task (Matthews et al., 2000). Furthermore, Hockey's (1997) compensatory model of performance regulation explains that although individuals may be given the same task, such as a simple data entry task, different individuals may have different set-points of effort and strategies for investing mental effort into the task. Among the many factors, tolerance to fatigue and the subject's feeling could exert modulating effects on exaggerating these individual differences. It is thus reasonable to expect that a significant relationship exists among performance, mental effort, and subjective feelings. If rest breaks have an effect on regulating energy consumption and its recuperation throughout prolonged data entry, then the pattern of such a relationship may be also modulated by different rest break schedules.

Since the concepts relating to mental workload vary, their terminology has to be standardized in this study. This study assumed that there is one simple entity of effort, which has two set-points. Instead of differentiating mental effort into one for state regulation and one for controlled processing, mental effort was quantified with heart rate variability (HRV). This study also assumed that the energetical state of an individual would be regulated to an optimal level at the beginning of the task engagement, and any variations of mental effort would reflect changes resulting from active control of the individuals. Based on this assumption, levels of mental effort would change across time if the individual utilized effortful processing. Otherwise, there would be no changes in mental effort across time engagement. *Activation* refers to the cortical activities measured by an electroencephalogram (EEG), which reflects the mental processes associated with performance on the task. Furthermore, *resources* denotes the energetical resources involved in the task. Although the term *resources* may also describe the processing modules involved (Wickens, 1992), the present study targeted a prolonged engagement in a single task, which should have been driven by a fixed set of processing modules.

Aim of the Study

The aim of this study was to use both behavioral and neurophysiological correlates to investigate how rest breaks influence information processing on a 6-hour work-simulated data entry task – a low-level task demand – and the differential effects of the two rest schedules on modulating mental effort and the mental processes associated with performance on a low-level information processing task. The findings are useful for (a) explaining how work/rest schedules can be used for performance enhancement in low-level information processing tasks, (b) enriching existing models and theories that explain prolonged information processing, and (c) refining the methodology for the study of mental workload associated with low-demand tasks like data entry.

The present study involved performance-based behavioral measures that included speed and accuracy on the task, subjective fatigue, and eye blink rate. The study also explored the association between these performance-based measures and the neurophsyiological measures (reflecting more on the processing state and internal energy regulation). The neurophysiological measures included heart rate variability, reflecting mental effort, and electroencephalograms, reflecting the brain activation underpinning the mental processes.

Research Questions and Hypothesis

The present study compared the patterns of performance-based behavioral results between two rest break schedules and examined the neurophysiological correlates associated with each behavioral variable in each of the two work-schedules. There were four research questions: (a) How does the pattern of performance on data entry tasks differ between two rest schedules, one with a longer rest duration but less frequent rest breaks, the other with a shorter rest duration but more frequent rest breaks? (b) Are there differences in the neurophysiological findings between the two rest break schedules? (c) How do the patterns of correlation between the performance-based behavioral measures and the neurophysiological measures differ between the two schedules? and (d) Which rest break schedule favors more efficient task performance and energy regulation throughout a prolonged task engagement.

The above literature review led to several hypotheses: (a) Task performance may decline because of fatigue and lowering of vigilance along with prolonged processing; (b) Rest breaks can enhance energy recuperation against its depletion across time; (c) Correlations exist between the performance-based behavioral variables and the neurophysiological variables in each of the two rest break schedules; and (d) The correlation patterns observed between the two rest break schedules differ, and the differences imply a differential underlying process associated with each of the two rest break schedules.

CHAPTER III

VALIDATION OF THE CHINESE VERSION OF THE SWEDISH OCCUPATIONAL FATIGUE INVENTORY (SOFI-C)

This chapter reports on the validation study conducted on the development of the Chinese version of the Swedish Occupational Fatigue Inventory (SOFI-C) for use in a Chinese population. Part of the content has been published in the journal *Applied Ergonomics* (Leung, Chan, & He, 2004). The original questionnaire (Ahsberg, 2000; Ahsberg, Gamberale, & Kjellberg, 1997) was translated into Chinese and evidence on its validity and reliability was gathered.

Background

Fatigue is a common phenomenon in the workplace. Previous studies have shown that occupations requiring strong physical demands, such as those of firemen and manual workers, have a significantly high correlation to physical fatigue (Ahsberg, 2000; Ahsberg & Gamberale, 1998). In contrast, people who work at night and those who engage in intense mental work suffer to a great extent from mental fatigue (Ahsberg et al., 1997; Ahsberg, Gamberale, & Gustafsson, 2000; Ahsberg et al., 2000). With sedentary work, fatigue is mostly mental since such work requires prolonged vigilance and mental activity. To a lesser extent, workers also report physical fatigue due to the prolonged use of a computer display screen and assumption of a sitting posture. Common symptoms reported by workers are feelings of tiredness, reduced motivation, and increased boredom (Finkelman, 1994; Rodahi, 1989). In view of the diversity and complexity of its measurement, a comprehensive instrument that taps into workers' subjective feelings is relevant for assessing perceived fatigue at work.

The Swedish Occupational Fatigue Inventory (SOFI) was developed for measuring work-related perceived fatigue (Ahsberg et al., 1997). It consists of 25 expressions that are categorized into five latent subscales. These are Lack of Energy (LE), Physical Exertion (PE), Physical Discomfort (PD), Lack of Motivation (LM), and Sleepiness (SL). Each subscale is defined by the content of the five expressions (Ahsberg et al., 1997) (details are given in Appendix I). Ahsberg et al. (1997) revealed particularly strong correlations between the LE subscale and the other four subscales, suggesting that it is an underlying dimension of fatigue. The PE and the PD subscales are considered physical factors, while the LM and the SL subscales are considered mental factors (Ahsberg et al., 1997). The validity of the SOFI has been established in previous experimental and work situation studies (Ahsberg, Gamberale, & Gustafsson, 2000; Ahsberg et al., 2000). The five-factor structure of the SOFI was also demonstrated by relating changes in the physiological parameters associated with fatigue, such as EEG and EMG measurements, with the SOFI scores.

This part of the validation study sought to translate the English version of the SOFI into Chinese and then establish the psychometric properties of the translated version using a group of Chinese sedentary workers. The evidence collected for the Chinese version included content- and structural-related validity, and test-retest reliability. Translating the SOFI and applying it to a Chinese population involved the assumption that the subjective evaluation of fatigue is universal in nature (Kandel, Schwartz, & Jessell, 2000). This assumption is based on the premise that the fatigue mechanism is neuropsychological in nature. Cross-cultural issues, such as the equivalence of using different languages for writing expressions of fatigue, were dealt with in the content-related validity. The plausible differences involved in using a

Likert scale to rate fatigue expressions were explored in the contrast group comparison and the test-retest reliability.

This part of the study was necessary because the present experimental study involved the evaluation of subjects' perceived fatigue. Since all subjects were Chinese, it was important to ensure that they understood the items in the SOFI. The use of a translated Chinese version of the SOFI was an advantage. In the experiment, to be reported in the next few chapters, the Chinese version of the SOFI was administered to the subjects three times: right before they commenced the task, and after the last morning and the afternoon task sessions. Therefore, both the validation and the test-retest reliability of the Chinese version of SOFI was essential to ensure the consistency of the instrument for reflecting the subjects' perceived fatigue throughout the experiment.

Development of the Chinese Version SOFI (SOFI-C)

The development process involved translation and an expert panel review. A qualified translator holding a bachelor's degree in translation was recruited to translate the SOFI into Chinese. An ethnocentric approach was used to guide the translation (Crocker & Algina, 1986). An expert panel consisting of 12 bilingual practitioners with a mean age of 25.8 years (*SD* = 2.7) was formed to evaluate the equivalence and clarity of the translation. They were all rehabilitation practitioners working in clinical settings such as hospitals with 2.0 years (*SD* = 1.1) of work experience. A questionnaire addressing the fluency and semantic equivalence of the test was designed to guide the evaluation process. The panel members were instructed to complete the questionnaire by assigning ratings on a 5-point Likert scale: excellent (5), very good (4), good (3), fair (2), and poor (1). The panel members were encouraged to provide written comments to justify their evaluations. Consensus was reached through discussion among the members to further improve the Chinese version. To ensure the SOFI-C could be easily understood by the general public, 10 sedentary workers with a mean age of 29.7 years (*SD* = 2.8) were asked to provide comments on the extent to which the Chinese SOFI was understood. These were office workers with 7.9 years (*SD* = 2.1) of work experience.

The mode of the ratings assigned by the panel members on the equivalence of the SOFI-C was computed. Of the 25 items, 21 had a mode rating of 4 or above, indicating a good-to-excellent equivalence of the item translation. The four items considered to be at most fairly equivalent (mode ratings ≤ 3) were "Lack of concern," "Falling asleep," "Spent," and "Drained." The members commented that the Chinese translation of these items seemed either inappropriate or difficult to understand. After discussion among the members, consensus was reached on the modifications to be made to the Chinese translation. The review by the 10 worker members indicated that the test instructions and all the 25 items were easy to understand.

The SOFI was then subjected to a content evaluation on its relevance and representativeness with respect to its five content factors describing fatigue. A review panel composed of four rehabilitation professionals and three sedentary workers was formed. The rehabilitation professionals were all occupational therapists with a mean age of 29.3 years (*SD* = 2.3) and at least 4 years of work experience in physical rehabilitation. The sedentary workers were frequent computer operators with a mean age of 35.7 years (*SD* = 7.4) who worked for at least 6 hours a day. All members were invited to attend a panel meeting and evaluate the extent to which the 25 SOFI items were relevant to Chinese culture in describing the feeling of fatigue. Similarly, the questionnaires were collected and a consensus was reached to guide the modification of the translated SOFI-C.

The five latent factors of the SOFI were all reported as relevant and adequately representing the assessment of occupational fatigue. All mode ratings were 4 or above, and the percentages of agreement ranged from 71% to 86%. All 25 items were agreed to be relevant and representative in regard to the evaluation of occupational fatigue under their corresponding subscales. Similarly, all mode ratings were 4 or above, and the percentage of agreement ranged from 71% to 100%. As a result, no items were adjusted and no additional items were added to the SOFI-C. The final version of the SOFI-C and its Chinese instruction manual are shown in Appendix II.

Method

Participants

A total of 104 sedentary workers working in a hospital setting were recruited to participate in the field test. At the time of recruitment, the hospital safety committee had launched a program for prevention of work-related musculoskeletal disorders. The names of potential participants were given to the research team. The participants were contacted via mail prior to the seminar. The mail contained a description pamphlet that introduced the purpose of the study and invited them to participate in the data collection during the seminar. A consent form was also sent to the participants together with the pamphlet. The participants were requested to sign the consent form and bring it with them when they attended the seminar. All participants worked in different clerical offices and support units and were predominantly sedentary office workers. They all worked 8-hour shifts during office hours. The total working hours were 44 per week. The demographic characteristics of the participants are summarized in Table 3.1. A majority were female (80.8%) with a mean age of 34.5 years (*SD* = 7.4). Nearly all participants (97.1%) were educated up to Form 5 or above. About one third (30.8%) had completed university courses. A few (3.8%) reported that they had received training in occupational safety. About half (49.0%) reported using a VDT for less than 4 hours a day, while 51% reported using one from 4 to 8 hours a day. At the time of data collection, they were participating in the action seminar, which lasted for 1 hour.

Table 3.1. *Demographic characteristics of the participants (N=104)*

Variables	Number
Age (years)	
Mean	34.5 years
SD	7.4 years
Gender	
Male	19.2%
Female	80.8%

Procedure

All participants gathered around 3:30 p.m. prior to the commencement of the action seminar, which was held in one of the conference rooms of the hospital. The participants who volunteered to join the study handed in their signed consent forms at the reception counter. Each received an instruction sheet, a demographic form, a musculoskeletal discomfort evaluation form, and two copies of the SOFI-C – versions A and B. A complete set of the above-mentioned forms is shown in Appendix III.

They were given 10 minutes to read the instruction sheet and complete the demographic form, the discomfort evaluation form, and the SOFI-C (version A). The demographic form contained items on age, gender, education level, work experience, and average number of hours spent using a VDT at work. The musculoskeletal discomfort evaluation form used a dichotomous yes/no format to solicit the participants' reports on discomfort in eight body parts, namely head, eyes, neck, shoulders, elbows, wrists, lower back, and legs. The SOFI-C (version A) contained the 25 expression items, which were arranged in the same sequence as in the original SOFI. The participants were instructed to assign ratings on each item that described their feelings of fatigue at that moment. The completed demographic form and the SOFI-C (version A) were collected from all participants before the seminar began. The ratings on version A reflected the fatigue level of the participants after working for an entire day.

The seminar lasted 60 minutes and covered the signs and symptoms of work-related injuries and their prevention and interventions. The two speakers were an orthopedic specialist and an ergonomics practitioner. After the seminar, the participants were instructed to complete the SOFI-C (version B), which had been distributed to them during the previous test. The ratings on version B reflected the fatigue level of the participants after attending the seminar, and were used to test the test-retest reliability of SOFI-C. Version B differed from version A in that the 25 expression items were rearranged in a randomized order. This was to reduce the impact of the memory effect of the participants due to their prior completion of the questionnaire an hour before. Version B took about 5 to 10 minutes to complete. The participants handed in the completed questionnaire before they left the conference room.

Data Analysis

The scores on the SOFI-C (version A) were analyzed to obtain evidence on its structural-related validity and internal consistency (Chan & Lee, 1999). Exploratory factor analysis was conducted using principle component extraction and varimax rotation to explore its subscale structure (Crocker & Algina, 1986). Cronbach's alpha was used to estimate the internal consistency of the SOFI-C (Crocker & Algina, 1986). Intra-class correlations (ICC) were computed on the results obtained from versions A and B, which estimated the test-retest reliability (Portney & Watkins, 2000). Analysis of variance (both univariate and multivariate) was used to examine the effects of the duration of VDT usage on SOFI-C subscale scores. Comparisons were conducted by first grouping the participants according to the average time they used a VDT, that is, 0-<2 hours, 2-<4 hours, 4-<6 hours, 6-<8 hours and ≥8 hours. This was followed by regrouping the participants into low (< 4 hours) and high (≥ 4 hours) usage groups. The latter would allow comparison of the results obtained in the study with those reported by Fahrbach and Chapman (1990). All statistical analysis was performed using the statistical package SPSS, and the significance level was set at $p < 0.05$.

Results

The scores on the SOFI-C (version A) are summarized in Table 3.2. The subscale score on Lack of Energy (LE) was highest, followed by Sleepiness (SL) and Lack of Motivation (LM). The lowest two were Physical Discomfort (PD) and Physical Exertion (PE). The majority of participants reported discomfort in the eyes (81.0%), neck (73.3%), and shoulders (61.9%) (Table 3.3). The frequency of discomfort reported with the other body parts was comparatively less (between 10.5% and 26.7%).

Table 3.2. *Mean (SD) of participants' scores on the SOFI-C (N=104)*

SOFI-C subscales	Beginning of seminar (Version A)	End of seminar (Version B)
Sleepiness (SL)	3.07 (2.03)	3.31 (2.25)
Physical discomfort (PD)	2.90 (1.93)	2.76 (1.92)
Lack of motivation (LM)	2.94 (2.05)	2.78 (2.26)
Lack of energy (LE)	3.52 (2.27)	3.45 (2.27)
Physical exertion (PE)	2.26 (1.79)	1.98 (1.74)

Table 3.3. *Body discomfort reported by participants (N=104)*

Body parts	Response "Yes" (%)
Head	23.8
Eyes	81.0
Neck	73.3
Shoulders	61.9
Elbows	12.4
Wrists	26.7
Lower back	15.2
Legs	10.5

Exploratory factor analysis indicated a five-factor structure, which accounted for 78.16% of the total variance (Table 3.4). Interpretable results were obtained when orthogonal rotation using the varimax technique was conducted. The five factors extracted appeared to coincide with those in the original instrument. These were Factor 1, SL 睡意; Factor 2, PD 身體不適; Factor 3, LM 缺乏動力; Factor 4, LE 缺乏精力; and Factor 5, PE 體力勞累. The initial analysis indicated that only 16 items (those with asterisks) were primarily loaded onto the original five subscales, which gave the highest factor loadings. As a result, Factors 1 and 2 showed the best fit with the original SL and PD subscales. However, the item Lazy 懶惰, which loaded the highest on Factor 3 (LM), showed a secondary loading on Factor 1. The same pattern was revealed for the item Numbness 痳痺, which loaded on Factor 3 followed by Factor 2. If the criterion of ≥ 0.3 factor loading was adopted to decide on the significance of the item-to-subscale relationship (Nunnally & Bernstein, 1994), 23 out of the 25 items in the SOFI-C were found to load onto the respective factors, which was similar to the original SOFI subscales. The only two items that did not have a factor loading above the decision rule were Listless 沒精打彩 (0.23) under LM and Palpitation 心跳急速 (0.28) under PE.

Table 3.4. *Factor loadings of the 25 items of the SOFI-C*

SOFI-C item	SOFI factors				
	1	2	3	4	5
Sleepiness (SL) 睡意					
Yawning 打呵欠	**0.85** *	0.11	0.09	0.13	0.27
Sleepy 渴睡	**0.82** *	0.32	0.13	0.16	0.09
Falling asleep 打瞌睡	**0.81** *	0.20	0.27	0.25	0.06
Drowsy 昏昏欲睡	**0.68** *	0.24	0.17	0.37	0.29
Lazy 懶惰	**0.44**	0.06	0.76 *	0.05	0.19
Physical discomfort (PD) 身體不適					
Tense muscle 肌肉繃緊	0.10	**0.82** *	0.15	0.26	0.13
Aching 疼痛	0.33	**0.76** *	0.22	-0.12	0.26
Stiff joints 關節僵硬	0.21	**0.63** *	0.35	0.25	0.22
Hurting 痛苦	0.14	**0.50** *	0.46	0.38	0.35
Numbness 麻痺	0.20	**0.39**	0.58 *	-0.05	0.33
Lack of motivation (LM) 缺乏動力					
Lack of concern 不感關注	0.02	0.26	**0.77** *	0.37	0.08
Indifferent 漠不關心	0.28	0.17	**0.63** *	0.52	0.26
Listless 沒精打彩	0.50	0.21	0.23	0.64 *	0.23
Passive 消極被動	0.44	0.15	**0.44**	0.57 *	0.24
Uninterested 枯燥乏味	0.41	0.19	**0.30**	0.52 *	0.44
Lack of energy (LE) 缺乏精力					
Spent 體力耗盡	0.33	0.44	0.25	**0.66** *	0.21
Exhausted 精力耗盡	0.22	0.57	0.17	**0.60** *	0.32
Drained 體力衰竭	0.47	0.45	0.28	**0.48** *	0.34
Overworked 操勞過度	0.37	0.68 *	0.14	**0.40**	0.19
Worn out 筋疲力竭	0.22	0.63 *	0.36	**0.47**	0.00
Physical exertion (PE) 體力勞累					
Warm 發暖	0.14	0.15	0.35	0.24	**0.70** *
Sweaty 冒汗	0.37	0.29	0.18	0.17	**0.69** *
Out of breath 喘不過氣	0.20	0.33	0.53	0.28	**0.55** *
Palpitation 心跳急速	0.06	0.35	0.65 *	0.28	0.28
Breathing heavily 呼吸沉重	0.30	0.28	0.50 *	0.27	**0.46**

Remarks:
Method: Principle component extraction with orthogonal varimax rotation
Items with * represent loading primarily on the five factors.
Items with bold type indicate loading onto their original subscale in the forced five-factor solution with factor loadings (≥ 0.3).

The Cronbach's alpha values estimated based on the SOFI-C (version A) results are presented in Table 3.5. The alpha values ranged from a high of 0.95 for the LE subscale to a low of 0.88 for the PD subscale, indicating satisfactory internal consistency for the SOFI-C subscales (Nunnally & Bernstein, 1994). The test-retest reliability indices of the SOFI subscales estimated by intra-class correlation (ICC) were between 0.69 and 0.83 (SEM = 0.64 to 0.21). If the criterion of ≥ 0.75 was adopted to indicate good reliability (Portney & Watkins, 2000), all of the SOFI-C subscales had satisfactory test-retest reliability indices except the SL subscale, which was moderate (ICC = 0.69, SEM = 0.64).

Table 3.5. *Internal consistency of SOFI-C subscales and their test-retest reliability indices (N=104)*

SOFI-C subscales	α	ICC* (95% C.I.)	SEM
Sleepiness (SL) 睡意	0.90	0.69 (0.57-0.78)	0.64
Physical discomfort (PD) 身體不適	0.88	0.83 (0.76-0.88)	0.23
Lack of motivation (LM) 缺乏動力	0.90	0.77 (0.68-0.84)	0.21
Lack of energy (LE) 缺乏精力	0.95	0.77 (0.68-0.84)	0.51
Physical exertion (PE) 體力勞累	0.89	0.80 (0.72-0.86)	0.59

Remarks:

The Cronbach's alpha coefficients (α) are computed on the SOFI-C (version A).

The test-retest reliability coefficients are estimated using intra-class correlations (two-way mixed model).

SEM = Standard error of measurement of test-retest reliability indices.

A review of the participants' SOFI-C subscale scores indicates that they scored the highest on the LE subscale and the lowest on the PE subscale (Table 3.6). The differences among the five subscale scores were statistically significant, $F(4,524) = 5.22$, $p < 0.005$). A post-hoc comparison adjusted by the Bonferroni method further showed that the participants had significantly higher scores on the SL and LE subscales ($p = 0.04$ and $p < 0.005$ respectively). The effect of duration of VDT usage on participants' fatigue ratings was tested by grouping the participants into five categories: 0- <2 hours, 2-<4 hours, 4-<6 hours, 6-<8 hours and ≥8 hours. The SOFI-C subscale scores appeared to peak at the 4-<6 hour and ≥8 hour groups (Table 3.6). However, multivariate analysis of variance (MANOVA) did not reveal any statistical significance in the differences among the five groups (Pillai's Bartlett trace: $F(20,340) = 1.319$, $p = 0.162$). The participants were regrouped into the low (< 4 hours) and high (≥ 4 hours) usage groups (Table 3.7). The SOFI-C scores of participants in the high usage group were found to be significantly higher than those in the low usage group (Pillai's Bartlett trace: $F(5,98) = 2.32$, $p = 0.049$). Univariate F-tests further indicated that the differences were in the PD ($F(1,104) = 7.51$, $p = 0.007$), LE ($F(1,104) = 6.45$, $p = 0.013$), and LM ($F(1, 104) = 4.09$, $p = 0.046$) subscales.

Table 3.6. *Mean (SD) of SOFI-C subscale scores of participants in five VDT usage groups (average number of hours/workday)*

SOFI-C subscales	0-<2 Hours (*n*=26)	2-<4 Hours (*n*=24)	4-<6 Hours (*n*=25)	6-<8 Hours (*n*=19)	≥8 Hours (*n*=7)
Sleepiness 睡意	3.28 (2.47)	4.05 (2.19)	4.40 (2.05)	3.64 (2.23)	4.69 (1.54)
Physical discomfort 身體不適	2.85 (2.31)	3.13 (1.95)	4.24 (1.76)	3.83 (1.53)	4.60 (1.48)
Lack of motivation 缺乏動力	2.56 (2.36)	3.70 (1.81)	4.53 (2.30)	3.51 (2.08)	4.11 (1.70)
Lack of energy 缺乏精力	3.49 (2.44)	4.34 (2.63)	5.16 (2.13)	4.27 (2.04)	5.46 (1.90)
Physical exertion 體力勞累	2.60 (2.19)	2.90 (1.66)	3.54 (1.99)	2.67 (1.76)	3.79 (2.07)

Table 3.7. *Mean (SD) of SOFI-C subscale scores between participants using a VDT for <4 hours versus ≥4 hours a day*

SOFI-C subscales	VDT < 4 Hours (*n*=51)	VDT ≥ 4 Hours (*n*=53)	All participants (*N*=104)
Sleepiness 睡意	2.89 (2.18)	3.24 (1.87)	3.07 (2.03)
Physical discomfort 身體不適	2.38 (1.91)	3.38 (1.83)	2.90 (1.93)
Lack of motivation 缺乏動力	2.53 (2.04)	3.34 (2.01)	2.94 (2.05)
Lack of energy 缺乏精力	2.95 (2.30)	4.06 (2.12)	3.52 (2.27)
Physical exertion 體力勞累	1.99 (1.69)	2.51 (1.86)	2.26 (1.79)

Discussion

The results of this study indicate that the 25 SOFI expressions and its five-factor structure are largely relevant for measuring fatigue in Chinese VDT users. The high content representativeness and fairly stable factorial structure suggest that the fatigue phenomenon associated with VDT work has little cultural bias. The findings also reveal that the Chinese version of the SOFI (SOFI-C) has satisfactory test-retest reliability. The five-factor SOFI scores were found to be useful in discriminating between workers who used a VDT for 4 hours or more at work and those who used one for less than 4 hours.

Previous literature has revealed that fatigue is both a physiological and a perceptual process. For mental fatigue, the neurophysiological mechanism involves the interplay between higher cortical functioning such as alertness and vigilance, and subcortical activation such as general arousal (Grandjean, 1988; Rodahl, 1989). This results in a central effect on the mental function, such as tiredness and sleepiness. For physical fatigue, the physiological mechanism primarily occurs at the neuromuscular junction, which inhibits muscle contraction. This has a localized effect on physical function, such as depleted muscle contraction. These mental and physical signals are elicited within and experienced by the individual. Such experiences were interpreted at the time individuals were requested to rate their fatigue state on the SOFI. Our findings do not reveal a strong cultural effect when the SOFI was translated into Chinese and rated by the Chinese participants. First, the expert panel members did not identify major problems with the relevance of the 25 SOFI expressions and the representativeness of the five-factor SOFI structure for measuring fatigue in the context of Chinese culture. Despite several studies that suggest the specificity of Chinese culture in regard to pain perception (Chung et al., 1999; Chung, Wong, &

Yang, 2000), the generalization of the results based on pain to the perception of fatigue seems to be limited. In general, the description of pain is complex and multi-dimensional in nature, and is largely influenced by language in its perception, interpretation, and expression (Chung et al., 2000; Kodiath & Kodiath, 1995). In contrast, fatigue is multifaceted, but its factorial structure is fairly simple, such as in the SOFI. The item descriptors use simple language, which places less demand on the interpretation and expression by the subjects. Second, the factorial structure of the SOFI-C is, to a large extent, comparable to the original SOFI developed by Ahsberg et al. (1997). The marginal findings in regard to a few of the Chinese expressions, which loaded differently from the original version, are probably attributable to the job nature of the subjects who participated in the field test, rather than to culture or language. For instance, the Palpitation 心跳急速 item had a low factor loading on the PE subscale. The fact was that prolonged VDT work rarely led to physical exhaustion, and hence the sensation of palpitation meant that the item carried a very small variance for the exploratory factor analysis. The loading of the Listless 沒精打彩 item on the LE instead of the LM subscale may be because the LE subscale is a more general description of fatigue for sedentary workers, which tends to attract the less stable item.

Our findings demonstrate the usefulness of the SOFI-C profiles for reflecting the differences in job demands among VDT workers. Further analysis shows that the participants who used a VDT for 4 hours or more a day scored significantly higher on the LE, LM, and PD subscales than those who used one for less than 4 hours. This finding concurs with Fahrbach and Chapman (1990), who concluded that using a VDT for 4 hours or more per day was a critical factor in the development of fatigue. This finding further indicates that the SOFI-C is adequate for reflecting the level of fatigue of VDT workers. The significant increase in the subscale scores based on the SOFI-C also matches the results from the original instrument of Ahsberg et al. (1997). They further asserted that the three subscales were accounted for because of the maintenance of a high state of vigilance and prolonged sitting in a static posture.

This part of the study translated the original English version of the SOFI into a Chinese version. The Chinese translation of the original SOFI does not appear to carry significant cultural or language effects. The test content and five-factor structure were preserved, which support its content-related validity and structural stability. The internal consistency and test-retest reliability of the Chinese version are also satisfactory. The results suggest that the SOFI-C can be used to measure the perceived fatigue of subjects in the present experimental study.

CHAPTER IV

METHOD – GENERAL

This chapter gives an overview of the experimental method used in studying the effects of different rest schedule designs on performance, mental load, and cognitive processes during prolonged data entry. The sampling method, study design, and equipment/instruments used in measuring different variables are explained in detail.

Sampling

A convenient sampling of 40 subjects, 20 females and 20 males, aged 18 to 24, was targeted for recruitment for participation in the study. The subjects were undergraduate students from universities in Hong Kong and participated on a voluntary basis. All participants were healthy and reported having normal sleep patterns as well as normal or corrected-to-normal vision at the time of the experiment. They had no history of injury to the shoulder and the upper back requiring medical consultation.

The sample size for the experiment was made in reference to the parameters used in the correlational analyses (Chapters VI, VII, and VIII). According to Kraemer and Thiemann (1987),

$$\Delta = (p-p_0)/ (1-pp_0)$$

where p is the upper range of the correlation coefficient and p_0 is the lower range of the correlation coefficient. Based on the results obtained in a previous similar correlational study (Leung et al., 2004), the parameters were set at 0.9 and 0.5. The Δ was computed as follows:

$$\Delta = (0.9\text{-}0.5)/\ [1\text{-}(0.9)(0.5)]$$

$$= 0.727$$

According to Kraemer and Thiemann (1987), the number of subjects should be governed by the formula $n = v + 2$, where v is a constant affected by the expected correlation coefficients to be obtained and the expected power to be reached in the study. Hence, for a two-tailed 5% test, with 95% power, $v = 15$ to 19 for Δ between 0.7 and 0.75 (referring to the table in Appendix IV). The number of subjects in each group would thus be $n = 15 + 2 =17$ to $19 + 2 = 21$.

The sample size was further estimated using PASS 2002, making reference to repeated measures ANOVAs conducted in the data analysis (Chapter V). For a repeated measures design with two between- and three measures, 40 subjects, 20 for each group, would achieve a power ranging from 80% to 100%. The *F* test for testing the group, time, and Group × Time factors at a 5% significance level gave effect sizes ranging from 0.46 to 0.65. In repeated measures ANOVAs, a power of at least 80% with an effect size of 0.40, requiring 20 subjects in each group of the comparison, would be good enough for three to four within-group comparisons.

The subjects were recruited by means of posting advertisements on student notice boards at The Hong Kong Polytechnic University and other universities in Hong Kong. The purpose and a brief description of the study were provided. Application forms were attached for interested students to write down their names and contact numbers. Potential subjects were then contacted and screened for appropriateness based on the selection criteria mentioned above. In order to keep data fully confidential, all subjects were assigned a code that was used in randomization, data recording, and all stages of data processing.

The Task Design – Schedule

The task performed by the subjects was a data entry task. The workday schedules were designed with reference to Kopardekar and Mital (1994), Okogbaa et al. (1994), and National Institute of Safety and Health guidelines for computer task engagement. It consisted of two 3-hour task blocks with a 1-hour lunch break in between. There were two different task and rest-break schedules. The longer and less frequent (LM) schedule consisted of three 50-minute sessions in the morning block (S1, S2, and S3) and another three sessions in the afternoon block (S4, S5, and S6). The LM rest break lasted for 10-minutes between each consecutive session, for a total of two in each block. The shorter and more frequent (SM) schedule consisted of five 30-minute sessions in the morning block (s1, s2, s3, s4, s5) and another five in the afternoon block (s6, s7, s8, s9, s10), and 5-minute microbreaks between each consecutive session. This provided a total of four breaks in each block (eight total).

The two LM and SM rest schedule protocols were constructed so that the total session times and total rest break times were the same between the two task schedules. In this way, any differences in results obtained between the two rest-break schedules would be due to the effect of the LM versus SM schedule. During the lunch break and intermittent rest breaks, the subjects stayed in the laboratory where the experiment was conducted. They were allowed to listen to radio but refrained from performing physical exercises. Details of the two experimental task conditions are summarized in Figure 4.1.

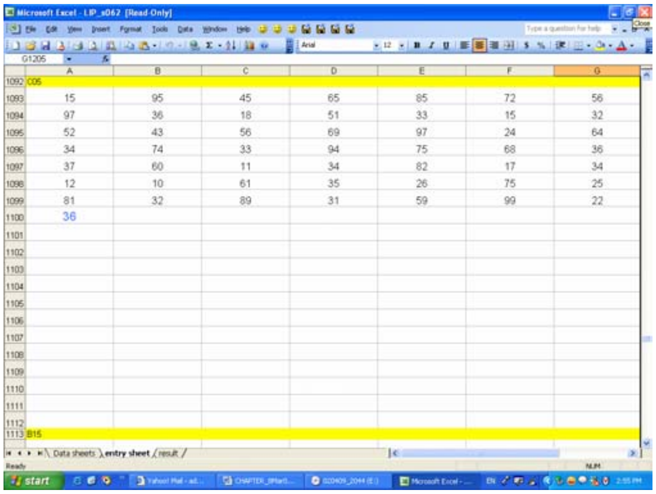
Figure 4.1. The two experimental task schedules.

Group: LM	Group: SM
Data entry (50 min)	Data entry (30 min)
	Break – 5 min
Break – 10 min	Data entry (30 min)
Data entry (50 min)	Break – 5 min
	Data entry (30 min)
	Break – 5 min
Break – 10 min	Data entry (30 min)
Data entry (50 min)	Break – 5 min
	Data entry (30 min)
Lunch break	
Data entry (50 min)	Data entry (30 min)
	Break – 5 min
Break – 10 min	Data entry (30 min)
Data entry (50 min)	Break – 5 min
	Data entry (30 min)
	Break – 5 min
Break – 10 min	Data entry (30 min)
Data entry (50 min)	Break – 5 min
	Data entry (30 min)

The Task Design – Task Content

The task used in this study required the participants to read and type in numerical data from data sheets into a computer file. The data set in the data sheet consisted of double-digit numbers organized in a 7-column by 30-row format. The dimension of each cell in the table was 7mm x 25mm. A total of 5,000 numbers, from 10 to 99, were generated from random numbers. The numbers were typed with Times New Roman font size 14 into the data table. The tables were printed on A4 size papers, sequenced and filed on a document holder. The data sheets were labeled by symbols, and six sheets were given to a subject at a time to avoid the subject's guessing the amount the data he/she had to enter. The data sheet was clamped onto a stand and placed on either the left or right side of the monitor, according to the subject's own preference. The subjects entered the data using the number-key pad of the keyboard. The data were entered into the Microsoft Excel window. The screen presented a 7-column by 15-row grid with font size 14. The subjects could scroll down the spreadsheet with either the mouse or keyboard. The subjects were instructed to enter the data as quickly and accurately as possible, and they were rewarded with a monetary token after completion of the task. Appendix V shows a sample page of the data entry sheet. The display of the data entry file on the monitor is shown in Figure 4.2.

Figure 4.2. The data entry worksheet on the monitor.



	A	B	C	D	E	F	G
1092	C05						
1093	15	95	45	65	85	72	56
1094	97	36	18	51	33	15	32
1095	52	43	56	69	97	24	64
1096	34	74	33	94	75	68	36
1097	37	60	11	34	82	17	34
1098	12	10	61	35	26	75	25
1099	81	32	89	31	59	99	22
1100	36						
1113	B15						

Positioning of Subjects at the Workstation

The experiment was conducted in the Ergonomics and Human Performance Laboratory located in The Hong Kong Polytechnic University. Each participant was seated at the computer workstation (Figure 4.3). The heights of the monitor, keyboard (including mouse), and chair were adjusted to maximize the participant-workstation fit as per the guidelines set out by the National Institute for Occupational Safety and Health (NIOSH). In addition, the distance between the participant and the monitor was controlled at 65 to 75 cm (Figure 4.4). The monitor was set at an angle 15^{o} below eye level. The subjects sat with elbows at right angles above the arm rest, back straight, and feet placed comfortably on a foot rest. Body anthropometry at the workstation was checked for reference, as shown in the list in Appendix VI. The illumination condition was standardized at 450±100 lux (measured 25 cm away from the monitor) for the light source and 150cd/sqm luminance for the monitor (Figure 4.5). The temperature of the room was set at $23^{o}C$, and the walls were sound attenuated.

Figure 4.3. The workstation used in the experimental task.

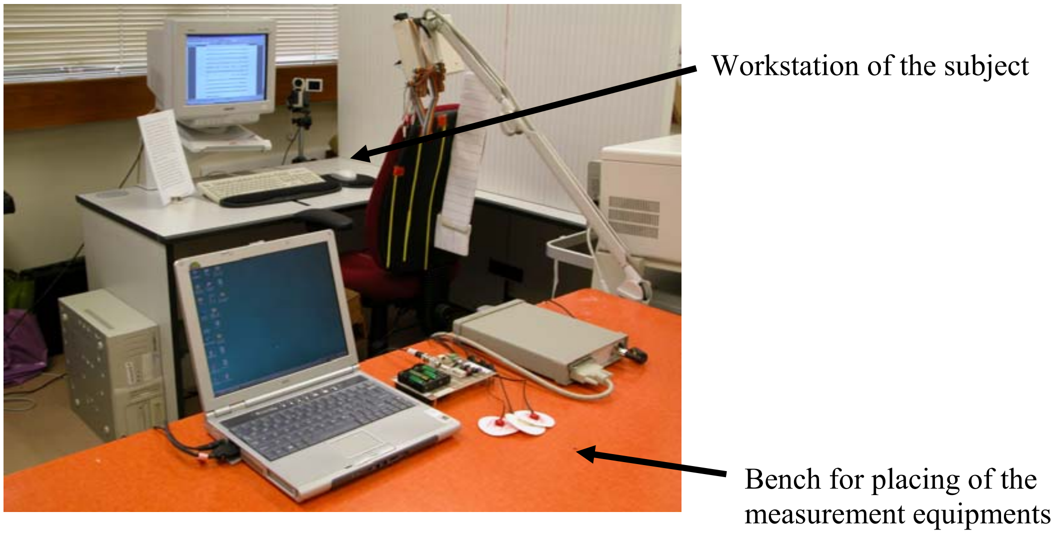


Figure 4.4. Measuring the distance between the subject and the monitor.

Figure 4.5. Measuring the light intensity at the workstation.

Measurements and Instrumentations

Performance on Data Entry Tasks

Performance on the data entry task was monitored with a tailor-made macro program written with Microsoft Excel. The total number of data entered and total number of incorrect entries were captured and computed using the program for each session. The computation was done manually and the results shown on another Excel spreadsheet. At the end of a task session, the last-entered data were highlighted in blue. A tailor-made icon inserted into the Excel spreadsheet was then pressed and the results listed on that spreadsheet. In every computation, the total data entered and the total number of incorrect entries and missed entries were counted from the first-entered data (the first cell) at the beginning of the entire task to the last data entered (i.e., the cell with the data marked in blue). The program thus reported accumulated performance across sessions of the data entry task. The performance of a single session was collected by subtracting the results obtained from that session by all the previous sessions (i.e., the precedent computation). Task performance was measured in units of error percentage (error rate) and rate of data entered (data entered per minute) in each session. The calculations are shown below.

Error percentage = (No. of incorrect entries / No. of data entered) × 100%

Rate of data entry = No. of data entered / time (minutes)

Incorrect entry was defined as the wrong data being entered in a cell. Wrong entry of any digits of the data in a cell contributed to an incorrect entry.

Measurement of Subjective Fatigue – SOFI-C

The Chinese version of the Swedish Occupational Fatigue Inventory (SOFI-C) (see Chapter III) was used to measure the perceived fatigue of the subjects at the beginning and end of the morning block and at the end of the afternoon block (Leung, Chan, & He, 2004). The SOFI is a five-factor multidimensional fatigue measure developed by Ahsberg et al. (1997, 2000) consisting of 25 items rated on an 11-point Likert scale, with '0' representing extremely low and '10' representing extremely high. The subjects were to mark the scale to reflect their subjective feeling of fatigue, with higher ratings reflecting more intense feelings of fatigue. There were five items on each subscale and a total of five subscales. The names of the subscales were Physical Exertion, Physical Discomfort, Lack of Energy, Lack of Motivation, and Sleepiness. The Cronbach's alphas for the SOFI-C subscales were between 0.88 and 0.95. These test-retest reliability indices (ICC) ranged from 0.69 to 0.83.

Measurement of Cognitive Processes - Electroencephalogram (EEG)

The EEG signals were captured by placing two electrodes on the left and right sides of the frontal area, that is, F_3 and F_4, and another two at the occipital sites, that is, O_1 and O_2, according to the International 10-20 system. The electrodes were secured on a standard 19-electrode EEG cap (manufactured by Electro-Cap International, Eaton, Ohio, U.S.A.) (Figures 4.6 and 4.7). Before fitting the cap onto the subject's head, a tape measure was used to measure the distance between the nasion (the top edge of the nose) and the inion (the bony prominence at the back of the occipital region of the head). Figure 4.8 shows the procedure for the measurement. The cap was then positioned on the scalp so that its front edge was at a level at 10% of the nasion-to-inion distance. In this way, the mid-Central (C_z) electrode was located at the junction halfway between the ears and halfway between the nasion and the inion. The electrode midway between the mid-Frontal (F_z) and the mid-Central (C_z) was selected as the reference electrode. The ground electrode was placed on the right arm using a Velcro strap instead of on the earlobe to minimize the discomfort of wearing it throughout an entire day.

Conductive gel (manufactured by Electro-cap International, Eaton, Ohio, U.S.A.) was injected into each of the five electrode sites using a dispenser tube and a blunt-tipped hypodermic needle (Figure 4.9). The electrodes were connected to a MEB-5540K multi-functional device manufactured by Nihon Kohden (Figure 4.10). The impedance was set below 5 kΩ. Continuous EEG signals were captured for 5 minutes in each recording. The analog EEG signals were collected via the multi-functional device and then transmitted to the analog/digital converter (DATAQ Instrument Inc., U.S.A.) with a sampling frequency of 1 kHz. A 50 Hz high frequency filter was used as a notch filter. The digitized signals were then displayed and recorded in the WindataQ signal acquisition software installed on an NEC notebook directly connected to the multi-functional device (Figure 4.11). The EEG signals were stored in the WindataQ program for data processing.

During data processing, each 5-minute EEG sequence of data was then segmented into 2-second epochs. This produced 150 epochs for each 5-minute data capturing period in each task session (6 for LM and 10 for SM). Artifact rejection was performed to remove epochs that contained spurious peaks. This was done by identifying the maximum amplitude of each epoch; the threshold value for rejection was then set at the mean ± 1 *SD* of all maxima over all task sessions. Epochs with a maximum amplitude higher than the threshold value were rejected. High-resolution parametric spectral analysis was performed on each of the artifact-free epochs using the Yule-Walker algorithm with the order of the autoregressive (AR) prediction model optimized from the data set (Gevins & Remond, 1987). The Yule-Walker algorithm is one of the standard methods used in estimating the spectral density in spectral analysis of EEG signals (Gevins & Remond, 1987). It is a parametric approach that directly provides a smoothed spectrum and avoids the disadvantages of non-parametric methods such as the smoothed periodogram (Gevins & Remond, 1987). Finally, the power spectral density (PSD) was obtained. A spectral power below 50Hz was extracted for analysis because the signals to be analyzed in this study ranged between 0 and 30Hz.

The baseline EEG was captured until the end of the 5th minute after the subject had commenced the task for 1 to 3 minutes at the beginning of the first task session (i.e., S1 in the LM and s1 in the SM schedules). Subsequent 5-minute EEG signals were measured within the last 10 minutes of each session. The signal capturing was randomized within the last 10 minutes to avoid the subjects becoming aware of the data capturing and so performing differently (Figure 4.11).

The spectral power of the epochs captured for each task session was decomposed into seven conventional wavebands: (delta (δ):0-4Hz; theta (θ): 4-8Hz; slow alpha1 (α_1): 8-10Hz; fast alpha2 (α_2): 10-12Hz; beta1 (β_1): 12-18Hz; beta2 (β_2): 18-21Hz; and beta3 (β_3) 21-30Hz). The spectral power was then averaged within each of these wavebands. The results were an array of spectral power cross wavebands for each subject in the form of a mean spectral power for each channel (4), each frequency band (7), and each session (a total of 6 for the LM and 10 for the SM schedules). All EEG spectral powers were log normalized and divided by the baseline. Details of the EEG measurement regimen and the normalization procedure are described in Chapter VI.

Figure 4.6. The EEG caps.

Figure 4.7. Location of the left frontal (F_3), right frontal (F_4), left occipital (O_1), and right occipital (O_2) area (left); the distribution of electrodes at side view (right) (Diagram extracted from Stern, Ray, and Quigley (2001), pp. 83).

Figure 4.8. Measuring the distance between the nasion and the inion of a subject.

Figure 4.9. Injection of the conductive gel.

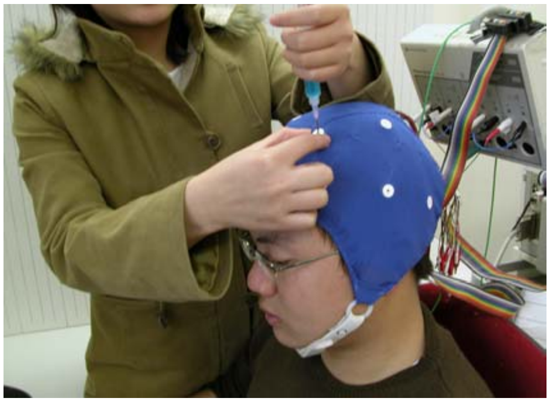


Figure 4.10. Nihon Kohden multi-functional device for capturing EEG signals.

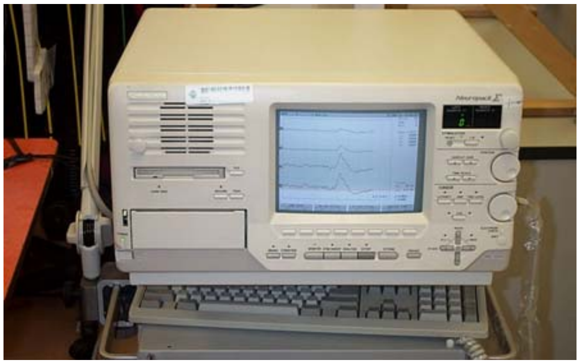
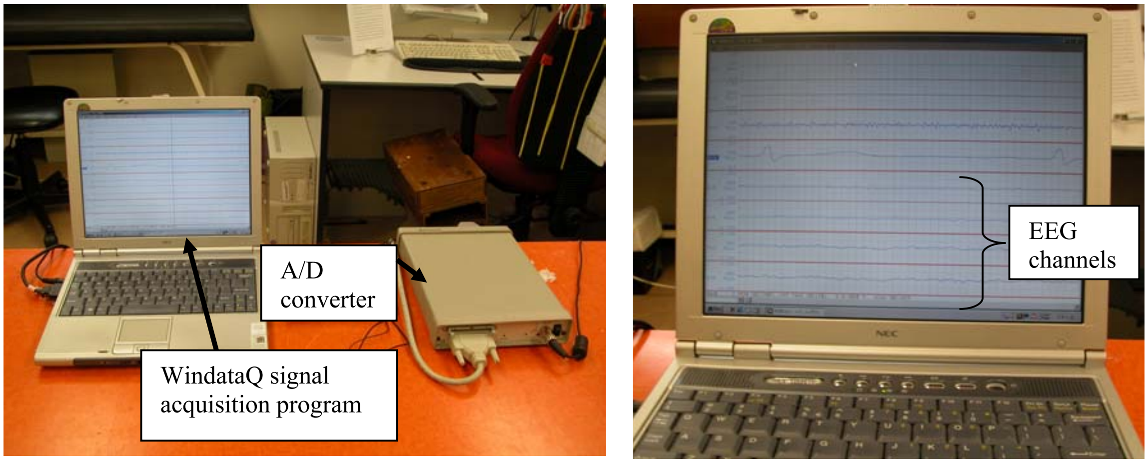


Figure 4.11. The DataQ A/D converter and the WindataQ signal acquisition program (left); the four EEG channels displayed on the WindataQ program.



Measurement of Mental Effort – 0.1 Hz Heart Rate Variability (HRV)

A tailor-made ECG capturing device was used to capture electrocardiography (ECG) signals (Figure 4.12). The subjects' skin was prepared with 70% ethanol. Three ECG Ag-AgCl disposable electrodes were placed on the standard CM5 positions (Froelicher, 1987; Kamada et al., 1992) (CM5 position: negative electrode at the 2nd interspace of left midclavicular line; positive electrode at the 6th interspace of left midclavicular line, details can be referred to Boyer (1997), pp. 248). Five-minute continuous ECG was recorded at the same time as the EEG signals. Similar to the EEG signals, the analog ECG signals were transmitted to the analog/digital converter (DATAQ Instrument Inc., U.S.A.) with a sampling frequency of 1 kHz (Figure 4.13). The signals were amplified, displayed, and recorded in the WindataQ/Lit (DATAQ Instrument Inc., U.S.A.) operated on the NEC computer. The computer software was used to detect the R wave of the ECG. The heart rate (HR) was computed based on the reciprocal of the RR interval (He et al., 1995). The spectral power was computed using Fast Fourier Transform (FFT) with Hann windowing. The absolute power of the midfrequency band, defined as the area under the curve between 0.07 and 0.14 Hz of the spectral power of the HRV, also known as the 0.1Hz component, indicated mental effort (Mulder, 1988; Shellekens et al., 2000) (Figure 4.14).

The absolute spectral power was normalized by dividing it by the total spectral power within the individual in each 5-minute time segment (Kamada et al., 1992). The total spectral power was defined as the area under the curve between 0.04 and 0.4 Hz of the power spectrum (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). This normalization method was used to account for the varying sympathetic and vagal activation influencing the spectral power (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). To make a direct interpretation, a reverse polarity transformation was done and each normalized value was multiplied by -1. Thus, a greater value (i.e., a less negative index) reflected greater mental effort and vice versa. Details of the ECG signal capturing regimen are described in Chapter VI.

Figure 4.12. The tailor-made ECG capturing device designed by J. He (upper) and the three electrodes (lower).

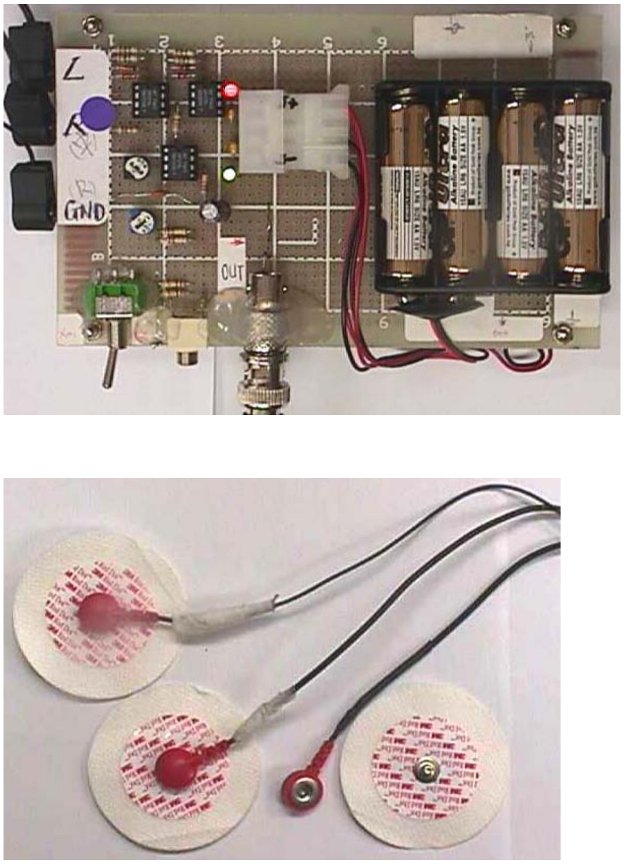
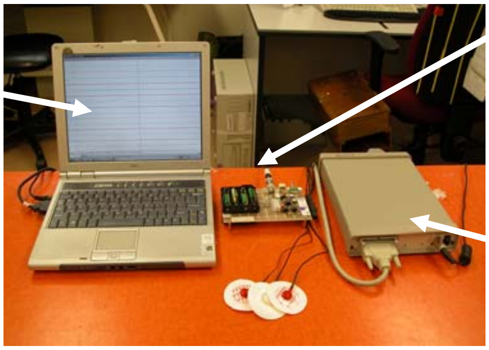


Figure 4.13. The ECG capturing system.

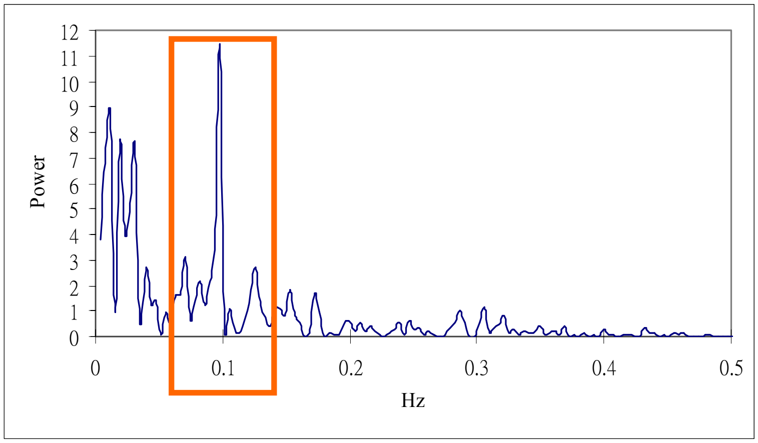


Signal Display & Recording

ECG capturing device
signal amplified by 100x
high pass filter:10Hz Low pass filter:50 Hz

Analogue Digital Converter, sampling rate 1000 Hz

Figure 4.14. Diagrammatic representation of the area under the curve between 0.07 and 0.14 Hz of the spectral power of the HRV.



Measurement of Attention - Eye Blink Rate

A video camera was placed in front of the workstation and focused on the subject (Figure 4.15). The subject was told that recordings would be taken at random time periods that would not disturb his/her engagement in the task. Each video capturing lasted for 2 minutes. The eye blink rate was measured as the number of eye blinks per minute during the 2-minute recording (Bentivoglio et al., 1997). *Eye blink* was defined according to Cho et al.'s (2000) study as simply a downward movement of the upper eyelid. A project helper was hired and well trained for counting the number of eye blinks within each 2-minute video recording. All eye blink data were counted by a single person to avoid inter-interviewer variation. The measurement regimen of the eye blink rate is described in Chapter V.

Figure 4.15. Video camera for recording the eye blink rate.

General Procedure

All subjects engaged in the same data entry task. They were assigned to participate in either the LM or SM schedule using block randomization. For the randomization, each of the two groups was subdivided into four blocks of five units each. Before participating in the experiment, subjects were randomly assigned to either the LM or the SM group and filled out the blocks. To balance the distribution of gender between the two schedules, two blocks were filled out by female subjects and the other two by male subjects for each schedule. The assignment began with a subject being assigned to the first block of the LM schedule. The next subject was assigned to the same block if he/she was of the same gender as the first. Otherwise, that subject was assigned to the first block of the SM schedule. The assignment continued until the first blocks were filled out. Then the placement of the next block began, but the gender assignment of the block differed from that of the previous block. The assignment of subjects continued until all the blocks were filled out.

The experiment began after the subject was positioned at the workstation. A basic cash reward equivalent to US$30 was paid to the participants for participating in the experiment. In addition, all participants were reminded that they would receive a bonus equivalent to US$13 for good performance. The purpose of giving a monetary token to participate was both to remunerate the subjects for the time spent on the experiment and to reinforce their motivation throughout the experiment. All participants were in fact awarded the bonus payment. Details of the procedure for the analysis of different variables and their measurement regimens as well as the statistical analyses and the results obtained are described in the next few chapters.

CHAPTER V

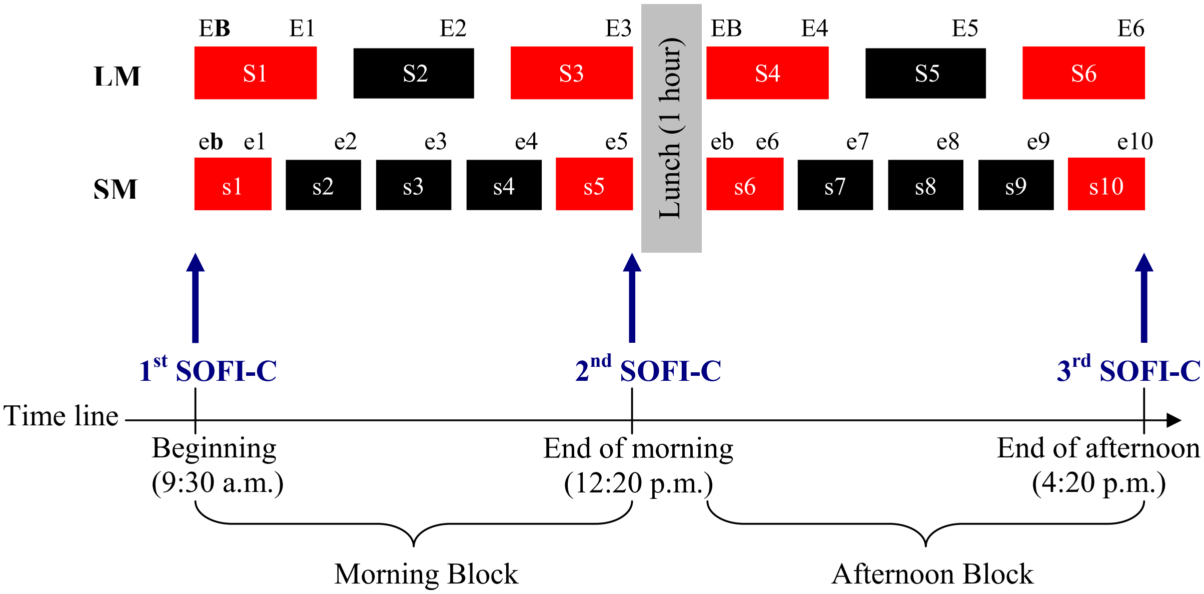
BEHAVIORAL OUTCOMES OF TASK PERFORMANCE

This chapter reports the results obtained from the three behavioral variables, that is, error rate, perceived fatigue, and eye blink rate, of subjects in the LM and SM rest schedules after carrying out the 6-hour data entry task. The details of the measurements are described, and the findings are discussed in light of the effects on subjects' performance on task, perceived fatigue, and attention. The advantages and drawbacks of using behavioral variables for studying low-level information-processing tasks for a prolonged period are also highlighted.

Measurement Regimen

Figure 5.1 is a schematic diagram showing the measurement regimen of the three behavioral variables.

Figure 5.1. Measurement regimen of the three behavioral variables.



Keys:

LM (longer and less frequent rest schedule) = 50-minute task session and 10-minute rest break.

SM (shorter and more frequent rest schedule) = 30-minute task session and 5-minute rest break.

Rectangles are task sessions (S1 – S6 for LM; s1 – s10 for SM).

Spaces between rectangles are rest breaks.

E1 – E6 (LM) and e1 – e10 (SM) are eye blink measurements at end of sessions.

E**B**, EB, e**b,** and eb are baseline measurements.

Task performances are captured throughout S1 – S6 (LM) and s1 – s10 (SM).

Blue arrows are completion of SOFI-C by subjects.

SOFI-C

The SOFI-C was administered to the subjects right before they commenced the task in the first session (as a baseline), at the end of the morning session (after S3 of LM and s5 of SM), and at the end of the afternoon session (after S6 of LM and s10 of SM). The items sequence was modified in the second and third completions for reducing possible confounding effects due to the memory of the subjects.

Task Performance

The percentage of errors committed and the rate of data entered for each task session were computed by a tailor-made computer program after the task session was completed (details of the operation are mentioned in the previous chapter, pp. 67-69). There were a total of 6 sets of measurements (P1 to P6) for the LM schedule and 10 sets of measurements (p1 to p10) for the SM schedule.

Eye Blink Rate

The eye blink rate of subjects was captured for 2 minutes at the beginning of the morning (baseline) (E**B** for LM and e**b** for SM) and afternoon (EB for LM and eb for SM) sessions and by the end of each task session (E1 – E3 for LM and e1 – e5 for SM for the morning; E4 – E6 for LM and e6 – e10 for SM for the afternoon). For the baseline measurement, a 2-minute video recording on eye blinking was randomly allocated within the 10-minute time window between the 4th and 13th minutes, 3 minutes after the subjects began the task. For all other measurements, the recording was randomly allotted within the last 10-minute window prior to the end of the task session. Excluding the two baselines, there were 6 measurements in the LM (E1 to E6) and 10 measurements in the SM (e1 to e10) schedules.

Measurement Procedure

The subject arrived at the Ergonomic and Human Performance Laboratory at 8:30 a.m. He/she was informed about the study and given an information sheet to read (Appendix VII). The subject then signed the consent form (Appendix VIII) and was asked to fill out a demographic questionnaire (Appendix IX). Prior to his/her arrival, the subject had already been assigned to either the LM schedule or the SM schedule according to block randomization, and a record sheet for guiding the measurement of the eye blink rate and neurophysiological variables was selected (Appendix X).

All experimental setups and baseline measurements were conducted between 8:30 a.m. and 9:30 a.m. In the setup, the subject was positioned at the workstation as described on pp. 69-70. The baseline sitting posture was standardized and measured based on the list shown in Appendix VI. Afterwards, the subject was asked to complete the SOFI-C (Appendix II) based on his/her subjective feeling at that time for establishing the baseline level of perceived fatigue. Preparation was completed at around 9:30 a.m., when the subject was instructed to begin the data entry task. Just prior to beginning, the subject was reminded to fully participate in the task and to perform at his/her maximum level of effort. The subject was also reminded that he/she would receive a bonus payment for good performance, while the performance was monitored by the computer throughout the task.

The morning task block took place between 9:30 a.m. and 12:20 p.m. Three minutes after the subject had begun the task, the researcher turned on the video camera using a remote control to record the subject's eye blinks for 2 minutes. A stopwatch was used to time the recording duration. Within the last 10 minutes of the first session, the researcher selected a 2-minute time segment and began the video recording to capture the end-of-session eye blinks. The 2 minutes were selected according to a predetermined time sheet that guided the measurement (Appendix X). At the time the first task session ended (after 50 minutes for the LM and 30 minutes for the SM schedules), the subject was required to stop keying in the data. The last data entered by the subject were highlighted in blue (described on pp. 71). This marker marked the cell at which the subject stopped at the end of the task session. The subject's performance was computed and immediately displayed using the tailor-made program (described on pp. 71-72). The subject was informed of his/her performance during the session and was encouraged to keep up the performance in the next session to receive the bonus payment.

During the rest break, the subject was allowed to walk around the laboratory or sit down to rest but was not permitted to perform any exercise. When the rest break was over, the subject was instructed to resume the task. The process was repeated, except that no eye blink measurements were conducted at the beginning of the session.

After the subject completed the last session in the morning, he/she was asked to complete the SOFI-C again for the second time for measuring the perceived fatigue at that time. Afterwards, the subject took a 1-hour lunch break in the laboratory, where he/she took a lunch box for the meal. The subject was restricted from taking any drink containing caffeine. At 1:30 p.m., the subject was told to prepare for resuming the task, and the entire afternoon process replicated that of the morning.

The afternoon task block was held between 1:30 p.m. and 4:20 p.m. After completing the last session, the subject was required to complete the SOFI-C for the third time to measure his/her perceived fatigue at that time. The entire experiment was then complete, and the subject was debriefed on the experiment. The subject then left the laboratory after signing the receipt for the monetary reward for participating in the study.

Data Analysis

Group Comparisons

Three-way repeated measures ANOVA were conducted on each of the three behavioral variables. For the SOFI-C, the three-way repeated measures ANOVA was a 2 Schedules × 3 Times × 5 Subscales model. The 3 time points were at the baseline (before S1 and s1), the end of morning (after S3 of LM and s5 of SM), and the end of afternoon (after S6 of LM and s10 of SM). The five subscales were SL, PD, LM, LE, and PE. The two schedules were LM and SM. For performance (percentage of error rate and speed of data entered), the three-way repeated measures ANOVA was a 2 Schedules × 2 Blocks model. The 2 blocks were the morning and the afternoon. The 2 sessions were the first session (S1 and s1 in the morning or S4 and s6 in the afternoon) and the last session (S3 and s5 in the morning or S6 and s10 in the afternoon). For the eye blink rate, the three-way repeated measures ANOVA was set up with a 2 Schedules × 2 Blocks × 2 Sessions model. The 2 sessions were the first session (E1 and e1 in the morning or E4 and e6 in the afternoon) and the last session (E3 and e5 in the morning or E6 and e10 in the afternoon).

Within-group Across-time changes

For the SOFI-C, a one-way repeated measure ANOVA was conducted on all three time point measurements on each of the five subscales. For the performance errors and speeds and the eye blink rate, two-way repeated measures ANOVA were performed on all sessions (2 Blocks × 3 Sessions for LM and 2 Blocks × 5 Sessions for SM).

All statistics were computed using SPSS 12.0. The significance level for all statistical tests was set at $p \leq 0.05$. For all within-subject effects in the repeated measures ANOVA, Greenhouse-Geisser was reported to correct for the significance in case of violation of assumption on sphericity. Bonferroni adjustments were applied to all post hoc comparisons.

Results

Demographic Data

Twenty females and 20 males were evenly distributed between the LM and SM schedules. The mean ages of the female subjects were 21.2±1.2 and 20.7±1.4 years for LM and SM respectively, while that of the male subjects were 20.6±1.3 and 21.2±1.23 years for LM and SM respectively (Table 5.1). The mean sleeping hours of the subjects were between 5.5 and 6.6 hours. The mean weight and height were between 49.3 and 65.3 pounds and between 159.2 and 174.5 cm respectively.

Univariate ANOVA with fixed factor *Gender* (male and female) and *Schedule* (LM and SM) was performed on each of the above four demographic characteristics (age, sleeping hour, weight, and height) to examine if the subjects between the two schedules were comparable. The results revealed neither significant group nor interaction effects on age and sleeping hours, $F(1,36) = 0.012$ to 2.69, $p = 0.11$ to 0.90. Compared to the female subjects, the male subjects were significantly heavier, $F(1,36) = 15.10$, $p < 0.001$, and taller, $F(1,36) = 43.11$, $p < 0.001$.

Table 5.1. *Demographic characteristics of the subjects on the LM and SM schedules*

	LM		SM	
	Female (*n*=10) Mean (*SD*)	Male (*n*=10) Mean (*SD*)	Female (*n*=10) Mean (*SD*)	Male (*n*=10) Mean (*SD*)
Age (yrs.)	21.20 (1.23)	20.60 (1.26)	20.70 (1.42)	21.20 (1.23)
Sleeping hour (hrs.)	6.55 (0.96)	6.20 (1.16)	6.20 (0.68)	5.50 (1.18)
Weight (lbs.)	50.72 (7.66)	65.29 (16.18)	49.30 (8.25)	61.84 (9.89)
Height (cm.)	160.40 (7.35)	174.50 (7.32)	159.15 (6.70)	173.00 (5.35)

SOFI-C

Descriptive statistics

Tables 5.2 and 5.3 show all the subscale scores of SOFI-C measured at the beginning of the task, and the end of the morning and end of the afternoon sessions. In general, the SOFI-C scores were found to increase across time in both schedules.

Table 5.2. *Subscale scores of SOFI-C of subjects on the LM schedule*

Subscales	LM Beginning Mean (*SD*)	 End of morning Mean (*SD*)	 End of afternoon Mean (*SD*)
Sleepiness (SL)	2.37 (2.00)	3.37 (2.60)	4.10 (2.42)
Physical discomfort (PD)	0.69 (0.77)	2.70 (1.74)	3.85 (2.16)
Lack of motivation (LM)	1.34 (1.46)	2.32 (1.87)	3.24 (1.95)
Lack of energy (LE)	1.45 (1.86)	2.85 (2.45)	4.36 (2.64)
Physical exertion (PE)	0.92 (0.89)	0.93 (1.02)	1.31 (1.48)

Table 5.3. *Subscale scores of SOFI-C of subjects on the SM schedule*

Subscales	SM Beginning Mean (*SD*)	 End of morning Mean (*SD*)	 End of afternoon Mean (*SD*)
Sleepiness (SL)	2.37 (2.00)	3.47 (2.28)	4.27 (2.66)
Physical discomfort (PD)	0.56 (0.64)	1.95 (1.15)	3.24 (1.65)
Lack of motivation (LM)	1.55 (1.73)	2.93 (2.25)	3.67 (2.26)
Lack of energy (LE)	1.06 (1.30)	2.85 (1.72)	4.32 (2.23)
Physical exertion (PE)	0.76 (0.97)	0.96 (0.98)	1.43 (1.49)

Comparisons of SOFI-C Subscale Scores Between the LM and SM Schedules

Three-way repeated measures ANOVA (2 Schedules × 3 Times × 5 Subscales) revealed significant main effects on Time, $F(1.43,54.31) = 53.10$, $p < 0.001$; Subscale, $F(2.94,111.69) = 30.23$, $p < 0.001$; and Time × Subscale interactions, $F(4.41,167.82) = 12.93$, $p < 0.001$. No significant differences in subscale scores were revealed between the LM and SM schedules, $F(1,38) = 0.008$, $p = 0.931$. Post-hoc comparison revealed that for both the LM and SM schedules, the scores of the SL subscale were significantly higher than all other subscales at the beginning of the task, while the scores of the PE subscale were significantly lower than all other subscales at the end of the morning and afternoon sessions.

Across-time Changes of SOFI-C Subscale Scores on the LM and SM Schedules

Following the significant main effect of Time, post-hoc comparisons were performed for each of the five subscales. For both LM and SM schedules, the scores of all subscales, except PE, increased significantly from the beginning of the task to the end of the morning session ($p < 0.001$), from the end of the morning to the end of the afternoon sessions ($p < 0.04$), and from the beginning of the task to the end of the afternoon session ($p < 0.001$). In the PE subscale of both LM and SM schedules, the scores increased significantly only from the end of the morning to the end of the afternoon sessions ($p < 0.005$), and from the beginning of the task to the end of the afternoon session ($p < 0.03$).

Task Performance

Descriptive Statistics

Tables 5.4 and 5.5 present the error rates of the data entered and the typing speed for each session of the LM and SM schedules. The mean error rate was very low, ranging between 0.60% and 1.19%. However, the standard deviations of the error rates were relatively large. To be able to compare the results obtained in this study with other previous studies (Galinsky et al., 2000; Henning et al., 1989), further transformation of the error rate and typing speed was not conducted at this stage.

Table 5.4. *Error rate and typing speed of subjects on the LM schedule*

Blocks	Session (S)	LM	
		Error rate (%)[1]	Speed (data per minute)[2]
		Mean (*SD*)	Mean (*SD*)
Morning	S1	1.01 (0.88)	27.75 (8.20)
	S2	0.61 (0.55)	32.48 (10.26)
	S3	0.65 (0.50)	34.38 (10.79)
Afternoon	S4	0.63 (0.57)	30.11 (6.78)
	S5	0.75 (0.94)	30.25 (6.46)
	S6	0.71 (0.84)	30.32 (6.75)

[1] Error rate was defined as the total number of incorrect entries divided by the total number of data typed within a session and then multiplied by 100.

[2] Speed was defined as the total number of data entered in a session divided by the duration (minute) of that session.

Sessions marked with underline were included in the group comparison.

Table 5.5. *Error rate and typing speed of subjects on the SM schedule*

Blocks	Session (s)	SM	
		Error rate (%)[1]	Speed (data per minute)[2]
		Mean (*SD*)	Mean (*SD*)
Morning	s1	1.19 (1.95)	28.56 (6.95)
	s2	0.84 (0.64)	31.87 (7.86)
	s3	0.87 (0.69)	33.54 (8.86)

	s4	0.63 (0.61)	31.87 (7.48)
	s5	0.75 (0.67)	22.04 (7.32)
Afternoon	s6	0.74 (0.67)	34.22 (8.10)
	s7	0.67 (0.59)	33.62 (11.11)
	s8	0.75 (0.69)	36.88 (9.24)
	s9	0.67 (0.91)	31.40 (7.97)
	s10	0.60 (0.66)	37.51 (10.28)

[1] Error rate was defined as the total number of incorrect entries divided by the total number of data typed within a session and then multiplied by 100.

[2] Speed was defined as the total number of data entered in a session divided by the duration (minute) of that session.

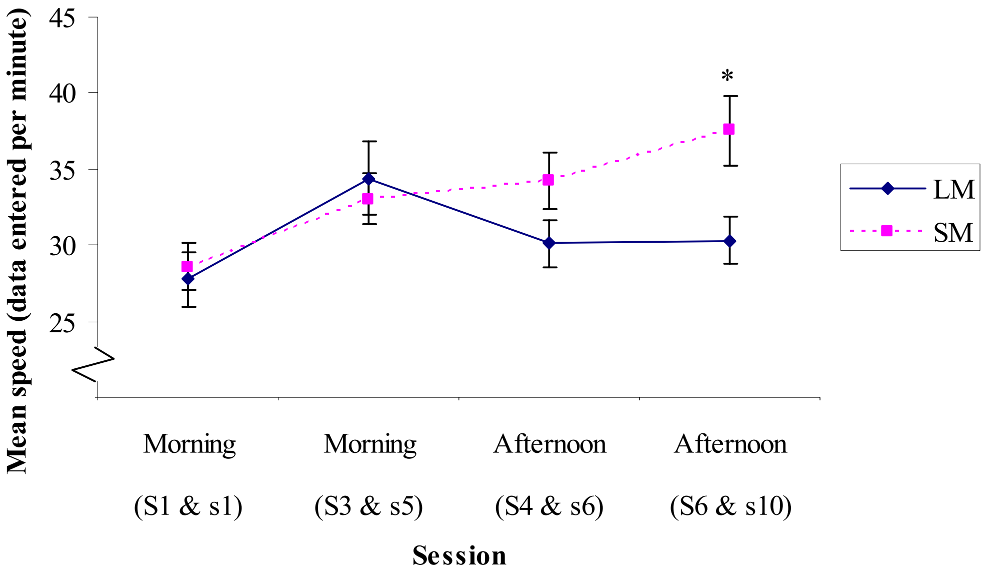
Sessions marked with underline were included in the group comparison.

Comparisons of Task Performance Between the LM and SM Schedules

For errors committed when entering data, three-way repeated measures ANOVA (2 Schedules × 2 Blocks × 2 Sessions) did not reveal any significant main effect on Block, $F(1,38) = 2.94$, $p = 0.095$; Session, $F(1,38) = 2.31$, $p = 0.137$; or interaction effects among the main effects, $F(1,38) = 0.27$ to 2.12, $p = 0.153$ to 0.608. No significant differences in error rate were revealed between the LM and SM schedules, $F(1,38) = 0.15$, $p = 0.700$.

For the speed of data entry, three-way repeated measures ANOVA (2 Schedules × 2 Blocks × 2 Sessions) revealed a significant main effect on Session, $F(1,38) = 22.34$, $p < 0.001$; Block × Session interactions, $F(1,38) = 10.17$, $p = 0.003$; Schedule × Block interactions, $F(1,38) = 7.24$, $p = 0.011$; and Schedule × Block × Session interactions, $F(1,38) = 4.81$, $p = 0.035$. No significant differences in speed of data entry, however, were revealed between the two task schedules, $F(1,38) = 1.54$, $p = 0.222$. Post-hoc comparisons revealed that in the LM schedule, the speed of data entry was faster in the last than the first morning sessions ($p < 0.001$), but no differences were observed between the first and last afternoon sessions ($p = 0.851$). In the SM schedule, the speed of data entry was faster in the last than the first morning session ($p = 0.003$) and afternoon session ($p = 0.042$) (Figure 5.2). An independent *t* test comparing the rates of entering data between the LM and SM schedules at the four time points indicated that the SM subjects typed significantly faster than the LM subjects only in the last session in the afternoon, $t_{38} = 2.62$, $p = 0.013$.

Figure 5.2. Speed of data entered across four time points between the LM and SM schedules (Mean ± 1 S.E.).



* indicates statistical significance at $p \leq 0.01$

Across-time Changes of Task Performance in the LM Schedule (from S1 to S6)

For the performance error rate, two-way repeated measures ANOVA (2 Blocks × 3 Sessions) revealed significant Block × Session interactions, $F(2,38) = 4.58$, $p = 0.017$, but non-significant main effects on Block and Session, $F(1,19) = 0.35$, $p = 0.563$ and $F(2,38) = 0.71$, $p = 0.499$ respectively. Paired *t* tests showed that the error rate of only S1 (first morning session) was higher than that of S4 (first afternoon session) ($t_{19} = 2.30$, $p = 0.033$). The differences between S2 and S5, and S3 and S6, were statistically not significant (Figure 5.3). Further one-way repeated measures ANOVAs comparing the differences among the six sessions did not reveal significant differences.

For the speed of data entry, two-way repeated measures ANOVA (2 Blocks × 3 Sessions) revealed a significant main effect on Session, $F(2,38) = 6.95$, $p = 0.003$, and Block × Session interactions, $F(2,38) = 8.06$, $p = 0.001$, but no significant main effect on Block, $F(1,19) = 0.63$, $p = 0.437$. Post-hoc comparisons among the sessions within each of the two blocks showed that throughout the morning sessions, the speed of entering the data in S2 was significantly faster than in S1 ($p = 0.002$), and S3 was faster than S1 ($p = 0.001$). No significant changes were found among sessions throughout the afternoon sessions. Further one-way repeated measures ANOVA on all six sessions indicated that the speed in S2 and S3 was significantly higher than that in S1 ($p = 0.008$ and $p = 0.006$ respectively). Figure 5.4 shows a graphical representation of the changes.

Figure 5.3. Error rate of subjects across the three morning (S1 to S3) and three afternoon (S4 to S6) sessions in the LM schedule (mean ± 1 S.E.).

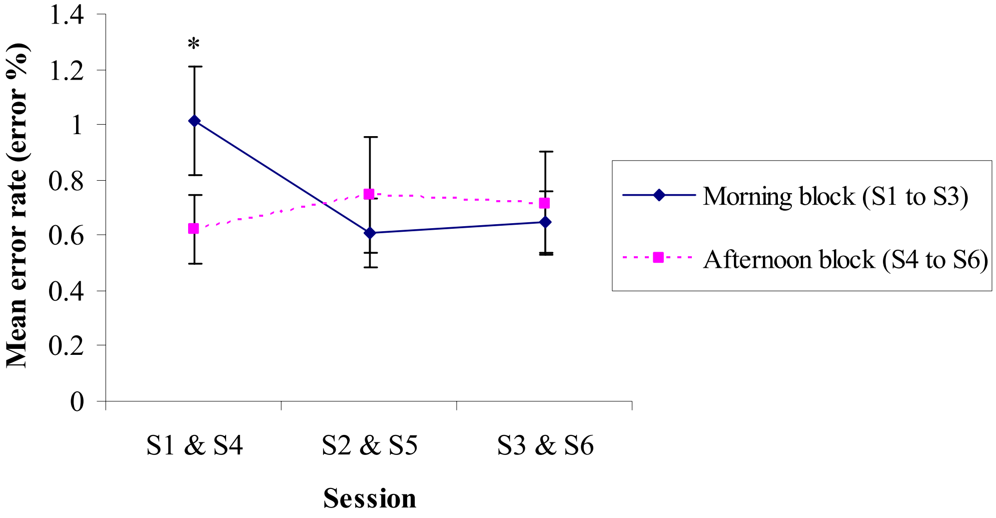
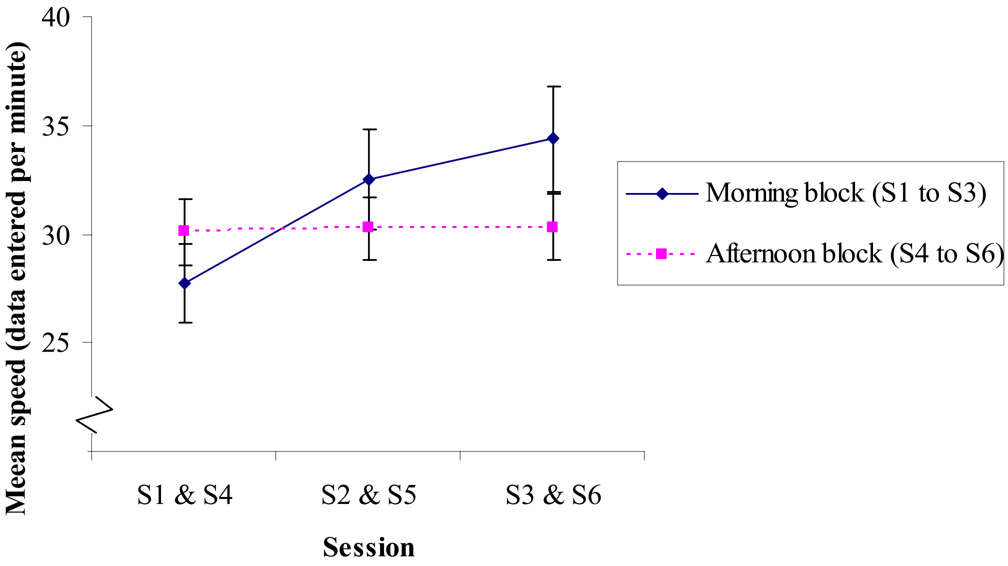


Figure 5.4. Speed of data entry of subjects across the three morning (S1 to S3) and three afternoon (S4 to S6) sessions in the LM schedule (mean ± 1 S.E.).



Across-time Changes of Task Performance in the SM Schedule (from s1 to s10)

For the performance error rate, two-way repeated measures ANOVA (2 Blocks × 5 Sessions) revealed neither a main effect on Block, $F(1,19) = 1.64$, $p = 0.216$, or on Session, $F(2.23,42.38) = 0.90$, $p = 0.424$, nor their interaction effects among the main effects, $F(1.74,33.05) = 0.500$, $p = 0.586$. One-way repeated measures ANOVA on the differences in speed of data entry across all 10 sessions did not reveal any significant results. Figure 5.5 shows a graphical representation of the error rate.

For the speed of data entry, two-way repeated measures ANOVA (2 Blocks × 5 Sessions) revealed a significant main effect on Block, $F(1,19) = 11.12$, $p = 0.003$, and Session, $F(4,76) = 5.35$, $p = 0.001$, but no significant Block × Session interactions, $F(4,76) = 2.03$, $p = 0.098$. Post-hoc comparisons indicated that the speed of entering data was generally faster in the morning than afternoon sessions ($p = 0.003$). In addition, the speed of data entry in s5 was faster than that in s1 ($p = 0.028$). No significant variations were shown among the afternoon sessions. Further one-way repeated measures ANOVA on the speed of data entry across all 10 sessions revealed that the speed in s8 was significantly faster than that in s1 and s2 ($p = 0.012$ and $p = 0.036$ respectively), and the speed of data entry in s10 was significantly faster than that in s1 ($p = 0.007$). Figure 5.6 shows a graphical representation of the changes.

Figure 5.5. Error rate of subjects across the five morning (s1 to s5) and five afternoon (s6 to s10) sessions in the SM schedule (mean ± 1 S.E.).

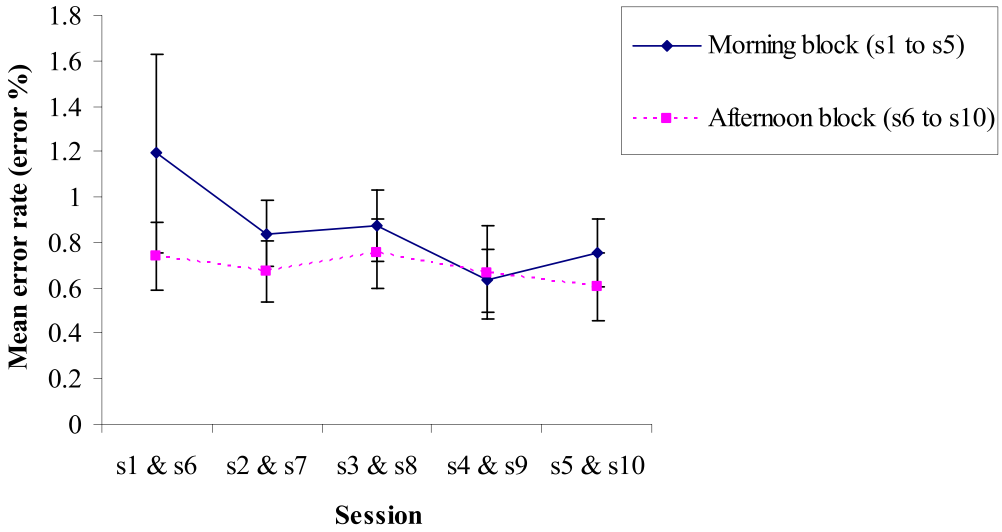
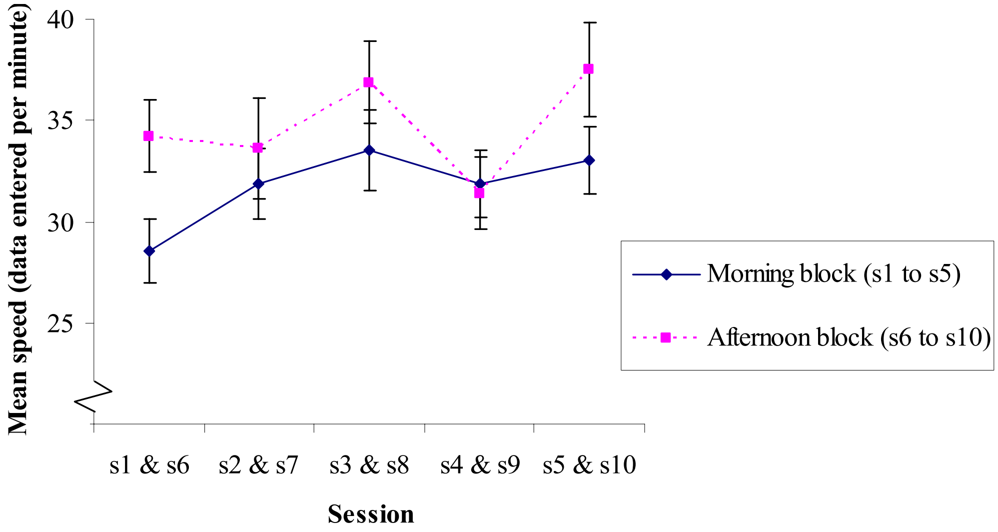


Figure 5.6. Speed of data entry of subjects across the five morning (s1 to s5) and five afternoon (s6 to s10) sessions in the SM schedule (mean ± 1 S.E.).



Eye Blink Rate

Descriptive Statistics

Tables 5.6 and 5.7 summarize the eye blink rate obtained in the study. Because large variations occurred in the number of eye blinks captured from the subjects, this number was normalized with an individual subject's baseline eye blinks captured at the beginning of the first morning and afternoon sessions (refer to Tables 5.6 and 5.7 for details of the normalization process). The normalized eye blink results are used in all subsequent analyses in this part of the chapter.

Table 5.6. *Results of eye blinks of subjects in the LM schedule*

Blocks	Session (S)	LM	
		Raw data[1] Mean (*SD*)	Normalized eye blink rate[2] Mean (*SD*)
Morning	Beginning of S1	10.77 (8.36)	---
	S1	13.85 (14.66)	1.36 (0.80)
	S2	11.45 (8.98)	1.21 (0.63)
	S3	13.80 (13.40)	1.16 (0.66)
Afternoon	Beginning of S4	14.25 (12.81)	---
	S4	15.35 (13.64)	1.52 (1.51)
	S5	12.75 (9.83)	1.25 (0.96)
	S6	11.55 (9.73)	1.01 (0.51)

[1] Raw data refers to total number of eye blinks in 2 minutes.

[2] Normalized eye blink rate is defined as the number of eye blinks captured in each session divided by their respective baselines captured at the beginning of the first

session of the task block.

The sessions marked with underline were included in the group comparison.

Table 5.7. *Results of eye blinks of subjects in the SM schedule*

Blocks	Session (s)	SM	
		Raw data[1]	Normalized eye blink rate[2]
		Mean (*SD*)	Mean (*SD*)
Morning	Beginning of s1	12.80 (13.95)	---
	<u>s1</u>	11.40 (13.95)	1.20 (0.92)
	s2	11.45 (14.69)	1.01 (0.55)
	s3	10.30 (10.45)	1.16 (0.98)
	s4	10.35 (13.32)	0.99 (0.60)
	<u>s5</u>	10.30 (9.93)	1.46 (1.36)
Afternoon	Beginning of s6	9.25 (8.16)	---
	<u>s6</u>	8.55 (4.96)	1.11 (0.60)
	s7	9.25 (6.89)	1.07 (0.64)
	s8	9.85 (10.33)	1.05 (0.54)
	s9	9.20 (8.12)	1.07 (0.55)
	<u>s10</u>	12.25 (11.27)	1.45 (1.18)

[1] Raw data refers to total number of eye blinks in 2 minutes.

[2] Normalized eye blink rate is defined as the number of eye blinks captured in each session divided by their respective baselines captured at the beginning of the first session of the task block.

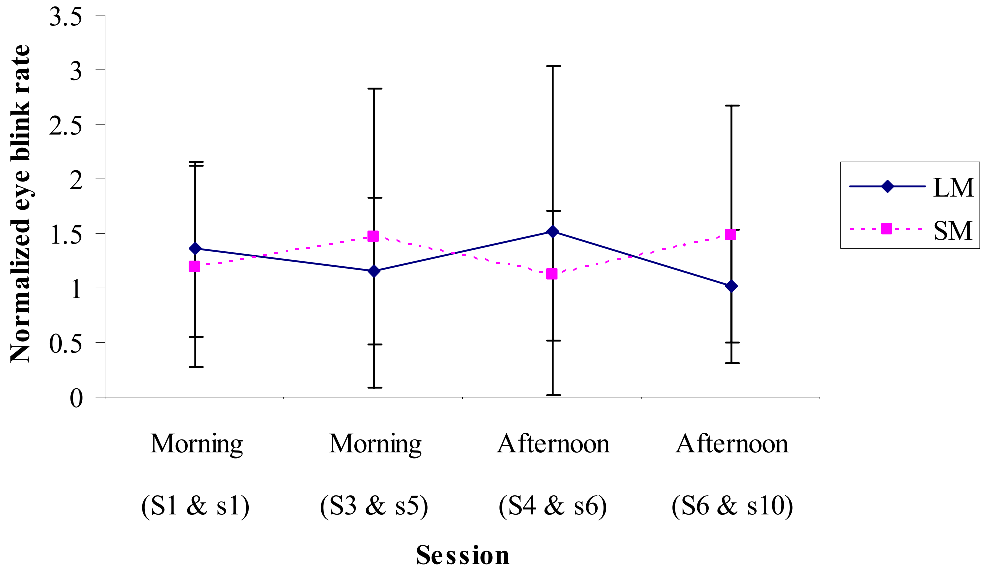
The sessions marked with underline were included in the group comparison.

Comparisons of Eye Blink Rates Between the LM and SM Schedules

Three-way repeated measures ANOVA (2 Schedules × 2 Blocks × 2 Sessions) revealed significant Session × Schedules interactions, $F(1,38) = 6.03$, $p = 0.019$. No significant main effects were observed on Block, $F(1,38) = 0.002$, $p = 9.969$, or Session, $F(1,38) = 0.202$, $p = 0.889$, nor was a significant group difference revealed, $F(1,38) = 0.091$, $p = 0.764$). Post-hoc comparison using an independent *t* test revealed no significant differences in eye blinks between the two schedules in each of the four pairs of sessions. Nevertheless, it appeared that in the LM schedule, the eye blink rate tended to decrease from the beginning to the end of the session in both the morning and afternoon task block, whilst in the SM schedule, a reverse trend was noted, that is, the eye blink rate tended to increase from the beginning to the end of the session (Figure 5.7). But because there were large variations in the normalized eye blink rate, all comparisons were statistically not significant.

In this part of the analyses, the four pairs of eye blink rates captured at the end of the task sessions were not exactly at overlapping time points. It appeared that the eye blinks measured in the LM schedule came before 50 minutes, while those measured in the SM schedule came before 30 minutes in each of the task sessions. Therefore, in addition to the above analyses, the eye blink rates were further adjusted so that those of the LM schedule were multiplied by 30/50 and those of the SM were multiplied by 50/30. This adjustment was based on the assumption that the longitudinal variation of eye blink rate follows a linear trend. The results revealed significant Session × Schedules interactions, $F(1,38) = 4.47$, $p = 0.041$, and group differences, $F(1,38) = 35.09$, $p < 0.001$. It appears that the eye blink rates of the SM schedule were greater than those of the LM.

Figure 5.7. Normalized eye blink rate across the four comparison time points of the two schedules (mean ± 1 S.E.).



Note: S1 & s1 and S4 & s6 are the first sessions of the morning and afternoon blocks. S3 & s5 and S6 & s10 are the last sessions of the morning and afternoon blocks.

Across-time Changes of Eye Blink Rates in the LM Schedule (from S1 to S6)

Two-way repeated measures ANOVA (2 Blocks × 3 Sessions) revealed neither a main effect on Block, $F(1,19) = 0.007$, $p = 0.934$, or on Session, $F(1.49,28.39) = 2.85$, $p = 0.087$, or their interactions, $F(1.50,28.41) = 0.53$, $p = 0.545$. One-way repeated measures ANOVA on the differences in normalized eye blinks across all six sessions revealed no significant results, $F(1.97,37.51) = 0.76$, $p = 0.473$.

Across-time changes of eye blink rates in the SM schedule (from s1 to s10)

Two-way repeated measures ANOVA (2 Blocks × 3 Sessions) revealed neither a main effect on Block, *F*(1,19) = 0.001, *p* = 0.971, or on Session, *F*(2.43,46.20) = 2.98, *p* = 0.052, or their interaction effects, *F*(2.16,41.08) = 0.17, *p* = 0.860. One-way repeated measures ANOVA on the differences in normalized eye blinks across all 10 sessions revealed no significant results, *F*(2.80,53.28) = 0.92, *p* = 0.431.

Discussion

The results show that as the subjects engaged in the 6-hour data entry task, their feelings of fatigue appeared to intensify across the morning and then the afternoon sessions. The extent to which the subjects felt fatigue nevertheless does not differ between the two rest schedules. The different effects of the rest schedule are observed on modulating the subjects' performance on the task. In general, subjects in both schedules showed a significant increase in speed as they progressed into the task. In the LM schedule, the speed of data entry increased from S1 to S2 and was then maintained till the end of the morning block. In contrast, in the SM schedule, the speed of data entry was higher in the afternoon sessions than in the morning sessions. More specifically, the speed in s5 was significantly higher than that in s1. The error rate, however, did not vary across time on task. There were also no significant changes in eye blink rates across the entire task, suggesting that attentional demands on subjects probably did not change in either the LM or SM schedules.

Task Performance

The findings on the errors committed and feelings of fatigue by the subjects in this study are consistent with those reported in Henning et al. (1989). Although there were no significant increases in error rates, there was a significant increase in subjective fatigue across the morning and afternoon task sessions. The task designs used in this study are similar to Henning et al's. In their study, the subjects performed a 2-day data entry task in a simulated office environment. Each day was divided into 2 blocks, each consisting of three 40-minute task sessions separated by a 10-minute rest break. Subjects were instructed to take additional self-adjusted microbreaks every 20 minutes in each task session. The main differences between this study and Henning et al.'s are that in the latter, the task lasted 2 days instead of 1, and self-adjusted microbreaks were given instead of a fixed rest schedule.

Other studies have produced different results from this study. For instance, Gao et al. (1990) observed deterioration in subjects' performance at around 45 to 60 minutes of engagement in the task, but a rebound of performance at around 70 to 80 minutes. The task used in Gao et al.'s study was a continuous 150-minute data entry task. Two groups of subjects were used, one performing simple data entry of two digits from 10 to 99, and the other performing complicated data entry of decimal numbers such as 3.7486, 0.5692, and so forth. The researchers found that performance in terms of correct entry in the complicated data entry group was relatively low during the first hour, followed by a significant rebound in the 70 – 80 minute period. They also found significant differences between the two groups during the 30 – 40 minute period, in which subjects in the simple data entry group showed significantly more correct entries. In addition, they transformed raw performance outcomes in terms of the number of correct data entered into standard scores during their analysis. They did this to compare the results between the simple and complicated data entry groups. In the current study the data could not be transformed, so the results obtained cannot be directly compared with those reported by Gao et al. There are three reasons for this. First, the design of the task was referenced to Henning et al.'s (1989) study, which based the performance outcome on raw data. Second, the error rate obtained in this study was too low to be considered for transformation. Third, the task performance obtained had to be correlated with other variables in the study.

Speed as a Function of Task Performance

The present study reveals a significant increase in subjects' speed of data entry. The SM subjects typed faster in the afternoon than in the morning. The LM subjects, however, showed no significant increases in their typing speed from the morning to the afternoon sessions, but did show significant increases in typing speed within the morning sessions, that is, the second and third sessions were faster than the first session.

There are two plausible explanations for the changes in typing speed throughout the data entry task. First, the increase in typing speed could be due to the subjects mastering the skills demanded by the task, which is considered a facilitative effect. The differences in subjects' typing speed between the SM and LM schedules could be interpreted as showing that the SM schedule had a stronger facilitative effect on subjects' performance than the LM schedule. Second, as subjects were not prohibited from making corrections to data entered incorrectly, the time spent on making corrections could have jeopardized typing speed. This is regarded as a hindrance effect on task performance. The differences in subjects' typing speeds between the two rest schedules could be interpreted as showing that the LM schedule had a stronger hindrance effect on subjects' performance than the SM schedule. The rest of this section further explores how the facilitative and hindrance effects could have influenced the subjects' typing speed in the LM and SM schedules.

According to Healy et al. (1994), when individuals engage in a task over time, performance can be influenced by either facilitative or inhibitory factors, or both

(Buck-Gengler & Healy, 2001; Fendrich, Gesi, Healy, & Bourne, 1995; Fendrich, Healy, & Bourne, 1991). Facilitative effects can improve performance. In data entry tasks, the performance will become more accurate and/or faster. It is further proposed that facilitative effects result from mastery of the skills required of the data entry task as a consequence of learning and practice (Healy et al., 2004). In contrast, inhibitory effects can lead to deterioration of performance in that data entry becomes less accurate and/or slower. According to Healy et al. (2004), inhibitory effects mostly result from the fatigue, boredom, and reduced attention experienced by individuals over long trial periods.

The results of the present study indicate that subjects in the SM schedule showed improvements in typing speed across the morning and afternoon task blocks. This suggests a stronger facilitative effect on the subject's performance brought about by the shorter and more frequent rest break schedule. The longer and less frequent rest break schedule appeared to weaken such a facilitative effect, if any. These improvements in performance could be attributed to practice (Healy et al., 2004; Matthews et al., 2000), skill acquisition (Healy et al., 2004; Matthews et al., 2000), or automatic processing of the data entry task (Shiffrin & Schneider, 1977). Each of these factors will be discussed separately below.

Practice. Practice can improve quantity of performance (Matthews et al., 2000). This means that, after sufficient practice on a data entry task, the subjects demonstrated a faster typing speed and hence entered more sets of two-digit numbers. Galinsky et al. (2000) reported that the mean performance of subjects on a typing task improved as the subjects progressed from day to day during the work week and from week to week. They further postulated that the increase in keystrokes was due to repeated practice, which, as they observed, was not influenced by different rest break schedules. In contrast, Healy et al. (2004) opined that the facilitative effects on data entry tasks include both practice and skill acquisition. They further proposed that practice produces both learning and fatigue-like effects, depending on whether speed or accuracy is used in measuring the performance on a task. In a simple and repetitive task like data entry, the learning effects after practice over trials enable subjects to perform faster and substantiate as speed increment (Healy et al., 2004). Matthews et al. (2000) further reinforced the concept of practice. They found that in the early stages of practice on a task, the subjects' performance increased rapidly. But as the subjects progressed on the task, the rate of improvement decreased. Healy et al. (2004) further suggested the notion of an inhibitory effect that acts against the facilitative effect in a data entry task. The effects are likely due to the fatigue experienced by subjects throughout the task.

In this study, subjects in the shorter and more frequent schedule were found to demonstrate significantly higher typing speeds than those in the longer and less frequent schedule in the afternoon. There were no differences in errors committed by the subjects in the two schedule groups. Based on Healy et al.'s (2004) proposition, it appears that the SM schedule provided stronger facilitative effects than the LM schedule on the subjects' performance. As data entry is a relatively easy task that is repetitive and does not require much skill, it is expected that the time needed for the practice effect to kick in would not be very long, perhaps the first and second hours after engaging in the task. In the LM schedule, the subjects' data entry speed increased from the first to the second sessions and was then maintained from the second to the third sessions. This observation suggests that the increase of the subjects' speed early in the morning was most probably facilitated by the practice effects and mastering of the skills. In the SM schedule, the subjects did not show an increase in speed during the first or second hour of the task, that is, from the first to the fourth sessions. Rather, the subjects demonstrated significantly faster speed only in the last morning session when compared to the first morning session in the morning task block. This suggests that the facilitative processes stemming from the rest schedule probably exerted their effects throughout the 6 hours of task, whilst these facilitative effects were strongest in the afternoon. Henning et al. (1997) found that short and frequent rest schedules in data entry tasks interrupted subjects' flow of work and produced a detrimental effect on their performance. It is therefore not certain that the schedule, besides the facilitative effects mentioned, could have had other, undesirable inhibitory effects, as addressed in the next two sections.

Skill acquisition. The theory of skill acquisition offers further explanation for the increase in the typing speed of the subjects. According to Fitt (1962), there are three stages at which an individual acquires skills. The first stage is a cognitive phase, when an individual attempts to carry out the task and the performance is mostly benefited by feedback. This stage is characterized by errors and inefficiencies. Inefficiency means the performance gain is less than expected and is not proportionate to the individual's effort invested in the task (Matthews et al., 2000). The next stage is an associative phase, during which the correct patterns of activity are practiced until they are error-free. The final stage is an automation phase, when the activity has been well practiced by the individual and has reached an autonomous state. This theory has been found to explain performance on signal detection or motor tasks (Matthews et al., 2000). However, there have been no studies using this theory to explain the performance on a data entry task.

In the present study, the subjects were not skilled data entry workers and were given no opportunity to become familiar with the task prior to the experiment. Since entering two-digit data is a rather simple task, the subjects could potentially learn the skills in the first 1 to 2 hours after engaging in the task. According to the theory of skill acquisition, the subjects should have committed more errors at the beginning, which then would have decreased as they progressed into the task. The results, however, do not appear to support this theory. Instead, subjects' error rates showed no significant increase throughout the task for either the LM or SM groups. It should also be noted that the subjects were allowed to make corrections to data entered as long as they noticed the error. The relatively low error rate throughout the task and no significant increases in error rates at the beginning of the task might be attributable to subjects making corrections on entries that were inaccurately typed in. If this is the case, the subjects' typing speed in the first one or two sessions could have been faster than what was obtained in the study. The results, however, show that the subjects' typing speed significantly increased from the first to the second sessions in the LM schedule and from the first to the last morning sessions in the SM schedule. This does not appear to tally with the theory's expectations. One possible explanation is that the time required for learning data entry might require an even shorter period than 1 to 2 hours. The facilitative effects resulting from practice could outweigh the delayed effect brought about by making corrections to inaccurate entries in the first few sessions in both the LM and SM schedules.

The same line of thought can be used to explain the changes in typing speed among subjects in the afternoon task sessions between the SM and LM schedules. Whereas the LM subjects showed no further increments in typing speed in the afternoon session, the SM subjects continued to show an increase in speed until the end of the entire task. The differences are likely to be attributable to the facilitative effects brought about by the SM rest schedule, which included shorter and more frequent breaks. The mechanism underlying the speculated facilitative effect is further explored in the next few sections.

Automatic processing. Automatic processing is a fast and effortless process that develops in situations where people consistently respond to repetitive stimuli (Schneider & Shiffrin, 1977). The word *effortless* refers to the state of an individual in which the performance of a task requires no conscious thinking or awareness (Matthews et al., 2000). Automatic processing is commonly found when individuals are asked to repetitively respond to familiar perceptual stimuli, such as a particular letter (LaBerge, 1983) or predetermined targets (Schneider & Fisk, 1982). Some examples of automatic processing tasks include riding a bicycle, signing one's own name, and reading numbers aloud (Wickens & Hollands, 2000). Controlled processing, in contrast, is slow and effortful. Schneider and Shiffrin (1977) regarded controlled processing as effortful because the processing requires step-by-step thinking, which is dependent on the individual's goals and motivation. These processes normally demand that subjects attend to complex stimuli or messages. Controlled processing is commonly found in visual search and working memory tasks.

For a data entry task, although the typing actions appear repetitive, accurate performance demands a continuous awareness of the data content and selection of the appropriate keys for keying in data. Previous studies on numerical data entry have rarely involved a detailed task analysis. In fact, data entry tasks are, strictly speaking, partially rather than fully automated tasks. When the subjects attended to the data entry task in this study, they had to identify the data written on the data sheet, initiate their motor actions, and then select the appropriate keys on the keyboard for keying in the data accurately. The cycle repeated after the subjects completed entering one unit of data, that is, two digits, and moved the cursor to the next cell on the Excel spreadsheet by pressing the cursor key on the keyboard. In each task cycle, the identification of the data, initiation of the motor action, and moving of the cursor to the next cell were likely to rely on automatic processing. This is because the data to be entered were always double digits and the data sheet was placed in a fixed location. It was expected that, after a relatively short period of time, the subjects could form a motor pattern that related their registration of the digits to the initiation of the motor execution. In contrast, there were also task processes in the task that probably relied more on controlled processing. These were the awareness of the content of the data to be entered and the identification of the appropriate keys for keying in the data. Since the two-digit numbers varied across entries, the subjects were required to attend to the two digits and select the appropriate keys. The combination of automatic and controlled processes is believed to occur throughout data entry tasks, with the former not being influenced by facilitative or inhibitory effects while the latter is.

In this study, all subjects participated in the same data entry task. That means their processing would be the same as that described above. However, the LM subjects showed significant increases in typing speed only across the morning sessions, while the SM subjects showed significant increases in typing speed across both the morning and afternoon sessions. The SM subjects also showed significantly higher typing speeds that the LM subjects in the last task session of the experiment. From these behavioral findings, it is likely that, in the afternoon task block, the shorter and more frequent rest schedule exerted greater effect on facilitating the controlled processes than did the longer and less frequent rest schedule. But other factors might have contributed to the observed increments in typing speed. It could be that the SM subjects were able to invest greater mental effort to boost their performance to a higher level, that is, to perform faster, in the afternoon. The LM subjects' typing speed in the afternoon sessions returned to a level comparable to that in the first morning session. There are two possible explanations for such a finding. First, the subjects might have needed more time to correct the inaccurate entries they had made. Second, the subjects might have typed more slowly to avoid making inaccurate entries. These behavioral variables, however, cannot themselves unravel the mechanisms behind these outcomes. This calls instead for an in-depth analysis using the neurophysiological variables and data captured in the study (see Chapters VI and VII).

Error as a Function of Task Performance

In this study, despite the very low error rate of both the LM and SM subjects, it is important to look at the types of errors the subjects committed. This is because the types of errors might reflect the subjects' mental processes and efforts made on the task. A review of the literature on human error suggests that errors committed by subjects on a data entry task are probably slips in nature. According to Norman (1981), slip errors most likely occur in highly familiar surroundings during the performance of frequently and/or recently executed tasks in which a considerable degree of automaticity has been achieved. Reason (1979) regarded slips as the price people pay for automaticity and showed that the occurrence of errors is commonly associated with internal preoccupation or some external distraction. For example, individuals who have been thinking about a certain number might key in that number very often. In data entry, slips can result in wrong data being typed, misordering of the components of a data sequence, and even omission of entire data. This kind of error differs from mistakes, which describe failures of interpretation or comprehension of a complex problem. In this study, the errors committed by the subjects were found to be exclusively false entries. Although some missing entries were observed in a few subjects, the frequency was very low and was not taken into account in the analysis.

The results indicate that the errors committed by the subjects were very few, and the increase in the number of errors across time is not significant. These results are consistent with a similar data entry study conducted by Henning et al. (1989). Henning et al.'s study required the participants to perform a 2-day numerical data entry task, each consisting of six 40-minute task sessions separated by a 10-minute rest break. In addition to the regular rest breaks, the study required participants to take a self-adjusted microbreak after 20 minutes into each task session. They found no significant increase in error rates between the first and second halves of the session and across all task sessions. But the question is why the subjects maintained a low error rate throughout the data entry task. One plausible reason is that they made corrections to their wrongly entered data. Rasmussen (1982) explained human errors in terms of rule-based, skill-based, and knowledge-based behavior. Skill-based behavior is mainly involved in sensory-motor performance, which has a goal or intention. A task performed with skill-based behavior typically proceeds in a highly integrated fashion with little control of conscious attention. Matthews et al. (2000) further found that slips of actions are particularly likely to happen in tasks performed with skill-based behavior, which tends to be automated and without conscious control (Heckhausen & Beckmann, 1990). Rule-based behavior is governed by rules that are either stored in memory or made available through explicit instructions or protocols, while knowledge-based behavior is based on the operator's knowledge of how a system works, such as operation of a machine, and of its current state, and on the decisions made in that light (Rasmussen, 1982). In contrast to skill-based errors, errors committed on tasks performed with rule-based and knowledge-based behaviors are likely to be mistakes and errors of planning and judgment. In general, the slips committed on a skill-based task such as data entry can be detected relatively easily. In contrast, the mistakes made in rule-based or knowledge-based tasks may often not be realized by the individual (Matthews et al., 2000). Objective findings from previous studies have shown a detection rate of 86% for skill-based errors, 73% for rule-based mistakes, and 70.5% for knowledge-based mistakes (Reason, 1990). Among them, slips appear to be more readily detected than mistakes (Reason, 1990). For instance, it has been found that a skilled typist who performs data entry (or typing) detects errors very rapidly. Once the errors are detected, the typist can make corrections accordingly (Matthews et al., 2000; Rabbitt, 1978). This possibly explains why errors committed by subjects who engage in a data entry task can remain at a very low and steady level. Back to Healy et al.'s (2004) study, its subjects were not given the opportunity to view the entries they had typed into the system and to make corrections even when they had been recognized. Therefore, the increase in error rates might be a valid representation of the slips committed in their 2-hour data entry task. As Healy et al. explained, this could be attributable to the subjects experiencing fatigue, which exerted an inhibitory effect on the performance. In contrast, in the present study, subjects were not restricted from making corrections to their entered data. The subjects were allowed to check and rectify their entries made throughout the entire session. Thus it is likely that the error rates obtained from this study underestimate the errors committed by the subjects throughout the tasks. It is unfortunate that the Excel program used in this study does not enable the researcher ascertain whether the subjects made any corrections to the data entered. In Henning et al.'s (1989) study, the subjects were limited to using only the backspace key to make corrections to errors committed in previous keying. Because slips can be readily detected by the subjects, most errors can be detected and corrected. Both the present study and Henning et al.'s study did not observe performance decrements in the subjects.

The factors of slips and correction of errors could mask the errors committed by the subjects. The expected increase in error rates across the two 3-hour task blocks thus was not observed. It is postulated that if subjects had not been allowed to correct their entries, then those in the LM rest schedule would likely have shown a significant increase in errors across the afternoon task sessions when they developed fatigue. The relationships between the error rates and other behavioral variables likely due to the same causes were not observed.

Neurophysiological Evidence on Data Entry

A review of the literature suggests that most workload studies have used behavioral variables to quantify subjects' performance. Neurophysiological parameters have not been commonly employed in this type of study. Floru, Cail, and Elias (1985) used EEG captured at bilateral occipital sites for measuring the level of arousal of subjects throughout a 2-hour data entry task. They observed a progressive decline in task performance in terms of correct data entry, reaching minimal values after 45-60 minutes of work, followed by a significant rebound of performance. Their behavioral findings concurred with a study using two similar task designs conducted by Gao et al. (1990). For the EEG activities, the results revealed that beta activity was directly proportionate to correct entry, while alpha and theta activities were inversely proportionate to correct entry. However, at the point when performance rebounded in terms of an increase in correct entries, the EEG activities were characterized by the highest beta1 and lowest theta and alpha activities. The researchers further integrated these findings with a decline in subjects' levels of arousal at the point when performance showed a decline. The performance rebound was associated with a heightening of arousal levels. Matthews et al. (2000) explained that the decline of arousal in repetitive tasks can be attributed to repetitive and prolonged exposure to the same simulation pattern being received by the same functional (cortical) structures. This process possibly induces an active inhibition of the structure, thus increasing the threshold of the selective, specific activations that are required for maintaining the process. They further suggested that regular rest breaks might help to alleviate the "unbalanced" internal state if they were scheduled before 45-60 minutes on task.

Floru and Cail (1987) replicated the above study but added a task schedule with a 5-minute rest break after 40 minutes of data entry. They found that, compared with the non-stop schedule, the one with a rest break showed a significant increase in task performance. In addition, subjects in the rest schedule group showed a steady increase in performance after the rest break and maintained it at a high level before the next rest break. The study also used EEG to measure levels of participant arousal. They found that beta activity at the bilateral occipital sites increased proportionately with task performance (inversely with error rate). The study also revealed that in the rest break group, peaks of beta activity were associated with enhancement of task performance in terms of a low error rate. The performance and EEG variations in the non-stop schedule were similar to those obtained by Floru, Cail, and Elias (1985).

The two studies mentioned above highlighted the relationship between task performance and EEG activities. The studies carried out by Floru, Cail, and Elias (1985) and Floru and Cail (1987), however, were limited to 2 hours of data entry and analysis of error rates. Moreover, the task they used involved entry of information found on checks, which involved long series of numbers and was more difficult. As a result, their findings might not apply to other types of data entry performed for a longer duration.

Summary of Task Performance – Development of Further Hypotheses

In the present experiment, no significant variations in error rates were observed in either the LM or SM schedules. Although the subjects' increase in typing speed in the morning could result from the facilitative effects brought about by practice of the task, it might as easily be due to the increase in effort paid by the subjects to boosting their performance on the task. The findings from Floru and Cail (1987) and Floru, Cail, and Elias's (1985) studies suggest the latter, since their subjects paid more effort to the task (reflected by increased beta activity) to increase performance. An alternative explanation not supported by the two studies is that the subjects became habituated to the task. Under these circumstances, the subjects would have maintained a relatively low attentional level, as reflected by an increase in theta and alpha (slow wave) activities.

In the afternoon, task performance differed between the LM and SM schedules. In the LM schedule, both task error and typing speed showed no significant increase. Two opposing processes might be responsible for this. The subjects might have paid more effort to maintaining a low error rate and/or making corrections on their entries, as reflected by an increase in beta activity and/or reduction of HRV. Or, the subjects might simply have maintained a low attentional level after becoming habituated to the task, reflected by an increase in theta and alpha (slow wave) activity. In the SM schedule, the subjects' typing speed increased. Although the increase in typing speed could result from facilitative effects or automaticity brought about by practice of the task, it might as easily be due to the increase in effort paid by the subjects to boost their performance on the task. The former would be reflected by an increase in theta and alpha activity, whilst the latter would be reflected by an increase in beta activity and/or reduction of HRV.

These hypotheses need to be verified using the results from the EEG. The results and discussion will be presented in Chapter VII.

SOFI-C

In this study, the subjective fatigue reported by the subjects increased across the morning and the afternoon sessions. This pattern is consistent with the results of Henning et al.'s (1989) study. Their study measured subjective mood states in every 40-minute task session and revealed a general elevation in levels of fatigue across all sessions. The SOFI-C appeared to be sensitive enough to reflect the changes in fatigue levels across time. The findings in the current study, however, reveal no differences in subjects' levels of fatigue between the LM and SM schedules. Such results are similar to those obtained by Kopardekar and Mital (1994), who reported no statistically significant differences in ratings between a task schedule of a 30-minute task plus a 5-minute break, and that of a 60-minute task plus a 10-minute break. The explanation could be either that subjective fatigue ratings were not sensitive enough to reflect the differential impact of task loads between different work schedules of data entry tasks, or that the effects between the two rest schedules were too weak to modulate the perceived fatigue ratings.

Subjective fatigue can be associated with a combination of indications of raised or depressed arousal (Matthews et al., 2000). The former occurs when an individual feels fatigue because he/she has to invest an extra amount of energy into maintaining the task performance (Craig & Cooper, 1992).The latter exists when an individual feels tired of performing a task because of qualitative underload, a condition when boredom and lowering of arousal develops (Grandjean, 1988). However, a pattern of increasing fatigue ratings only across time was insufficient to reflect the underlying process in this experiment. For the former situation to happen, the subjective fatigue should be associated with more intensive cortical activities, whereas for the latter situation to happen, the subjective fatigue should be related more to indices showing low arousal levels. In addition, fatigue may be conceptualized as either generalized fatigue or task-specific fatigue (Holdings, 1983; Matthews et al., 2000). The former concept describes an individual in a state of general tiredness, and switching to another task or simply taking a short rest will not help recovery. The latter concept explains that when an individual is tired of performing a particular task, the fatigue may be alleviated by doing some different activity or breaking the activity pattern (Craig & Cooper, 1992; Krueger, 1989). Since the pattern of task performance in the LM and SM schedules differed, the impact of the task load of the data entry was task specific rather than generalized, and the subjective fatigue measures supposedly reflected the subjects' task-specific feelings of fatigue. Since manipulation of the rest break frequency and duration resulted in different performance outcomes between the two schedules, the pattern of association between the subjective fatigue and neurophysiological indicators is expected to be substantially different between the two task schedules.

In the present study, the subjects reported an exceptionally high score on the Sleepiness subscale at the beginning of the task. This pattern is quite distinct from that of other studies (Leung, Chan, & He, 2004). It could be related to the fairly short duration of sleep that the subjects had prior to the experiment (between 5.5 and 6.6 hours). According to the qualitative findings from the questionnaire, the subjects reported that they were occupied by school work, reading, or leisure activities late at night prior to the experiment. Nevertheless, their feeling of sleepiness increased gradually across time. Another finding was that among the five subscales, the Physical Exertion subscale scored the lowest across time and also showed no significant increase from beginning to end of the afternoon. According to Ahsberg (2000), the Physical Exertion subscale is a physical description of fatigue that represents fatigue resulting from tremendous exercise. Although the Physical Discomfort subscale was also a physical description, the increase of this subscale score in this study was attributed to musculoskeletal discomfort, which is very common in prolonged VDT task engagement (Balci & Aghazadeh, 2004). The pattern of subscale scores obtained in this data entry task resembled those obtained from typical sedentary work tasks, such as cash registering and proofreading (Ahsberg, 2000).

Neurophysiological Basis of Subjective Feelings

Conscious feeling is mediated by the cerebral cortex, in part by the cingulate cortex and the frontal lobes (Kandel, Schwartz, & Jessell, 2000). Emotional states are mediated by a family of peripheral, autonomic, endocrine, and skeletomotor responses. These responses involve subcortical structures, namely, the amygdala, the hypothalamus, and the brain stem. In the brain stem, the nucleus of the solitary track directly innervates the heart and regulates and responds to changes in heart rate and blood pressure (Kandel, Schwartz, & Jessell, 2000). The hypothalamus, which forms part of the ascending reticular activating system (ARAS), is likely to be associated with regulation of the state of its activity (Zomeren & Wiebo, 1994). Since the ARAS plays a decisive role in activating the cortex, any physiological change is therefore expected to influence the activation as well as the interpretation of the emotion (Zomeren & Wiebo, 1994). As a result, as information processing progresses, mental effort, which suppresses heart rate variability and cortical arousal, which in turn influence these subcortical systems, is likely to be associated with the individual's emotion of subjective fatigue.

Summary of Fatigue – Development of Further Hypotheses

Although the fatigue ratings did not differ between the two schedules, the differential pattern of task performance does suggest some differences in the underlying internal regulation across time on task. It was expected that if the subjects' subjective feelings were related to intense mental activity, then a correlation between fast wave activity (i.e., beta activity) and SOFI-C subscale scores would be substantiated. On the other hand, if the subjective feeling reported by the subjects was associated with a general lowering of arousal levels, then a correlation between slow wave activities (i.e., delta and theta activities) would dominate. From the incoherent performance outcomes and the mediating effects of the rest breaks, it was also expected that the pattern of correlations across time on task and between the two task schedules would differ. The correlation of SOFI-C subscale scores with mental effort and with task performance was also examined. It was expected that if the subjects' feelings of fatigue were related to intensive effort, then a positive correlation with mental effort would show, and vice versa.

Eye Blink Rate

Apart from behavioral indices or subjective measures such as error rates, typing speed, and subjective fatigue, eye blink rate is another objective measure to assess the workload of individuals (Yamada, 1998). The present study, however, shows that the eye blink rate varied largely between individuals, and the change in eye blink rate across time was not prominent enough to draw conclusions. Schlote, Kadner, and Freudenthaler (2004) also reported high interindividual variability and distinct patterns of eye blink rates in people working on VDTs. In the past, eye blink rate has been found to decrease with increasing mental demands (Omori et al., 1996; Wood & Hassett, 1983). However, many studies have demonstrated a confusing relationship between blinking and mental work (Stern, Walrath, & Goldstein, 1984). The ambiguity of the results might be due to the particular task content and task demands imposed by the task (Stern, Walrath, & Goldstein, 1984). For example, eye blink rates obtained from a visual search task would differ from those obtained from simple reading because they involve different intensities of sustained visual attention (Wood & Hassett, 1983). Orchard and Stern (1991) also found that eye blink rates during reading are under perceptual and cognitive control. Measures of eye blink rate throughout a course of task engagement have been taken before, but none have been reported in numerical data entry tasks. In general, performance of a single task for long periods is often accompanied by blink rate increases, probably because of the reduction of arousal and the interactive effects of activation, effort, fatigue, and attention (Stern, Walrath, & Goldstein, 1984). Carpenter (1948) measured blink rate during a 2-hour vigilance task and found systematic increases in blink rate as a function of time. Similar increases in blink rate as a function of time on task have been reported during reading (Hoffman, 1946; Lukiesh, 1947; Tinker, 1946) and automobile driving (Pfaff, Fruhstorfer, & Peter, 1976). In the present experiment, the eye blink rate was compared between the same tasks, which differed only in their work-rest schedule. As a result, a confounding effect from varying task demands is not likely to exist. Hence, if the eye blink rate reflects mental processes across time on task, then it should demonstrate longitudinal changes or group differences, because task performance implies that the mental processes differed between the two schedules, especially in the afternoon. However, the results do not reflect any of the above speculations. It is most likely that the task demands imposed by the numerical data entry were inadequate to bring about large differences in eye blink rates of this group of subjects.

Acosta, Gallar, and Belmonte (1999) demonstrated that reduction of eye blink frequency elicited by the performance of a visual task with a computer appears to depend on central neural mechanisms and the sensation of discomfort an individual has on the task. This kind of eye blink, called involuntary blinking, takes place during waking hours without one's actually being aware of it and differs from reflex blinking, which occurs when something touches the cornea and stimulates the corneal nerves (Patel et al., 1991). Involuntary eye blinks are thought to be triggered by a mechanism within the basal ganglia and the reticular formation (Patel et al., 1991; Walsh & Hoyt, 1969). This is thought to be why attention, emotion, and degree of difficulty of a visual task affect the blink rate. However, the validity of eye blink rates in reflecting mental load and attention has been challenged in the past. The reason is because different task content or cognitive processes involved in the task often lead to different results of eye blink rates (Patel et al., 1991).

Summary of Eye Blink Rates

In this study, the results of the eye blink rates do not indicate significant differences or systematic patterns across task sessions. Moreover, owing to the fact that theoretical background concerning eye blink rates in mental load is weak, the present study do not intend to do further correlational analysis of the eye blink data with the neurophysiological variables (the EEG spectral powers and mental effort). However, readers who are interested in the results of their correlations can refer to Appendix XII.

Plan of Chapters VI and VII

The following chapters describe further analysis of the association between the behavioral and neurophysiological variables obtained in this study. The analysis begins with the SOFI-C (Chapter VI), because its behavioral results are the most consistent with past studies among the three behavioral variables. Correlational analyses with task performance are presented in Chapter VII.

CHAPTER VI

PERCEIVED FATIGUE AND NEUROPHYSIOLOGICAL CORRELATES

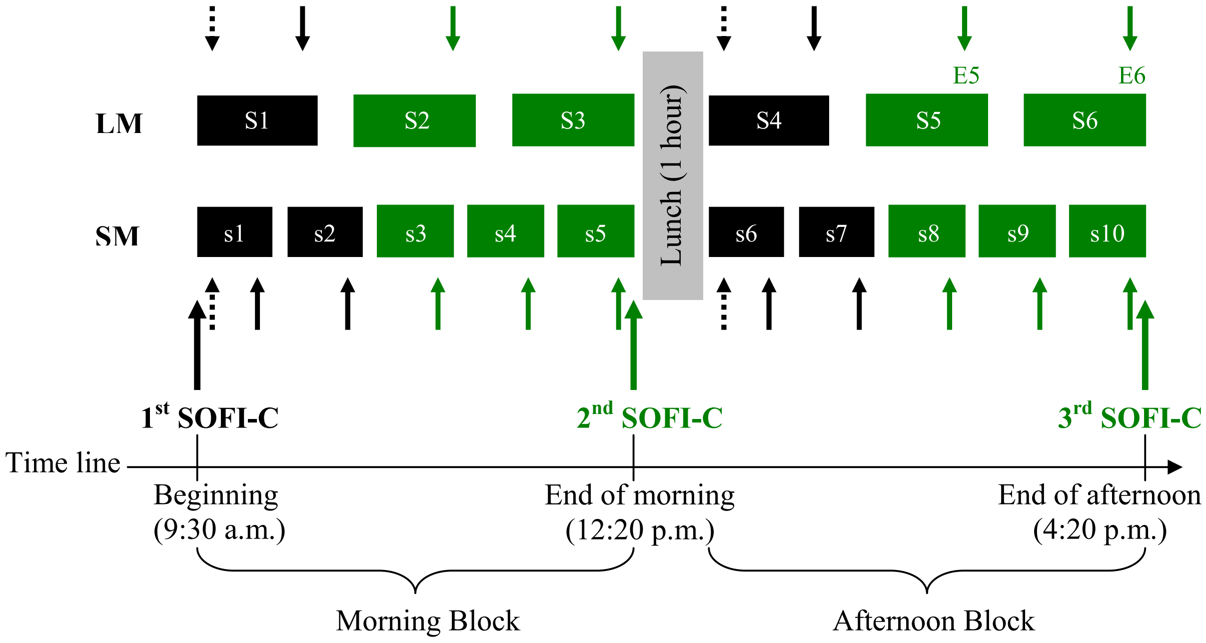
The results and discussion of the behavioral variables, that is, perceived fatigue, performance on task, and eye blink rate, were presented in Chapter V. The following three chapters report further analyses of the relationship between the behavioral variables and neurophysiological variables, namely the EEG and ECG data. The purpose of presenting further analysis is to guide the reader in further understanding the changes, if any, that are occurring within the cortical and subcortical systems, which could shed light on the mechanisms underlying these behavioral observations. The findings are further useful for refining the theoretical model on prolonged information processing.

Subjective fatigue reflected from the SOFI-C shows that the feeling of fatigue increased across time. Although no differences were found on the subscale scores between the two task schedules, a steady increase in the SOFI-C subscale scores across time prompted further investigation into the characteristics of these increases. The correlations of the SOFI-C with the EEG and ECG data are here presented and discussed.

Measurement Regimen of EEG and ECG

Figure 6.1 shows the measurement regimen of both the behavioral and neurophysiological variables. Both the diagram and the abbreviations are the same as those presented in Chapter V (pp. 83-84), except that the timeline and the measurement of the EEG and ECG are incorporated into this diagram.

Figure 6.1. Schematic diagram showing the measurement regimen of both behavioral and neurophysiological variables.



Keys:

LM (longer and less frequent rest schedule) = 50-minute task session and 10-minute rest break.

SM (shorter and more frequent rest schedule) = 30-minute task session and 5-minute rest break.

Rectangles are task sessions (S1 – S6 for LM; s1 – s10 for SM).

Small arrows indicate the simultaneous measurement of the 5-minute EEG and the 5-minute ECG in each of the two schedules. Arrows with dotted lines represent the baseline measurements of the EEG, one for the morning block and the other for the afternoon block, which were divided by their subsequent EEG data in the morning and the afternoon, respectively.

EEG and ECG (0.1 Hz HRV)

Both the EEG and the ECG signals were recorded concurrently using the WindataQ program. For both schedules, a continuous 5-minute recording of the EEG signals and the ECG signals were captured within the last 10 minutes of each task session. There were thus a total of 6 sets of continuous EEG and ECG signals in the LM schedule and a total of 10 sets of continuous EEG and ECG signals in the SM schedule. Additional baseline EEG signals were measured for 3 minutes within 10 minutes after the subject had commenced the task at the beginning of the first session of the morning block, giving a morning baseline (i.e., S1 for the LM schedule and s1 for the SM schedule), and the afternoon block, giving an afternoon baseline (i.e., S4 for the LM schedule and s6 of the SM schedule). The EEG signals were processed to produce a spectral power at the designated band widths described in Chapter IV (pp. 74-75). All spectral powers were logged to reduce skewness. Normalization was done by dividing the EEG spectral power obtained in the morning sessions by the morning baseline and that obtained in the afternoon sessions by the afternoon baseline. For the ECG signals, the 0.1 Hz HRV was calculated (described in Chapter IV pp. 78). Since normalization was done using the total spectral power obtained at the time of the recording, an extra baseline measurement was not necessary. Nevertheless, all normalized HRV were multiplied by -1. In this way, a higher spectral power could be directly interpreted as representing higher mental effort.

Data Analysis on Correlates

A Pearson product-moment correlation (*r*), was performed between the SOFI-C and all other variables in each task schedule. The correlation variables were established especially for the morning and afternoon blocks. Since there were a number of repeated measurements on a single variable within these two blocks, the significance levels of the analyses were further adjusted. In the LM schedule, one SOFI-C was administered at the end of the block, while three repeated measurements were obtained for the EEG, HRV, and task performance. The significance level was thus adjusted to $p < 0.017$ (i.e., $p < 0.05/3$). The adjustment did not take into account the repetition between the morning block and the afternoon block, because the behavioral result revealed differences in task output and subjective fatigue, which suggested that these two blocks might be characterized by the inherent processing of the individual. The same rationale was applied in the SM schedule. Since there were five repeated measurements of EEG, HRV, task performance, and eye blink in the SM schedule, the significance level was adjusted to $p < 0.01$ (i.e., $p < 0.05/5$).

Since the SOFI-C scores were obtained at the end of the morning and afternoon blocks, only the measurements taken closest to the end of the task blocks were included in the correlational analysis. The measurements taken in the last two sessions of a block (i.e., S2 and S3 in the morning and S5 and S6 in the afternoon) were selected for the LM schedule, and only those in the last three sessions (i.e., s3, s4, and s5 in the morning and s8, s9, and s10 in the afternoon) were selected in the SM schedule (Figure 6.1).

Results

All correlations with r equal to or greater than 0.50 are presented in Table 6.1. Correlations that are statistically significant at the adjusted p level are marked in the table.

Correlations with EEG Spectral Power

LM Schedule

In the morning task block, the SOFI-C was found to correlate negatively with the normalized EEG spectral powers at their bilateral occipital areas (O_1 & O_2) in S2. Among the SOFI-C subscales, most of the significant correlations were found with the Sleepiness (SL) and Physical Discomfort (PD) subscales, *r* ranging from -0.53 to -0.65. For the EEG spectral power, almost all significant correlations were with the beta wave (β_1, β_1, & β_3). Details are shown in Table 6.1.

Table 6.1. *Correlation between the SOFI-C measured at the end of morning and the EEG spectral power in S2 of the LM schedule*

Morning session	SOFI-C subscale	Normalized EEG spectral power	
		Left occipital (O_1)	Right occipital (O_2)
S2	SL	α_2: $r = -0.51, p = 0.022$	α_2: $r = -0.52, p = 0.019$
		β_1: $r = -0.58, p = 0.007$**	β_1: $r = -0.60, p = 0.005$**
		β_2: $r = -0.55, p = 0.012$**	β_2: $r = -0.62, p = 0.004$**
		β_3: $r = -0.58, p = 0.007$**	β_3: $r = -0.65, p = 0.002$**
	PD	α_2: $r = -0.53, p = 0.017$**	α_2: $r = -0.52, p = 0.020$
		β_1: $r = -0.57, p = 0.009$**	β_1: $r = -0.56, p = 0.010$**
		β_2: $r = -0.57, p = 0.009$**	β_2: $r = -0.57, p = 0.008$**
		β_3: $r = -0.58, p = 0.007$**	β_3: $r = -0.64, p = 0.003$**
	LM		β_3: $r = -0.53, p = 0.016$**
	LE	β_1: $r = -0.50, p = 0.024$	β_1: $r = -0.52, p = 0.018$
			β_3: $r = -0.55, p = 0.012$**

** adjusted significant p level at $p < 0.017$

In the afternoon task block, conversely, the SOFI-C was found to correlate positively with the normalized EEG spectral power at the left frontal area (F_3) in S5 and S6. Among the SOFI-C subscales, most of the correlations were found with the Sleepiness (SL), Lack of Motivation (LM), and Lack of Energy (LE) subscales, which are related to the mental aspects of fatigue, r ranging from 0.53 to 0.70. For the EEG spectral power, almost all significant correlations were with the delta (δ) and theta (θ) waves, which are slow waves. Details are shown in Table 6.2.

Table 6.2. *Correlation between the SOFI-C measured at the end of afternoon and the EEG spectral power in S5 and S6 of the LM schedule*

Afternoon session	SOFI-C subscale	Normalized EEG spectral power Left frontal (F_3)
S5	SL	δ: $r = 0.53, p = 0.016$** θ: $r = 0.59, p = 0.007$**
	LM	θ: $r = 0.58, p = 0.008$** α_2: $r = 0.66, p = 0.002$**
S6	SL	δ: $r = 0.70, p = 0.001$** θ: $r = 0.54, p = 0.014$**
	LM	θ: $r = 0.57, p = 0.009$**
	LE	δ: $r = 0.66, p = 0.001$** θ: $r = 0.58, p = 0.008$**

** adjusted significant p level at $p < 0.017$

SM Schedule

The SOFI-C subscale scores correlated with the normalized EEG spectral power positively in the morning task block, *r* ranging from 0.56 to 0.71, but negatively in the afternoon block, *r* ranging from -0.56 to -0.63. In s3 of the morning task block, the Physical Discomfort (PD) subscale score was found to positively correlate with the theta (θ), alpha1 (α_2), beta1 (β_1), beta2 (β_2) and beta3 (β_3) waves at the left occipital area (O_1). In s5 of the morning task block, the Physical Discomfort (PD) subscale score was found to positively correlate with the theta (θ) wave at the bilateral occipital (O_1 & O_2) and left frontal (F_3) areas; the Lack of Motivation (LM) subscale score was found to positively correlate with the slow waves, which are the delta (δ) and theta (θ) waves, at the left frontal area (F_3) only. In the afternoon, all SOFI-C subscales except the Physical Exertion (PE) subscale were found to negatively correlate with the slow waves [delta (δ) and theta (θ) waves] at the right frontal (F_4) and occipital (O_2) areas, *r* ranging from -0.56 to -0.63. Details of their correlations are shown in Tables 6.3 and 6.4.

Table 6.3. *Correlation between the SOFI-C measured at the end of morning and the EEG spectral power in s3, s4, and s5 of the SM schedule*

Morning session	SOFI[a]	Normalized EEG spectral power Left frontal (F_3)	Left occipital (O_1)	Right occipital (O_2)
s3	PD		θ: $r = 0.69, p = 0.001$** α_1: $r = 0.54, p = 0.015$ α_2: $r = 0.68, p = 0.001$** β_1: $r = 0.60, p = 0.005$** β_2: $r = 0.62, p = 0.004$** β_3: $r = 0.59, p = 0.006$**	δ: $r = 0.56, p = 0.010$** θ: $r = 0.65, p = 0.002$** α_2: $r = 0.53, p = 0.017$
	LM	δ: $r = 0.53, p = 0.017$ θ: $r = 0.52, p = 0.020$		
	LE		β_3: $r = 0.50, p = 0.024$	
	PE		β_1: $r = 0.56, p = 0.011$ β_2: $r = 0.52, p = 0.019$	
s4	SL	δ: $r = 0.53, p = 0.017$		
	PE		β_1: $r = 0.60, p =0.006$** β_2: $r = 0.57, p = 0.009$**	
s5	PD	θ: $r = 0.70, p = 0.001$**	θ: $r = 0.62, p = 0.004$**	θ: $r = 0.64, p = 0.002$**
	LM	δ: $r = 0.56, p = 0.010$** θ: $r = 0.71, p = 0.001$**		

[a] SOFI-C: SL = Sleepiness; PD = Physical Discomfort; LM = Lack of Motivation; LE = Lack of Energy; PE = Physical Exertion

** adjusted significant p level at $p < 0.010$

Table 6.4. *Correlation between the SOFI-C measured at the end of afternoon and the EEG spectral power in s9 and s10 of the SM schedule*

Afternoon session	SOFI[a]	Normalized EEG spectral power: Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
s9	SL	δ: $r = -0.56, p = 0.010$** θ: $r = -0.60, p = 0.006$**		
	LM	δ: $r = -0.62, p = 0.003$** θ: $r = -0.62, p = 0.004$**		
s10	SL	θ: $r = -0.58, p = 0.007$**	δ: $r = -0.53, p = 0.017$	
	LM	θ: $r = -0.63, p = 0.003$**		
	PD		θ: $r = -0.51, p = 0.022$	
	LE		δ: $r = -0.54, p = 0.015$	δ: $r = -0.59, p = 0.006$**

[a] SOFI-C: SL = Sleepiness; PD = Physical Discomfort; LM = Lack of Motivation; LE = Lack of Energy; PE = Physical Exertion

** adjusted significant p level at $p < 0.010$

Correlations with Mental Effort (0.1 Hz HRV × -1)

There were no significant correlations revealed between the SOFI-C subscales and the 0.1 Hz HRV in both the LM and SM schedules. Details of the results can be found in Appendix XII.

Discussion

Overview of Results

Subjective fatigue was found to correlate extensively with the EEG spectral power. At the middle of the LM morning schedule, the subjects' SOFI-C subscales, except the Physical Exertion subscale scores, showed a moderate and negative correlation with their beta activity, (i.e., fast wave) at the bilateral occipital areas. In the middle of the afternoon, that is, Session 5, the Sleepiness and Lack of Motivation subscale scores showed moderate and positive correlations with delta, theta, and alpha activity, (i.e., slow wave) at the left frontal area. When the subjects progressed to the end of the afternoon, that is, Session 6, the Sleepiness, Lack of Motivation, and Lack of Energy subscales showed strong positive correlations with delta and theta activities. In the SM schedule, conversely, the SOFI-C subscale scores correlated with the EEG spectral power positively in the morning and negatively in the afternoon. In the middle of the morning, that is, Sessions 3 and 4, the Physical Discomfort subscale scores showed moderate positive correlations with all EEG wavebands at the left occipital area, while the Physical Exertion subscale score showed moderate correlations with beta activity. When the subjects progressed on the task by the end of the morning session, the Physical Discomfort and the Lack of Motivation subscale scores showed fairly strong positive correlations with delta and theta activities at the left frontal and bilateral occipital areas. In the end of the afternoon, that is, Sessions 9 and 10, the Sleepiness, Lack of Motivation, and Lack of Energy subscale scores showed moderate negative correlations with delta and theta activities at the right frontal and occipital areas. No correlation, however, was observed between the SOFI-C subscale scores and mental effort as measured by HRV.

Neurophysiological Correlates of Perceived Fatigue

Studies reporting correlations between EEG and perceived fatigue are mostly found in the field of transportation (Lai & Craig, 2001). In driving studies, it has been demonstrated that state and trait anxiety are significantly associated with delta activity at the occipital and central areas during transition to fatigue (Lai & Craig, 2002). Reduced alertness has been found associated with elevated delta and theta activity at the occipital and central areas of the cortex (Lal & Craig, 2000). Lai and Craig (2002) also observed that during the onset of fatigue, delta and theta activity are present mostly in the frontal, central, and parietal areas of the brain with some anterior alpha and posterior beta. Other researchers have also reported that during drowsiness, increases in slow wave activity (delta and theta) occur at the centrofrontal and occipital areas (Santamaria & Chiappa, 1987). These reports highlight the suggestion that delta and theta activity are indicators of mental fatigue and are largely related to psychological assessment of fatigue throughout a highly vigilant and monotonous task (Lal & Craig, 2000, 2002).

Differential Neural Processes Associated with the LM and SM Schedules

In the LM schedule of the present study, there were two episodes of significant correlations between the EEG spectral power and SOFI-C subscales scores, one in the middle of the morning and another at the end of the afternoon. The latter episode occurred at the end of Sessions 5 and 6 (the last 2 hours in the afternoon), where high delta and theta activity at the left frontal area was found to correlate with high subscale scores of Sleepiness, Lack of Motivation, and Lack of Energy. In Lal and Craig’s (2002) study, maximum delta and theta activity at frontal regions was found when fatigue developed. Therefore, it is likely that in the last 2 hours of the afternoon task block, the subjects who felt more fatigue were experiencing a greater cortical manifestation of mental fatigue. Moreover, the subjective fatigue that the subjects experienced originated from the mental aspect of fatigue (Sleepiness and Lack of

Motivation) and the general description of fatigue (Lack of Energy) (Ahsberg, 2000). In contrast, the former episode occurred at end of Session 2 (the 2nd hour of the morning block), where most beta activity at the occipital areas was found to correlate with all subscales except the Physical Exertion subscale. It appears that subjects who felt less fatigue demonstrated higher beta activity at the bilateral occipital areas. In VDT studies, Floru and Cail (1987), Floru et al., (1985) and Hayashi, Chikazawa, and Hori (2004) have captured EEG signals at the occipital regions. It has been shown that brain activation in occipital areas represents general vigilance, while the presence of beta activity suggests intensive mental activity in response to investment of mental effort (Floru & Cail, 1987; Floru et al., 1985). In this study, the subjects who were willing to put forth more intensive mental activity reported less perceived fatigue in the morning. This phenomenon suggests an efficient utilization of energy rather than mental fatigue. According to Makeig and Jung (1996), increases in beta activity do not represent mental fatigue unless the increase is coupled with increases in theta activity. It is interesting to note that the brain activations were associated not only with the general description and mental aspects of fatigue, but also with Physical Discomfort, which is a physical aspect of fatigue (Ahsberg, 2000). The reason could be that data entry involves motor action, which would be executed more vigorously under effortful task engagement.

In the SM schedule, there are similarly two episodes of significant correlations between the EEG spectral power and the SOFI-C subscales scores. However, the manifestation of neurocorrelates differs from that in the LM schedule. At the end of Session 3 of the morning task block, the Physical Discomfort subscale, a physical aspect of fatigue, was found to correlate with theta, alpha, and beta activities at the left occipital area, and delta and theta activities at the right occipital area. It appears that subjects who felt more discomfort and perceived fatigue demonstrated higher delta, theta, alpha, and beta activity at the occipital areas. Kiroy, Warsawskaya, and Voynov (1996) reported a significant increase of slow (delta and theta) and fast (beta) activities at the end of a continuous calculation task in a group of highly motivated adults. They interpreted the results as a deterioration of general brain state activity caused by prolonged mental work and the simultaneous additional brain activation needed to provide a sufficient vigilance level and a successful task performance (Kiroy, Warsawskaya, & Voynov, 1996). Lal and Craig (2002) found that after subjects had driven for 2 hours, their delta, alpha, and beta activity correlated with fatigue-inertia, a measure of mental state in the Profile of Mood States (POMS) for assessing subjects' resistance to fatigue on a task. According to Lal and Craig (2002), the fatigue-inertia may describe the phenomenon observed by Kiroy et al. (1996). Hence, it is plausible that the subjects' higher perceived fatigue, specifically bodily discomfort, is related to their act of investing higher brain activation to resist the general deterioration of the brain state. Based on Hockey's (1997) and Gaillard's (1993) information processing theories, this is a compensatory act, and subjects reporting high perceived fatigue are thought to have mobilized extra energy, which is effortful and contributes to energy depletion in the later stages of task engagement. At the end of Session 4, beta activities at the occipital area were found to correlate with the Physical Exertion subscale scores. This phenomenon is similar to that which occurred in the LM morning episode. Hence, subjects who put forth more intense mental activity tended to report a higher level of perceived fatigue. At the end of Session 5 (the last morning session), the pattern of correlation was very similar to that in the LM afternoon schedule, in which the delta and theta activities correlated positively with the subscale scores. The only difference is that in the SM schedule, only the Physical Discomfort and Lack of Motivation subscales were significantly correlated with the brain activations, and the correlations were comparatively stronger and more extensively spread to the occipital areas. It is likely that the subjects who reported high perceived fatigue were experiencing mental fatigue at the end of the morning. In the afternoon, the correlations only appeared at the last hour of the entire task block. Both delta and theta activities at the right frontal were found to correlate negatively with Sleepiness and Lack of Motivation at the end of Session 9, while the delta activity at the right occipital area was found to correlate negatively with the Lack of Energy subscale at the end of Session 10. Correlation of delta activity has been reported in Lal and Craig's (2002) study. They found that changes in delta activity are inversely related to vigor-activity, a measure of mental state in the POMS for assessing the perceived energy levels of subjects (Lal & Craig, 2002). Hence, it seems that the greater the change in delta activity, the less energy the subjects have. In this study, since the spectral power was normalized by the spectral power captured at the baseline, the greater the normalized value would mean the greater the deviation from the baseline. Hence, it appears that subjects who reported higher perceived fatigue could have been in a higher energy state. One possible explanation is that the subjects in the SM group regulated their energy level to an optimum to facilitate task performance in the last hour of the afternoon task block. This postulation is supported by a comparatively higher typing speed of the subjects at end of the SM schedule (the typing speed in Session 10 was faster than in Session 1 of the SM schedule, while the typing speed in Session 10 of the SM schedule was faster than in Session 6 of the LM schedule).

For both the LM and SM schedules, subjects reported an increase in perceived fatigue across time with no differences in the rate of change between the two schedules. Examination of their neurophysiological correlates indicates that the underlying neural processes relating to the perceived fatigue might have differed in the subjects between the two schedules. When the SOFI-C subscale scores were relatively lower by end of the morning, the SM subjects who showed a significant positive correlation between SOFI-C subscales scores and fast and slow wave activities at the frontal and occipital areas would have experienced cortical manifestation with measures of mental fatigue, while LM subjects would not. In the middle of the SM morning block, a high level of perceived fatigue among the subjects was likely related to their putting forth more effort to counteract the deterioration of brain activation. This could have contributed to the feeling of mental fatigue at end of the morning. In the SM afternoon schedule, however, there were no significant neurophysiological correlates with measures of mental fatigue, though subjects expressed a high level of perceived fatigue. This probably is also due to the comparatively higher energy dissipation when performing on the task during the last hour of the afternoon session. In the LM schedule, conversely, the subjects showed no significant neurophysiological correlates with measures of mental fatigue until reaching the last 2 hours of the afternoon session. For the LM morning schedule, the significant neurophysiological correlates suggest that the perceived fatigue of the subjects was related to their intense mental processing for meeting the task demands rather than level of fatigue. Hence it is plausible that the perceived fatigue in the LM schedule was associated with efficient regulation of mental resources and investment of mental effort for task performance in the morning. In the afternoon, on the other hand, the neurophysiological correlates with the SOFI-C are mostly measures of drowsiness. Therefore, the fatigue associated with subjects in the LM afternoon schedule is characterized by reduced arousal rather than intensive mental activation.

It is also interesting to note that there are no significant neurophysiological correlates with the scores on Sleepiness. According to Higuchi et al. (2001), repeated vigilance tasks, such as discrimination tasks, increase ratings on sleepiness, alpha activity, and reaction time on task. They found that alpha activity is a sensitive physiological indicator for assessing sleepiness during vigilance tasks. In this study, the subjects reported subjective sleepiness, which increased across time. However, the perceived fatigue, and particularly the subscale that measured the level of sleepiness, show no significant correlations with the subjects' alpha activity. This suggests that the subjects' feeling of sleepiness might not necessarily have a physiological origin. Apart from this, other researchers have argued that left frontal activity is associated with positive emotions, while right frontal activity is associated with negative emotions (Cacioppo, 2004). The lateralization of feelings could be generalized to all kinds of tasks (Gevins et al., 1979). In this study, EEG activities are found in both the left and right frontal areas. The results may indicate that data entry, because of its simple operations, is a fairly neutral task in terms of emotion. In addition, low frequencies, such as delta, are reportedly influenced by artifacts of the experimental task, such as breathing and movement of subjects (Gasser, Bacher, & Steinberg, 1985). Nonetheless, delta activity has been reported to be a sensitive neurophysiological indicator of fatigue (Lai & Craig, 2002, 2005). In the present study, the subjects were engaged in a data entry task that did not require large body movements or vigorous activity that could have confounded the slow wave activity. The significant correlations between delta activity and perceived fatigue further support the findings on the subjects' level of fatigue.

CHAPTER VII

TASK PERFORMANCE AND NEUROPHYSIOLOGICAL CORRELATES

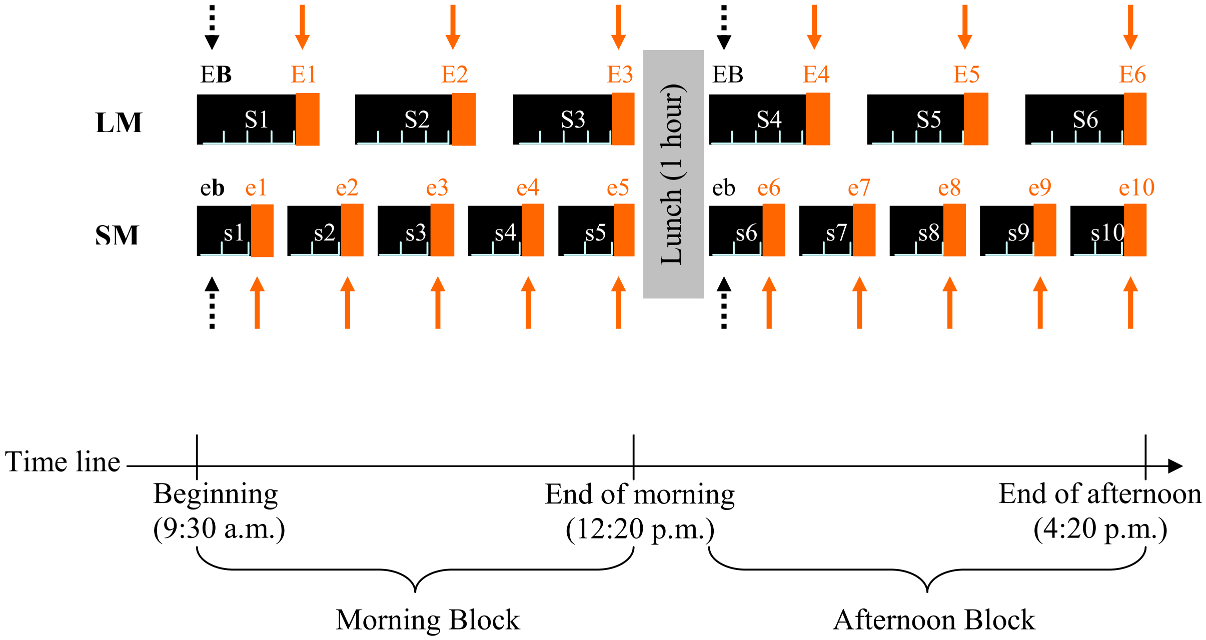
This chapter is the counterpart of Chapter VI on describing the neurophysiological correlates with performance on the data entry task. The subjects' performance on the task was reanalyzed using a different data management strategy. This enabled a direct correlational study with the EEG spectral power and the 0.1 Hz HRV. The findings could shed light on the mechanisms behind the performance observations, and are further useful for refining the theoretical model on prolonged information processing.

The analysis of the task performance in Chapter V showed that the subjects' error rate did not vary systematically across time, while the speed of data entry increased across the SM morning and afternoon sessions but not the LM sessions. In this chapter, the performance of subjects is studied in greater depth by correlating it with the EEG and HRV data. However, since the EEG and HRV were captured within the last 10 minutes for only 5 minutes, the task performance within each session has to be further broken down into 10-minute segments so that the correlations between variables can be more reasonably established. The segmentation of the task performance is based on the assumption that the speed of data entry within any session did not vary significantly. Such an assumption has been verified by a follow-up study, in which another 20 subjects were recruited to compare with the LM rest schedule task. In this study, both speed and accuracy were recorded in every 10-minute segment. The details of the follow-up study and its results are summarized in Appendix XI.

Measurement Regimen

All variables to be analyzed in this section and the procedure of their measurement have already been described in Chapters V and VI. Below is a schematic diagram summarizing the measurements selected for analysis. The diagram is exactly the same as the one presented in Chapter VI, except that the error rate in each session has been subdivided into several 10-minute segments. Details on the segmentation are described as follows.

Figure 7.1. Schematic diagram showing the measurement regimen of segmented error rate and neurophysiological variables.



Keys:

LM (longer and less frequent rest schedule) = 50-minute task session and 10-minute rest break.

SM (shorter and more frequent rest schedule) = 30-minute task session and 5-minute rest break.

Rectangles in orange represent the error rate in the last 10-minute duration, which are correlated with the EEG spectral power and the HRV at the same time of measurement (arrows in orange) in each of the two schedules.

Segmentation of the Task Performance

The total number of data entered by each subject was counted by the tailor-made macro program in Microsoft Excel. In the LM schedule, the total number of data entered in each session was divided by 5 to estimate the amount of data entered if counted every 10 minutes. In the SM schedule, the total number of data entered was divided by 3 to produce three to estimate the 10-minute typing. The number of incorrect entries in the 10-minute subsession was counted and then divided by the estimated data entered during the subsession, multiplied by 100. In this way, the percentages of error rate per every 10-minute subsession were calculated for all task sessions in the two schedules.

Data Analysis

Since the error rate was segmented into consecutive 10-minute subsessions, the changes across all subsessions in each of the two task schedules were examined. Correlations between the variables were reported.

Across-time Changes

A three-way repeated measures ANOVA was performed on the segmented error rate in each of the two schedules. In the LM schedule, the repeated measures ANOVA was set up with 2 Blocks × 3 Sessions × 5 Subsessions to encapsulate all 10-minute subsessions throughout the entire task. In the SM schedule, the repeated

ANOVA was set up with 2 Blocks × 5 Sessions × 3 Subsessions.

Correlation

A Pearsons product-moment correlation (*r*) was conducted on the 10-minute error rate and typing speed with all other variables at the end of each task session in each of the two schedules. The correlations were performed separately for the morning and afternoon task blocks. The rationale behind the adjustment of the *p* level in each of the morning and afternoon sessions has been discussed in Chapter VI (pp. 128). The significant *p* level for the correlation with each variable in the LM schedule was adjusted to $p < 0.0056$ (i.e., $p < 0.05/9$, a bivariate between three measurements of the error rate and three measurements of the EEG spectral power/HRV), while that in the SM schedule was adjusted to $p < 0.002$ (i.e., $p < 0.05/25$, a bivariate between five measurements of the error rate and five measurements of the EEG spectral power/HRV).

Results

Tables 7.1 and 7.2 summarize the descriptive statistics of the error rates of the subjects across each 10-minute data entry segment in the LM and SM schedules. They show that, while the error rates were very low in each subsession, the standard deviations of the error rates were comparatively large.

Table 7.1. *Mean (SD) of error rates in each 10-minute task segment in the LM schedule*

Block	Session (S)	Error rate of subsessions[1] (%)				
		1	2	3	4	5
Morning	S1	1.03 (1.40)	1.03 (1.20)	0.98 (1.04)	1.18 (1.56)	0.69 (0.77)
	S2	0.80 (0.83)	0.51 (0.77)	0.63 (0.89)	0.16 (0.22)	0.46 (0.50)
	S3	0.46 (0.50)	0.64 (0.71)	0.57 (0.55)	0.58 (0.63)	1.00 (1.81)
Afternoon	S4	0.44 (0.67)	0.70 (0.89)	0.44 (0.67)	0.95 (1.53)	0.52 (0.64)
	S5	0.36 (0.53)	0.81 (0.97)	0.70 (1.18)	0.63 (0.33)	0.65 (0.69)
	S6	0.61 (0.63)	0.51 (0.78)	0.24 (0.34)	0.67 (0.89)	0.91 (1.12)

[1] Each subsession is a 10-minute segment

Table 7.2. *Mean (SD) of error rates in each 10-minute task segment in the SM schedule*

Block	Session (s)	Error rate of subsessions[1] (%)		
		1	2	3
Morning	s1	0.68 (0.81)	0.66 (0.69)	0.87 (1.03)
	s2	0.94 (0.96)	0.67 (0.78)	0.94 (0.84)
	s3	0.97 (1.00)	1.04 (1.17)	0.56 (0.82)
	s4	0.76 (0.74)	0.39 (0.39)	0.72 (1.04)
	s5	0.78 (1.01)	0.77 (0.71)	0.93 (0.92)
Afternoon	s6	1.02 (0.86)	0.70 (0.90)	0.50 (0.65)
	s7	0.65 (0.60)	0.70 (0.93)	0.45 (0.76)
	s8	0.47 (0.63)	0.72 (0.61)	0.76 (1.17)
	s9	0.40 (0.61)	0.43 (0.42)	0.96 (2.22)
	s10	0.84 (1.39)	0.46 (0.54)	0.63 (1.08)

[1] Each subsession is a 10-minute segment

Across-time Changes

LM Schedule

A three-way repeated measures ANOVA (2 Blocks × 3 Sessions × 5 Subsessions) revealed a significant Block × Session interaction effect, $F(2,38) = 4.18$, $p = 0.023$, and Session × Subsession interaction effect, $F(8,152) = 2.24$, $p = 0.028$. A further two-way repeated measures ANOVA (Session × Subsession) on each of the two blocks revealed a significant main effect on Session, $F(2,38) = 5.38$, $p = 0.009$, in the morning block. The error percentages appear to be higher in S1 than S2 (marginally significant with $p = 0.054$, with Bonferroni adjustment). There were significant linear and quadratic trend effects on the error rate, $F(1,19) = 4.82$, $p = 0.041$ and $F(1,19) = 6.20$, $p = 0.022$, respectively. Figure 7.2 shows the percentage errors with a decrease in error rates from S1 to S2. Error rates increased from S2 to S3. A one-way repeated measures ANOVA also indicated significant linear and quadratic effects on the error rate, $F(1,19) = 4.83$, $p = 0.041$, and $F(1,19) = 4.88$, $p = 0.040$, respectively. There were, however, no significant effects revealed in the afternoon block, $F(2,38) = 0.02$, $p = 0.937$ to $F(8,152) = 1.59$, $p = 0.132$ (Figure 7.2).

SM Schedule

A three-way repeated measures ANOVA (2 Blocks × 5 Sessions × 3 Subsessions) revealed no significant results, $F(1,19) = 1.85$, $p = 0.190$ to $F(2,38) = 0.07$, $p = 0.933$. Figure 7.3 shows a graphical representation of the error rate.

Figure 7.2. Plot of subsession error rates in the LM schedule (mean ± 1 S.E.); S1a represents the first 10 minutes of S1, S1b represents the second 10 minutes, S2a represents the first 10 minutes of S2, etc.

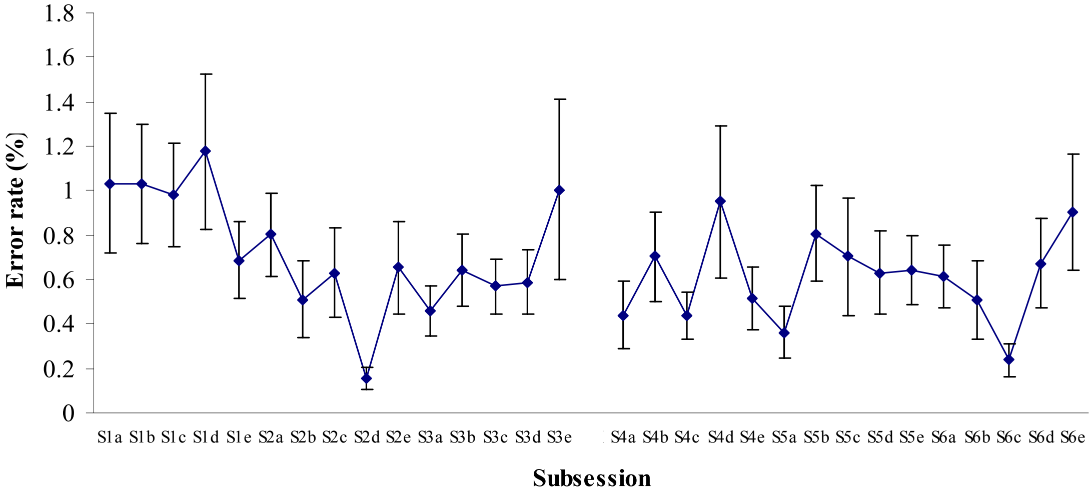
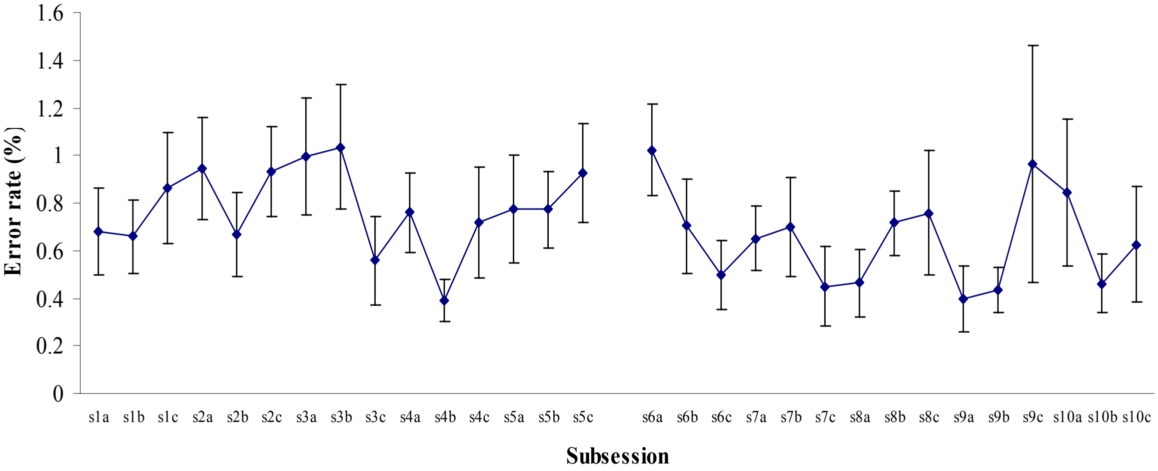


Figure 7.3. Plot of subsession error rates in the SM schedule (mean ± 1 S.E.); s1a represents the first 10 minutes of s1, s1b represents the second 10 minutes, s1c represents the third 10 minutes; s2a represents the first 10 minutes of s2, etc.



Correlations with EEG Spectral Power

LM Schedule

No significant correlations were revealed between the error rates and the EEG spectral power. Details on their correlations are listed in Appendix XII. For the speed of data entry, significant correlations were found in the S3 in the morning block and S5 in the afternoon block. In the S3 of the morning, the speed of data entry was positively correlated with beta2 and beta3 activities at the left occipital site (O_1) (r = 0.59), while in the S5 of the afternoon, the speed of data entry was negatively correlated with delta activity at the right frontal site (F_4) (r = -0.60). Details of the correlations are shown in Table 7.3.

Table 7.3. *Correlations between speed of data entry in the last 10-minute session and the EEG spectral power in all task sessions of the LM schedule*

Session	Normalized EEG spectral power			
	Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
S2	$\beta_1 : r = 0.53$, $p = 0.017$ $\beta_2 : r = 0.57$, $p = 0.008$ $\beta_3 : r = 0.55$, $p = 0.013$			
S3	$\beta_1 : r = 0.54$, $p = 0.014$ $\beta_2 : r = 0.53$, $p = 0.017$ $\beta_3 : r = 0.50$, $p = 0.024$		$\alpha_1 : r = 0.52$, $p = 0.020$ $\beta_1 : r = 0.53$, $p = 0.015$ $\beta_2 : r = 0.59$, $p = 0.006$**	$\beta_1 : r = 0.53$, $p = 0.017$ $\beta_2 : r = 0.51$, $p = 0.021$ $\beta_3 : r = 0.53$, $p = 0.016$

		β_3 : $r = 0.59$, $p = 0.006$**
S5	δ : $r = -0.60$, $p = 0.005$** β_1 : $r = -0.56$, $p = 0.010$ β_2 : $r = -0.48$, $p = 0.032$ β_3 : $r = -0.47$, $p = 0.037$	

** adjusted significant p level at $p < 0.006$ (marginally significant at $p < 0.0056$)

SM Schedule

Error rates were found to positively correlate with the beta wave (fast wave) at the left occipital area (O_1) at around the middle of the entire morning block (r ranging from 0.62 to 0.63) (Table 7.4). No significant correlation, however, was obtained in the afternoon block (details can be found in Appendix XII). Significant correlations between the speed of data entry and the EEG spectral powers were found only in the last session of the afternoon task block (alpha1 and alpha2 activities at the left occipital areas (O_1), with r ranging from 0.64 to 0.70) (Table 7.5).

Table 7.4. *Correlations between the error rates and the EEG spectral power in the morning block (s1, s2, s3, s4, or s5) of the SM schedule*

Morning	Normalized EEG spectral power			
Session	Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
s2	$\theta : r = 0.50$, $p = 0.025$			
s3		$\alpha_1 : r = 0.55$, $p = 0.012$	$\alpha_1 : r = 0.60$, $p = 0.005$ $\beta_1 : r = 0.63$, $p = 0.002$** $\beta_2 : r = 0.54$, $p = 0.015$	
s4	$\alpha_1 : r = 0.51$, $p = 0.023$	$\alpha_1 : r = 0.58$, $p = 0.008$	$\alpha_1 : r = 0.55$, $p = 0.012$ $\beta_1 : r = 0.62$, $p = 0.002$**	

** adjusted significant p level at $p < 0.002$

Table 7.5. *Correlations between typing speed and the EEG spectral power in the afternoon block (s6, s7, s8, s9, or s10) of the SM schedule*

Afternoon	Normalized EEG spectral power	
Session	Left occipital (O_1)	Right occipital (O_2)
s9	$\theta : r = 0.57$, $p = 0.009$ $\alpha_1 : r = 0.51$, $p = 0.022$	$\theta : r = 0.51$, $p = 0.021$ $\alpha_1 : r = 0.56$, $p = 0.010$ $\alpha_2 : r = 0.54$, $p = 0.015$
s10	$\alpha_1 : r = 0.70$, $p = 0.001$**	$\alpha_1 : r = 0.60$, $p = 0.005$

α_2 : $r = 0.64$, $p = 0.002$**	α_2 : $r = 0.56$, $p = 0.010$
β_1 : $r = 0.52$, $p = 0.019$	β_1 : $r = 0.50$, $p = 0.024$

** adjusted significant p level at $p < 0.002$

Correlations with Mental Effort (0.1 Hz HRV × -1)

LM Schedule

The error rate at the end of Session 2 was found to correlate negatively with mental effort (0.1 Hz HRV × -1), $r = -0.64$, $p = 0.002$. No significant correlation was obtained for any task sessions of the afternoon block. Neither was a significant correlation obtained between speed of data entry and HRV. Details on the correlations are listed in Appendix XII.

SM Schedule

No significant correlation was obtained between mental effort (0.1 Hz HRV × -1) and task performance (i.e., both the error rate and the speed of data entry in the last 10 minutes of the task session) in any of the task sessions of both the morning and afternoon blocks. Details of the correlations are listed in Appendix XII.

Variation of the EEG Spectral Powers

This part of the analysis provides additional information on the differences of the EEG spectral powers between the LM and SM schedules and across the task sessions. A five-way repeated measures ANOVA involved a 2 Schedules × 4 Sites × 7 Wavebands × 2 Blocks × 2 Sessions model. The two blocks were the morning and afternoon blocks. The two sessions were S1 and S3 for the morning and S4 and S6 for the afternoon block of LM; and s1 and s5 for the morning and s6 and s10 for the afternoon block of SM. The seven wavebands were delta, theta, alpha1, alpha2, beta1, beta2, and beta3. The four sites were the left and right frontal and occipital areas. In addition, a three-way repeated measures ANOVA with 2 Schedules × 2 Blocks × 2 Sessions was performed on each waveband and site. If the model revealed significant Schedule × Block interactions, then the differences in the EEG spectral powers between the morning and afternoon blocks were examined using a two-way repeated measures ANOVA with 2 Blocks × 3 Sessions for LM and 2 Blocks × 5 Sessions for SM. Lastly, across-sessions variations of the EEG spectral power in each schedule were examined using a one-way repeated measures ANOVA. Post-hoc comparisons were performed using a Bonferroni adjustment because there were too many multiple comparisons.

Comparisons of EEG Spectral Powers Between the LM and SM Schedules

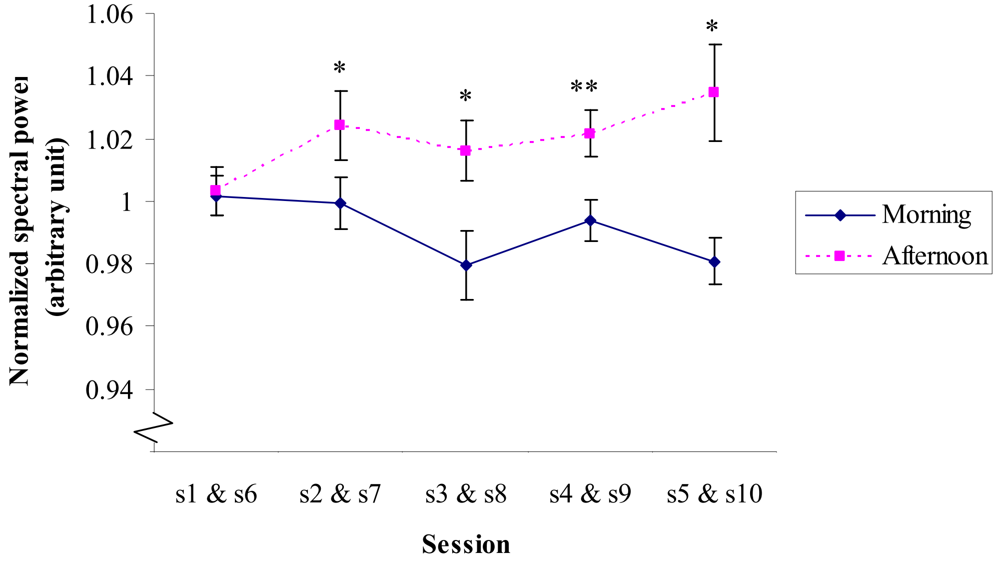
The five-way repeated measures ANOVA (2 Schedules × 4 Sites × 7 Wavebands × 2 Blocks × 2 Sessions) revealed significant main effects on Site, $F(1.92,73.00) = 4.13$, $p = 0.021$; Session, $F(1,38) = 6.34$, $p = 0.013$; Site × Waveband interactions, $F(3.16,119.94) = 6.38$, $p < 0.001$; Schedule × Site × Block interactions, $F(2.15,81.81) = 4.05$, $p = 0.019$; Site × Waveband × Block interactions, $F(3.00,113.82) = 4.59$, $p = 0.005$; and Schedule × Site × Waveband × Block × Session interactions, $F(3.63,138.05) = 2.60$, $p = 0.044$.

The three-way repeated measures ANOVA (2 Schedules × 2 Blocks × 2 Sessions) at each site and waveband revealed significant main effects on Schedule at the right frontal alpha1 and alpha2 activities, $F(1,38) = 3.51$, $p = 0.069$ (marginally significant) and $F(1,38) = 11.05$, $p = 0.002$, respectively. A post-hoc comparison revealed that the LM schedule generally showed higher alpha activities than the SM schedule. The model also revealed a significant main effect on Time at the left frontal theta, alpha2, beta1, beta2, and beta3 activities; right frontal delta, beta1, and beta2 activities; and left occipital beta1, beta2, and beta3 activities, $F(1,38) = 4.14$ to 9.64, $p = 0.004$ to 0.049. There were significant Schedule × Block interactions at the left occipital alpha1 and right occipital alpha1, alpha2, beta1, beta2, and beta3 activities, $F(1,38) = 4.27$ to 6.75, $p = 0.013$ to 0.046; Schedule × Block × Session interactions at the left occipital alpha2 and right occipital alpha2 and beta1, beta2, and beta3 activities, $F(1,38) = 4.40$ to 12.91, $p = 0.001$ to 0.043; and Block × Session interactions at the left occipital alpha2, beta1, and beta2 and right occipital alpha1, alpha2, and beta1 activities, $F(1,38) = 4.40$ to 12.91, $p = 0.001$ to 0.043.

Across-time Changes in EEG Spectral Powers in the LM and SM Schedules

In the SM schedule, a two-way repeated measures ANOVA (2 Blocks × 5 Sessions) revealed a significant main effect on Block at the left occipital alpha2 and right occipital alpha2, beta1, and beta2 activities, $F(1,19) = 4.40$ to 12.58, $p = 0.002$ to 0.049; Session at the right frontal delta, left occipital beta1 and beta2, and right occipital beta1 activities, $F(4,76) = 2.49$ to 3.23, $p = 0.017$ to 0.05; and Block × Session interactions at the left occipital alpha2 and right occipital alpha2, beta1, beta2, and beta3 activities, $F(4,76) = 2.54$ to 3.83, $p = 0.007$ to 0.047. It appears that the EEG spectral powers varied mostly at the occipital areas and within the alpha and beta activities in the SM schedule. Post-hoc comparisons indicated that those alpha and beta activities demonstrating significant interaction effects exhibited the same pattern of variation, with their spectral powers tending to increase across the morning while decreasing across the afternoon sessions. Further paired t tests found that the afternoon sessions showed a higher spectral power than their corresponding morning sessions at the left occipital alpha2 (s10 versus s5), t_{19} = 3.49, p = 0.002; right occipital alpha2 (s10 versus s5, s9 versus s4, s8 versus s3, and s7 versus s2), t_{19} = 2.67 to 3.53, p = 0.002 to 0.015; right occipital beta1 (s10 versus s5), t_{19} = 2.58, p = 0.018; right occipital beta2 (s10 versus s5, s8 versus s3, and s7 versus s2), t_{19} = 2.19 to 2.73, p = 0.013 to 0.041; and right occipital beta3 activities (s10 versus s5, and s7 versus s2), t_{19} = 2.14 and 2.47, p = 0.023 to 0.046, respectively. Figure 7.4 shows a diagrammatic presentation of the alpha2 activity at the right occipital area. No significant findings were revealed from the two-way repeated measures ANOVA (2 Blocks × 3 Sessions) in the LM schedule.

Figure 7.4. Plot of the alpha2 activity at the right occipital area in the SM schedule.



* indicates statistical significance at $p \leq 0.05$

** indicates statistical significance at $p \leq 0.005$

A one-way repeated measures ANOVA revealed significant across-session changes at the left occipital alpha2 and right occipital alpha1, alpha2, beta1, beta2, and beta3 activities in the SM schedule, *F*(2.50,47.54 to 3.40,64.65) = 3.08 to 6.21, $p = 0.001$ to 0.037. Details of the results of the post-hoc comparison are shown in Table 7.6. No significant results were obtained in the LM schedule.

Table 7.6. *Post-hoc comparisons of EEG spectral power across all sessions of the SM schedule*

	Post-hoc comparisons from s1 to s10
EEG wavebands	Bonferroni adjustment*
O2 α_1	s10 > s6
O2 α_2	s1, s7, s9 > s5
O2 β_1	s9-s10 > s6
O2 β_2	s10 > s6
O2 β_3	s10 > s6

* significant p level at $p < 0.05$

Variation of the HRV Spectral Power

No significant differences were found on the HRV spectral power, which reflected the mental effort of subjects between the LM and SM schedules and across all task sessions ($p \geq 0.05$).

Discussion

Overview of Results

In the morning block of the LM schedule, the error rate showed an inverted U shape pattern, with the error rate lowest around the end of midmorning, that is, Session 2. Correlational analyses revealed that the error rate was negatively associated with mental effort at the end of Session 2. At the same time, the speed of data entry was positively associated with beta activity at the left occipital area at the end of Session 3, and negatively associated with delta activity at the right frontal area at the end of Session 5. In addition, mental effort was positively correlated with alpha and beta activities at the occipital areas at the end of Session 3, and with alpha activity at the left occipital area at the end of Session 6; it was, however, negatively correlated with alpha activities at the right frontal and bilateral occipital areas at end of Session 4. In the SM schedule, however, the error rate did not differ across time, and correlational analyses revealed only positive associations between error rate and beta activities at the left occipital area at the end of Sessions 3 and 4, and between typing speed and alpha activities at the left occipital area at the end of Session 10. Further analyses found that the LM schedule generally showed higher alpha activities than the SM schedule throughout the course of task engagement. The analyses also indicated that alpha and beta activities at the right occipital area tended to increase across the afternoon sessions while decreasing across the morning sessions, and were consistently higher at the end of Session 10 when compared to the end of the first afternoon session and of Session 5.

Neurocorrelates of Task Performance

Since the EEG was captured at the end of the task session, segmentation of the error rate into consecutive 10-minute segments enabled a more valid interpretation of correlations between error rates and EEG spectral powers (both measures were overlapped within the last 10 minutes of each task session). It appears that subjects who showed a low error rate elicited a high mental effort (revealed from the HRV) in the middle of the LM morning schedule. As the subjects' speed of data entry increased from Session 1 to Session 2 (reported in Chapter V, pp. 95) and the error rate tended to be lowest in Session 2, it appears that subjects who invested more mental effort at the same time maintained a high overall performance in Session 2. By Hockey's (1997) model, it appears that these subjects were undertaking Loop B of the effort monitor, which says that better performance is regulated with a goal of achieving better task performance. This will be further discussed in the general discussion section in Chapter VIII. At the end of Session 3, more intense mental activity was related to better performance, because the subjects who showed an increase in typing speed also elicited an increase in beta activity at the left occipital area. Cortical activity at an occipital site has been shown to reflect general vigilance in data entry tasks (Floru et al., 1985; Floru & Cail, 1987), while high beta2 activity at the left occipital area has been found related to mental effort and heightened vigilance (Coull, 1998; Paus et al., 1997). However, as the subjects' typing speed in Session 3 was significantly higher than that of Session 1 but not Session 2 (reported in Chapter V, pp. 93-97), the intense mental activity and heightened vigilance, if present, would reflect an increase in typing speed from Session 2 to 3.

In the middle of the LM afternoon session, decrease in speed of data entry was related to an increase in delta activity, suggesting that subjects were in a drowsy state. Similar to the present findings, past studies have reported that increasing delta activity is associated usually with the lower ranges of arousal, poorer performance, and higher levels of sleepiness (Akerstedt & Gillberg, 1990; Ogilvie & Simons, 1992), while the activation at the right frontal area is a more general phenomenon accompanying lower attentive or less vigilant activity (Deutsch et al., 1987). The neurocorrelates of task performance are consistent with those revealed for SOFI-C. Delta activity has been found to be associated with subjective feelings of sleepiness and poor motivation.

Subjects in the SM schedule demonstrated a very different pattern of neurocorelates. In Sessions 3 and 4, subjects who showed a high error rate at the mean time elicited high beta activity at the left occipital area. According to Campagne, Pebayle, and Muzet (2004), beta activity reflects cortical activation that corresponds to a state of arousal or to brain reactivation following a temporary episode of sleepiness. This suggests that the higher arousal states were coupled with an increase in typing errors. One possible explanation is that some subjects who were in an aroused state underwent a compensatory act for preventing further decline of performance. This postulation is consistent with the observation that the delta and theta activities at the right frontal and occipital areas are inversely correlated with the Sleepiness, Lack of Motivation, and Lack of Energy subscale scores of the SOFI-C measured at the end of the afternoon. This means that high perceived feelings of fatigue are associated with low slow wave activities, suggesting that the subjects' feelings of fatigue did not originate so much from drowsiness but from the intense mental activity. At the end of the last session of the SM schedule (Session10), subjects who showed a higher typing speed elicited more intense alpha activity at the left occipital area. The increase in alpha activity can be interpreted in three ways. First, an increase in alpha activity is generally associated with an increase in relaxed alertness (Higuchi et al., 2001). Relaxed alertness means a state in which an individual is just awake but does not need to engage in mentally demanding activities. Second, an increase is an indication of reduced cortical activation after practice when the activity is distributed at the central and occipital areas of the cortex (Larson et al., 1998). Third, the increase occurs after extensive practice on a task, and the activity at the frontal and posterior areas, such as the parietal and occipital areas of the cortex, is positively correlated with task performance (Gevins & Smith, 2000). The main difference this study reveals, compared with other studies, is the presence of significant alpha activities only at the left occipital area. One plausible reason is that the EEG activities were captured at only two main locations, the frontal and occipital areas. Therefore, the study is unable to reveal activations at other posterior cortical sites, such as the parietal and central areas. It is reasonable to assume that, in performing a monotonous task like data entry, the subjects became familiar with the task and were already highly practiced in it as they approached the end of the entire task engagement. Moreover, the typing speed of the SM subjects was generally higher in the afternoon, and was higher in Session 10 than in Session 1. Therefore, the high association between typing speed and alpha activity could be attributed to practice-related cortical activation (Gevins & Smith, 2000; Larson et al., 1998). But in comparison with the present study, past studies have reported different locations of alpha activity related to the practice effect. This would, however, be due to the differences in task content that utilize specific parts of the cortex. For example, Gevins and Smith (2000) studied spatial working memory tasks and reported activations at the frontal and parietal areas. Other researchers have regarded such a reduction of cortical activation as evidence of an improved neurophysiological ‘efficiency’ (Parks et al., 1989). Further studies of this aspect are needed.

Changes of EEG Spectral Power

In a previous study of a continuous 2-hour data entry task, Floru et al. (1985) observed significant across-time changes of the EEG spectral power. Their subjects demonstrated an autoarousal phenomenon, in which beta activity increased along with a decrease of alpha activity during the middle of the entire task engagement (Floru et al., 1985). They believed that this autoarousal mechanism was elicited via the cortico-reticular system, which corresponds to a state requiring the operator's effort to mobilize energy (Kahneman, 1973). In the present study, however, energy recuperation was facilitated by rest breaks. Therefore, a large variation of the EEG spectral power across task sessions was not expected, and only sampled EEG signals were captured in each task session. Indeed, comparison of the EEG activities across task sessions revealed no significant changes in the LM schedule. However, those in the SM schedule generally elicited a higher level of alpha and beta activity at the right occipital area throughout the entire afternoon, particularly in the last two afternoon sessions. This simultaneous increase of slow waves (alpha activity) and fast waves (beta activity) in a prolonged monotonous task suggests that the subjects might have approached a fatigue state, particularly at the end of the afternoon (Lal & Cail, 2001).

It is interesting to note the several differences in the performing behaviors and the manifestation of neurocorrelates across the task sessions of the two schedules. In the LM schedule, although the subjects showed no changes in EEG spectral powers, they did demonstrate an increase in typing speed and elicited a strong association between mental effort and cortical activation only until end of the morning task block. In the SM schedule, the subjects appeared to show signs of fatigue, which manifested in an elevation of slow and fast wave activities, but continued to improve their typing speed in the afternoon until reaching a maximum at the end of the afternoon. The alpha activity of the LM subjects was higher than that of the SM subjects throughout the entire task engagement, which indicates that the LM subjects generally manifested a lower level of cortical arousal as compared to the SM subjects (Larson et al., 1998). This phenomenon indicates that the LM schedule facilitated subjects in executing an efficient internal regulation of energy and mental effort to facilitate the data entry performance throughout the morning, whereas the SM schedule appeared to delay the fatigue of the subjects and enable better performance at the expense of higher cortical activities.

These findings show that a longer and less frequent rest break schedule (LM) of data entry enables a relatively lower level of cortical arousal for enhancing better performance and efficient energy regulation for the first 3 hours of task engagement. However, the associated mental effort and energy involvement in the middle of the morning might have been so intensive that the depleted energy of some subjects was unable to recuperate thereafter, resulting in a comparatively low performance outcome in the afternoon. In contrast, a shorter and more frequent rest break schedule (SM) of data entry manifested a relatively higher cortical activation to maintain better performance for the entire 6 hours of engagement. Unlike the LM schedule, some subjects in the SM schedule did not elicit an association between effort and energy investment. Rather, some of them may have depleted their energy in the middle of the morning because of their associated compensatory effort to intervene in the performance (discussed in Chapter VI, pp. 135-140). Nevertheless, the compensatory effort appears to be related only to their high ratings of perceived fatigue, which might explain why the SM subjects were still able to increase their cortical activity to further improve their task performance in the afternoon.

In this study, the neurocorrelates of task performance and the longitudinal changes of EEG spectral power were observed only in the occipital beta and alpha activities, not in the frontal theta activity. It appears that the location and rhythms of the cortical activities are dependent on task content. For instance, past studies like Gevins and Smith (1997) and Sammer (1996) have shown that frontal theta activity is associated with mental load, and that a positive correlation of frontal theta activity with task difficulty and with practice indicates the need to focus attention and mental effort. Chouinard et al. (2003) also reported an association between frontal theta activity and task error. Indeed, a common characteristic of all these studies is that the tasks under experimentation required spatial working memory. In addition, although Yamamoto and Matsuoka (1990) observed changes of frontal midline theta in VDT operation, their experiment was based on a visual search task. In fact, some studies have already shown that attention and visual stimulus processing tends to be associated with changes in alpha activity at posterior electrode locations like the occipital area (Pfurtscheller, Neuper, & Mohl, 1994; Van Winsum, Sergeant, & Geuze, 1984). Moreover, the involvement of beta and alpha activity in data entry performance was also observed by Floru et al. (1985) and Floru and Cail (1987). The only problem in the interpretation of the findings is the physiological meaning of activation of the left and right occipital areas. In this study, it consistently appears that the beta and alpha activity correlated with task performance solely at the left occipital area, but correlated with mental effort mostly at the right occipital area with some at the left occipital and left frontal areas. Nevertheless, there is a dearth of evidence from the literature, and the phenomenon requires further investigation. Apart from this, the mental effort reflected by HRV does not vary across time in both the LM and SM schedules. This result is consistent with Henning et al. (1989). Others have argued that HRV as a measure of mental effort is not sensitive enough, and that the heart rate is unstable because it is easily influenced by external factors such as sudden pressure or anxiety (Sammer, 1998). In addition, the findings do not suggest an overdominance of automatic processing as task engagement progressed in the data entry task. If the data entry task is performed automatically, the execution of the task performance should be effortless and the effect of fatigue should be minimal (Shiffrin & Schneider, 1977). However, the findings of this study show that in both the LM and SM schedules, the subjects exhibited neurophysiological correlates of mental effort. Moreover, throughout SM afternoon sessions, the increase in typing speed coincided with an increase in beta activity. Hence, task performance was related to more heightened mental activity together with practice, rather than simply reflecting automatic processing.

CHAPTER VIII

DISCUSSION – GENERAL

This chapter discusses how the results obtained in the present study benefit the understanding of low-level information processing tasks like numerical data entry. The discussion focuses on four aspects. First, the method used in studying data entry is discussed and the advantages of employing the measurements in the present study are elaborated. Second, the implications of rest breaks are analyzed by drawing on results of the present study and some relevant past studies. Third, a model of prolonged low-level information processing is proposed based on the findings of the present study and past literature. Last, the benefits of the present study for enhancing the occupational health of sedentary workers working on computer-based data entry tasks are highlighted.

Measurements Used in Data Entry Studies

The present study employed both behavioral and neurophysiological measurements and made use of correlations between them to verify the underlying processes of the behavioral changes across time on task. The use of these combinations of measurements was not new, but the selection of physiological measurements has varied greatly in the past. The most commonly used physiological measurement has been heart rate variability for reflecting mental effort (Boucesin & Thum, 1997; Fairclough & Houston, 2004; Schleifer & Okogbaa, 1990). The present study, however, shows that HRV does not appear to be sensitive enough to reflect differences in mental effort between different rest break schedules of data entry, or changes in mental effort across time on low-demand tasks. Henning et al. (1989) also observed no differences in HRV in their subjects across six 40-minute sessions of a data entry task. Boucesin and Thum (1997) also used both task performance and HRV measures in their study of rest break schedules. They observed significant differences in HRV between subjects who worked on a schedule of a 50-minute task plus a 7.5-minute break, and a 100-minute task plus a 15 minute break. However, the VDT task that they employed was a complex visual display task. Therefore, the sensitivity of the HRV for reflecting mental workload appears to be content specific and more likely to reflect difficult tasks, which demand mostly controlled processing.

Many studies have combined both behavioral and electroencephalogram findings to investigate mental workload, but most have been done on high-demand tasks such as truck driving and piloting (Hartley et al., 1994; Okogoaa, Shell, & Filipusic, 1994). In data entry tasks, the use of EEG to reflect levels of arousal and to relate to changes in task performance is limited to the studies carried out by Floru, Cail, and Elias (1985) and Floru and Cail (1987), as mentioned in Chapter V. Hayashi, Chikazawa, and Hori (2004), however, did use EEG to examine their subjects' stage of sleep during a 20-minute nap in the course of a 2-hour VDT task. But they did not relate the EEG to task performance.

Physiological measures in data entry task engagement also include systolic and diastolic blood pressure, hormones, and end-tidal partial carbon dioxide levels, which are thought to reflect the work strain associated with human computer interaction (Lundberg et al., 1993; Schleifer & Ley, 1994). It appears that past studies have employed a large variation of neurophysiological measures in studying data entry tasks. Although some measures are specific, such as HRV reflecting mental effort, hormonal levels reflecting stress and work strain, and so forth, theoretical models are necessary to guide measurements in studying mental workload. As a result, many previous studies on data entry tasks might not be comprehensive enough to explain the underlying processes of subjects throughout prolonged data entry.

In the present study, the use of neurophysiological correlates helps to explain the differential behavioral patterns observed in the LM and SM schedules. The behavioral findings indicate that the LM subjects showed a significant increase in perceived fatigue and typing speed across the morning sessions, but a significant increase only in perceived fatigue across the afternoon sessions. The SM subjects, however, showed an increase in perceived fatigue and typing speed across both the morning and afternoon sessions. If only these behavioral findings are considered, without taking into account the energetical regulation of the subjects, then it appears that the SM subjects performed better across the board than did the LM subjects. In fact, the EEG findings show that the LM subjects elicited an overall less intensive cortical activation when compared to the SM subjects. The neurophysiological correlates suggest that the LM subjects utilized a more efficient regulation of energy and mental effort in the morning task sessions than the SM subjects did. It should also be noted that in the afternoon sessions, the LM subjects exhibited neurophysiological correlates of drowsiness, whereas the SM subjects demonstrated correlates of heightened cortical activations, attention, and mental fatigue. These neurophysiological findings indicate that the SM subjects, who performed at a high level generally, experienced more intensive mental processing in the afternoon. The SM subjects demonstrated an increase in typing speed, and it is likely that the gain in performance was due to their willingness to raise their cortical arousal and intensify their mental activity. This study demonstrates that correlation of behavioral measures, such as perceived fatigue and task performance, with EEG data is effective in revealing the mental processes underlying prolonged data entry. Since low levels of information processing like data entry do not require effortful processing, large variations are to be expected in the performances and effort among the subjects. Because of this, the behavioral variables of performance and perceived fatigue might not reflect the differences in the effects of the two rest break schedules. The present study demonstrates the value of using neuropsychological correlates to show the differences in individuals among each of the rest schedule groups. It also finds that the differences in mental load resulting from manipulating the rest break schedule modulate EEG activity more than HRV. Thus, the results further support the importance of addressing both the behavioral and EEG parameters for studying mental workload, particularly on tasks that demand a low level of information processing, like data entry.

Some scholars have suggested that the individual's ability to monitor his/her own level of fatigue is important in regulating task performance (Tucker, 2003). This means that if the individual can resist the fatigue and continue to invest effort, then he/she will still be able to maintain the performance at a high level. It appears that in tasks of low information processing like data entry, this ability varies greatly among subjects. The results of the present study suggest large interindividual variations in task performance, eye blink rate, EEG, and HRV in the subjects of both rest schedules. The variations may hinder the statistical significance of the changes in these parameters, particularly the eye blink rate, EEG, and HRV, across time on task. Therefore, whether the nonsignificant changes are due to the low task demands of the data entry task or to the interindividual variation is still unknown. Nevertheless, the neurophysiological correlates on the behavioral measures provide valuable information in revealing the underlying processes associated with the performance outcome on low information-processing tasks like data entry.

Implications of Rest Breaks

The present study compared the performance on task and the neurophysiological correlates between two different rest schedules of data entry: one with a less frequent but longer rest duration (i.e., a 50-minute task followed by a 10-minute break, designated LM), and one with a more frequent but shorter rest duration (i.e., a 30-minute task followed by a 5-minute break, designated SM). The findings reveal that the SM subjects showed a quite steady task performance but exhibited correlates of heightened cortical activities, with increased perceived fatigue at the middle of the 3-hour morning session. In contrast, the LM subjects showed a tendency toward a reduced error rate around the middle of the 3-hour morning task block, which modulated the correlates of better performance and less perceived fatigue with mental effort investment during that time. Although the error rate tended to rebound in the last morning session, the overall typing speed was still faster than at the beginning of the morning. Thus, a rest schedule of a 50-minute task followed by a 10-minute rest is probably sufficient for enhancement of performance and efficient energy regulation for a 3-hour data entry task in the morning. In the afternoon, the rest schedule of a 50-minute task followed by a 10-minute rest, however, appears to be not as favorable as for the morning 3 hours. The LM subjects generally did not invest much effort into the task and were found to exhibit a strong neurophysiological correlate of drowsiness with perceived fatigue. In contrast, some of the SM subjects were shown to be able to increase their typing speed, which required intensive cortical activation. It is interesting to note that both the LM and SM subjects might have developed a certain degree of fatigue that did not manifest a sharp performance decline but did influence their internal efficiency of energy regulation: The SM subjects were able to invest more effort and heightened mental activity to boost their performance, whilst the LM subjects were not.

The implication of the present findings is that the effectiveness of the rest schedule depends not only on the task content but also on how long the task has been performed. This suggestion runs contrary to some studies, which have suggested that optimum rest schedules are likely to be specific only to the nature of the work activity involved and differences in the individual's state and traits (Tucker, 2003). This study finds that if the data entry task is to be carried out across the morning and afternoon, which is about 6 hours, then a rest schedule of a 30-minute task followed by a 5-minute break should be more effective in enhancing task performance but is likely to demand higher levels of mental activity. But if the task is to be performed only for about 3 hours, then a rest schedule of a 50-minute task followed by a 10-minute break is adequate to enhance performance increment. These propositions concur with Floru et al. (1985), who suggested that a rest break incorporated before 45 or 60 minutes of a continuous data entry task would be appropriate. Since their study only covered a 2-hour data entry task, which did not account for prolonged engagement for an entire workday, say 6 hours, the consistency of findings between these two studies is limited to the first 2 or 3 hours of the data entry task.

When and for how long an individual should be given a rest break has been a difficult issue. The National Institute of Occupational Health (NIOSH) has recommended a 15-minute break for every 2 hours of VDT work under moderate demands, such as quality assurance and filing tasks, and after 1 hour for operators under high visual demands and/or for those engaged in high mental loads or repetitive tasks, like proofreading and data entry (Dooley, 1981). For instance, Kopardekar and Mital (1994) examined three work/rest schedules: 30 minutes of VDT work and a 5-

minute break (30-5), 60 minutes of VDT work and a 10-minute break (60-10), and 2 hours of VDT work without any break. They found that only the nonstop working group reported significantly more errors and a higher intensity of fatigue. They did not reveal any differences between the 30-5 and 60-10 rest schedules. The present study uses a prolonged 6-hour data entry task and takes into account the energetical regulation and mental state of subjects to investigate the effects of rest breaks. The results further support the notion that more frequent rest breaks can enhance energy recuperation and delay the negative impact of fatigue on task performance in a prolonged task of 6 hours. Though some studies have focused on the effects of microbreaks, such as McLean et al. (2001), Henning, Kissel, and Maynard (1994) and Henning et al. (1989), the design of the present study does not readily offer an explanation regarding microbreaks.

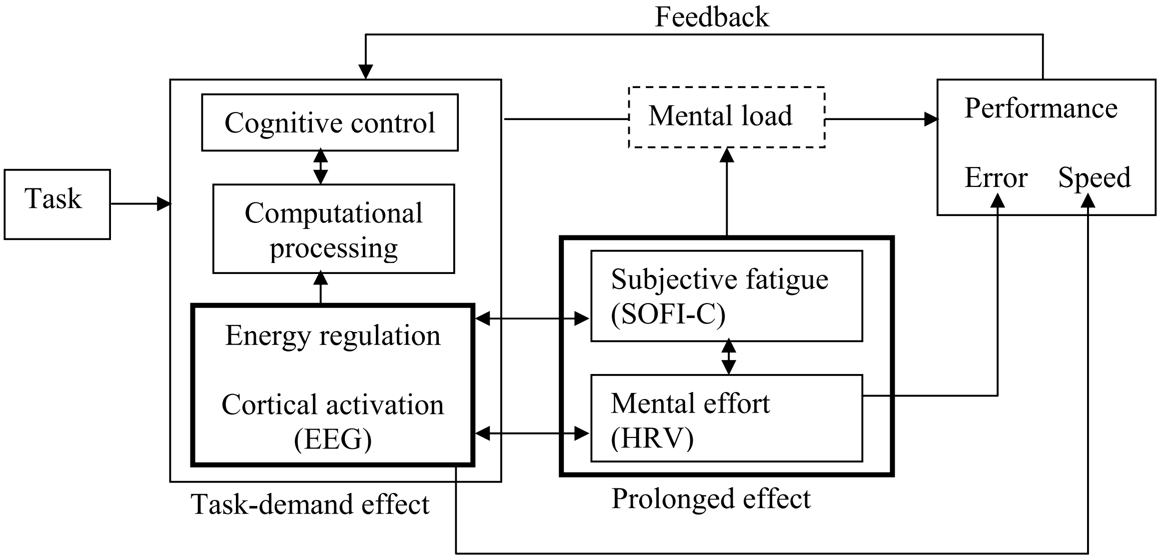
Model of Prolonged Information Processing

Figure 9.1 depicts a plausible model of a prolonged information processing task based on the results obtained in this study. The proposed model is particularly useful for explaining individual performance on a low-level processing task such as data entry. The proposed model makes reference to Gaillard’s (1993) and Hockey’s (1997) theoretical frameworks, in which task performance is primarily related to the cognitive demands imposed by the task, which in turn are modified by feedback. This is represented by the relationship between the “task-demand effect” and “performance” in the model. Under normal circumstances, an individual’s energetical resources are sufficient to meet the task demands, and the individual regulates his/her energy so that task performance is optimal (Gaillard, 1993; Hockey, 1992; Hockey, Gaillard, & Coles, 1986). As an individual continues to work on a task that demands mental processing, his/her energetic resources are likely to fluctuate. To maintain a steady and even an enhanced performance, an individual requires mental effort to adjust his/her energetical state to the desired level of performance on a task (Hockey, 1997). This "trying harder" action is initiated voluntarily, depending on an individual's motivation to attain the goal (Gaillard, 1993; Hockey, 1992; Hockey, Gaillard, & Coles, 1986). Unlike the previous frameworks, this proposed model incorporates a "prolonged effect" component. This component links the variables of mental effort and feeling of fatigue to the individual's cognitive system and performance. These two factors, feeling of fatigue and mental effort investment, are not new to information processing theories, but they are supposed to be exaggerated only when the task engagement progresses for a long period of time. This study finds that mental effort and intensive cortical activation are associated with task performance and perceived fatigue at a time when the subjects are likely to experience fatigue. Such a condition is demonstrated in our data in two ways. First, mental effort was related to a low error rate during the period when the LM subjects showed a relatively low error rate. Second, there was a strong correlation between subjects' cortical activation and mental effort when the error rate tended to increase at the end of the LM morning session, and when the subjects showed signs of fatigue in the middle of the SM afternoon task block.

The proposed model modifies two existing concepts stipulated in Hockey's (1997) and Gaillard's (1993) theories and incorporates these concepts into the model. First, the present model describes only one level of effort. Hockey (1997) suggested that there is one effort but two set points. He supposed that individuals have to invest effort whenever the required level of effort for performing a task exceeds the lower set point of the effort monitor, whether due to the high task demand or the need to mobilize extra energy to counteract fatigue. Otherwise, automatic processing needs to operate only under Loop A of his compensatory control model, which does not require effort. In data entry tasks, the subjects are expected to use a certain amount of controlled processing. That means that the processing of the task purely under Loop A is not possible. Therefore, the proposed model does not overemphasize the two set points of effort. Rather, in this model, mental effort is outlined as a drive necessary to withstand fatigue or boost performance, which seems to be better reflected in the high beta and low alpha and theta activities of the EEG signals than in the HRV. It is worth noting that mental effort is still required in the regulation of energy in normal circumstances, as Gaillard (1993) mentioned. It is just that the mental effort in the prolonged effect component describes the effort used to mobilize more energy as fatigue sets in after a long period of task engagement. This effort investment is likely to be related to an increase in perceived fatigue. Indeed, the findings indicate that mental effort and cortical activation were strongly associated with perceived fatigue in both the morning and afternoon sessions, when the subjects appeared to develop fatigue in both rest break schedules.

Second, the model deliberately includes a “mental load” component. This mental load component is a concept and exists only virtually. The mental load in the model is influenced by both the “task-demand effect” and the prolonged effect. In most theories on information processing, mental load refers to the capacity to process information in a task situation (Gaillard, 1993). This capacity depends on the availability of cognitive resources (e.g., a particular function of a specific cortical area) and the state of the individual (e.g., arousal or fatigue). Additionally, there are differences in processing capacity between operators and fluctuations in capacity within one operator due to fatigue, sleep loss, anxiety, and/or psychosomatic complaints (e.g., eye strain) (Gaillard, 1993). In prolonged information processing like the data entry performance of this study, mental load is more likely influenced by the fatigue of the subjects and acts like a final threshold to determine how well the task can be performed after taking into consideration all remaining mental resources. For example, the LM subjects were shown to elicit intensive mental processing in the morning to boost their performance (i.e., to increase typing speed and reduce error). As a result, they were likely to exhaust their energy and feel fatigued at end of the morning. This increased the mental load of this group of subjects to a point where they were not able to invest more effort to improve their performance in the afternoon. Conversely, the SM subjects appeared to experience a lower level of mental load on the task and therefore were able to perform better at the expense of more intensive mental activity.

Figure 9.1. Proposed model of prolonged low level information processing such as data entry.



Application to low demanding tasks particularly data entry

This model emphasizes the energy regulation and the prolonged effect component because it is constructed particularly for explaining prolonged task engagement. Rest breaks influence the efficiency of energy regulation and resulted in differential correlation patterns. From the data, it appeared that subjective fatigue related directly with the cortical activation. When the subjects felt tired subjectively, it could be that they were investing intensive mental activity to maintain the task performance or simply became drowsy and reduced alertness on the task. However, the subjective fatigue did not relate directly with task performance. This might be because the task was simple and required only low level of cognitive demand, so that the task performance was not influenced too much by the negative emotion of the subjects. On the other hand, the increase in typing speed, which was probably reflecting a facilitative effect on the task, seemed to show a neurocorrelate that explained practice effect and automatic processing. It was also worth to note that mental effort was related to error rate when the subjects were at the stage executing their intensive mental activity.

Application to other tasks

Since the results obtained from the present study only tap on data entry task, the application of this model to other tasks can only be discussed from a hypotheoretical point of view. Basically, the model may explain task engagement in prolonged high demanding tasks. In high demanding tasks, e.g. driving, the component of the model probably remains the same except that the relationship among the variables would be different. We suspect that in high demanding tasks, people need to invest great amount of mental effort which probably exaggerates mental fatigue and aggravates subjective fatigue feelings much more than in low demanding tasks. As the result, the “prolonged effect” that acts on the mental load of the individual would be much greater and a higher level of energy state has to be reached in order to produce the same level of task performance as in low demanding task. In addition, high demanding task might induce greater level of subjective fatigue as compared to that induced by the data entry task, therefore it is postulated that individuals’ subjective fatigue rating during prolonged high demanding task will relate directly with task performance. One thing which could be very different between low and high demanding tasks is the requirement of mental effort. In low demanding task like data entry in this experiment, the task was so simple that it did not require the subjects to push their mental effort to the limit for attaining a high level of task performance. Therefore, the subject should be able to perform it well and the investment of mental effort would depend also on other factors such as the subjects’ goal and motivation, which resulted in large inter- and intra- individual variation. As the result, many parameters such as mental effort, energy (as measured using EEG) as well as the task performance did not show significant changes across time, most probably because of large standard variation of the measurement data. In high demanding task, in contrast, the task is more difficult and individuals must invest large amount of mental effort to maintain a certain level of task performance, making the degree of variation of mental effect investment both within and between individuals minimal. Therefore, it may be possible to reveal longitudinal change of cortical activities, mental effort and task performance. In fact, many previous studies on high demanding tasks like driving, piloting did revealed differences in the aforementioned variables (Brown, 1994; Cabon et al., 1993; Hankins & Wilson, 1998; Hartley et al., 1994; Neri et al., 2002).

Mental Fatigue Phenomenon

Prolonged engagement on task provokes mental fatigue. In this study, since the task was simple, prominent performance decrement was not expected. Therefore, fatigue was measured and defined using the perceived fatigue ratings rather than performance decline. This study revealed that subjective fatigue ratings increased across time. According to Holding (1983), fatigue can be conceptualized into task specific fatigue or general fatigue. The former describes that the person is tired of performing a particular task and that the fatigue can be alleviated by taking rest break or by doing some different activity. The latter describes that the person is in a state of general tiredness, drowsiness and short rest breaks or switching to other tasks do not help alleviate the fatigue. In this study, it was likely that the data entry task induced task specific fatigue because the 1-hour lunch break seemed to help the subjects recuperated from the transient fatigue in the SM schedule. It was also suspected that the subjective fatigue revealed in this study probably reflected general fatigue but not task specific fatigue because the fatigue ratings increased across the day. The fact that subjective fatigue ratings reflected general fatigue but not task specific fatigue was also evident in SOFI-C ratings of high speed craft masters who showed increased fatigue scores across workday and work shift (Leung et al., 2006). Task specific fatigue, on the other hand, was probably reflected from the neurophysiological findings in this study, particularly from the neurophysiological correlates. The neurocorrelates that represented subjects' intention to invest intensive mental activity to maintain task performance and recovery from transient fatigue suggested that neurophysiological parameters could be a better measurement tool for revealing task specific fatigue in low demanding task.

Implications for Occupational Health

With the enactment of the Occupational Safety and Health Ordinance and its subordinances in Hong Kong (Hong Kong Government Gazette, 1997), it has become necessary for the Labor Department and the Occupational Safety and Health Council to provide guidance notes that can be readily applied by management in the determination of risk levels associated with mental fatigue with respect to VDT workers. Data entry is a common sedentary work task in VDT operation (Faucett & Rempel, 1996). The results of the present study provide a scientific basis for establishing guidelines and standards for enhancing workers' health and performance on sedentary office VDT work tasks, such as data entry.

Over the past decade, much has been done with respect to computer-based data entry tasks, such as evaluation of ergonomic workstations, examination of musculoskeletal symptoms and visual fatigue associated with engagement of the task, and investigation of job stress and time pressure in relation to data entry performance (Eklund, Boyce, & Simpson, 2001; Faucett & Rempel, 1996; Harada et al., 1995; Murata et al., 1991). However, studies on rest break schedules for data entry tasks have been limited, and their results are not quite consistent. While rest breaks are quoted as a common strategy in alleviating physical discomfort and mental fatigue, the optimal time and frequency of rest breaks has not been properly investigated. The present study is the first to involve a comprehensive review of two contrasting rest schedules of a prolonged data entry task using an energetical approach to human information processing. The findings enable a better understanding of how rest breaks modulate energy regulation and hence performance in this kind of worker.

Last but not least, the proposed model of prolonged low levels of information processing provides a theoretical framework for guiding similar research in the occupational health of sedentary workers. It is particularly useful because it guides the proper selection of measurements that are necessary to discover the mental processes and fatigue associated with low levels of information processing tasks.

Significance of the Study

This study was the first study to make use of both behavioral performance and neurophysiological correlates, and revealed two differential patterns of rest break schedules associated with a 6-hour data entry task. It was found that effectiveness of the rest schedule depends not only on the task nature but also on how long the task has to be performed. It was showed that mental effort and energy utilization seemed to be more efficiently regulated under the 50-minute task plus 10-minute rest schedule only in the morning when the speed of data entry increased. If the task is to be carried out for six hours for a full work day, then a 30-minute task plus 5-minute break is more favorable because it enhanced performance improvement in the latter half of the day i.e. the afternoon. It was also observed that this 30-minute task plus 5-minute break may not be all the way better even though it enhanced speed increment in the afternoon because the mental activities increased across the entire afternoon. These findings have not been obtained in the past, probably because those studies were done without taking into account the energy regulation mechanism and without revealing cortical activities concurrently with the performance data. This also explains why there were so many inconsistencies of results in the past. Hence, the rest schedule here recommended can be used as guidelines for establishing occupational health for sedentary VDT workers.

In addition, this study brings a new piece of information to the literature regarding the measurement of human information processing. This study measured subjective fatigue of subjects and found that their ratings were significantly related to intensive mental activity which seemed to reflect a task specific fatigue phenomenon somehow during the task engagement in addition to general fatigue and lowering of activation. Hence, purely subject fatigue rating was not adequate to reveal the underlying fatigue phenomenon. It seemed that in the past, there were no studies addressing correlational analysis between perceived ratings and EEG data in prolonged and monotonous low level information processing particularly data entry. The result obtained here can also empirically test a model which proposed particularly for prolonged information processing. This model can be used to guide future research.

CHAPTER IX

CONCLUSION

This chapter elaborates the findings of the present study and highlights the contributions of the findings to the field of ergonomics and rehabilitation. The chapter ends with limitations of the study and suggestions for further research in this area.

While findings have been equivocal on rest break schedules and performance of sedentary work like data entry, the present study attempted to use both behavioral and neurophysiological variables to offer explanations for the phenomenon. The findings suggest that if a data entry task is to be performed for 3 hours, or approximately half a workday, then a rest break schedule of a less frequent but longer rest duration, such as a 50-minute task followed by a 10-minute rest break, is more desirable than a schedule of a more frequent but shorter rest duration, such as a 30-minute task followed by a 5-minute rest break. Conversely, if the data entry task is to be performed for 6 hours, or an entire workday, then a rest break schedule of a more frequent but shorter rest duration, such as a 30-minute task followed by a 5-minute rest break, should better enhance task performance than the longer but less frequent rest break schedule. This finding provides an important piece of information to the effect that the duration of the entire task is a factor that affects the choice of rest break schedules in sedentary work tasks like data entry. In the past, once a rest break schedule is selected for a particular task, say data entry, it has been applied to the entire task performance, regardless of whether the task is to be done for a short period, say 2 to 3 hours, or a long period, say 6 to 8 hours. The findings of the present study also explain why some studies have produced results inconsistent with each other.

One plausible reason is that these studies usually have not used the same duration for their entire experimental data entry task. Since the effect of rest breaks at different periods of the task engagement differs, it is obvious that studies using different durations of task would report different results.

The present study contributes to the field of ergonomics in two ways. First, it further enriches the model of information processing for application in prolonged low-level tasks like data entry. The proposed model of information processing is empirically based on the findings of the present study. The behavioral and neurophysiological variables as measures of the component of the model are found to be useful for demonstrating the differential effects of long (10 minutes) versus short (5 minutes) rest breaks on facilitating an individual's performance and mental workload on a data entry task. The results further support the importance of addressing mental load, cognitive processes, and energetic state simultaneously in studies of low information-processing work tasks. Second, the results shed light on a strategy for enhancing the occupational health of office workers and work rehabilitation. In view of the limited benefits of ergonomically designed workstations in alleviating worker fatigue, the rest schedule is a useful alternative. The present study uses a work-simulated data entry task so that the findings can be generalized to guide the design of work/rest schedules, particularly for data entry tasks or other low demanding work tasks of office work. In rehabilitation, therapists can reinforce the awareness of workers and employers regarding the negative impact of mental fatigue on workers' health and psychological well-being, as well as recommend the present rest break schedule as a strategy in their work rehabilitation program.

Limitations of the Present Study

First, the task was highly work-simulated in that the subjects were not restricted from making corrections to their incorrect entries. In this way, the error rate obtained might underestimate the actual numbers of errors committed by the subjects. The limitation was mainly due to the Excel program, which was unable to report the correction attempts made by the subjects.

Second, the subjective fatigue ratings (SOFI-C results) of the subjects were not captured at the same time as the task performance and other neurophysiological variables. The relationships between these variables should be regarded as an approximation rather than actual information. However, it is unreasonable to have the subjects rate their subjective feelings too frequently because memory effect will click in and the subjects will be able to remember their prior ratings and make their own adjustment independent of the effect from the prolonged task.

Third, the subjects recruited were all undergraduate students, who would have had different skills and performance abilities, cognitive processes, motivations, and fatigue states from those of sedentary workers entering data. If skilled workers are used, it is expected that they will make even less errors. They may not need to invest the same level of effort and intensive cortical activity as that needed for the students. Therefore what we could see would be neurocorrelates that is more related to drowsiness and low activation at approaching the end of the task engagement. They may feel very boring to work on such easy task and execute a more “automatic” circuit than students did. Hence, the practice-related cortical activation may be more dominated. However, skilled workers would have a more similar level of cognitive control and skills on the task than students, which may result in lower standard deviation of the outcome variables and able any longitudinal changes across time to be statistically significant.

Fourth, the capturing of EEG and ECG signals was not conducted continuously throughout the task. Rather, these signals were captured within a random 5-minute time window during the last 10 minutes of performance on the task. This biased the fluctuation of performance across the task in each session. Nevertheless, previous studies have reported reduced fluctuations of the EEG signals with rest breaks incorporated into the task. Therefore, because of limited resources, the present study was not able to perform a continuous signal capture.

Fifth, because the scalp EEG was recorded at only two frontal and two occipital sites, brain activity occurring in other parts of the brain could have been overlooked. Particularly, if the EEG signals were collected also on the parietal and central location, then the phenomenon regarding the practice effect of data entry in the afternoon of the SM schedule could be revealed with more confidence. It is because past studies have found that practice-related cortical activities usually show a neurocorrelates of alpha activities that spread extensively to the frontal, central, parietal and occipital areas (Gevins et al., 1997). Indeed, the reason for using only frontal and occipital site in this study was due to limitation of the equipment at the time that the study was carried out.

Lastly, because of limited samples in this study (20 subjects per group), correlation was used as the main statistical method to analyze the relationships of the components in the model. In fact, with larger sample size, the analysis of such relationships can be done using path analysis so that the results could even be more convincing.

Generalization of the Findings

The present study examined behavioral performance and neurocorrelates in a 6-hour simulated data entry task. Since the subjects were students and the task was a simple data entry task, generalization of the present findings to real work situation has to be cautioned. Nevertheless, the findings obtained in this study enable further understanding of the relationships among mental effort, energy, subjective fatigue and performance during engagement in prolonged task. The model proposed for prolonged information processing was particularly useful to explain performance in low demanding tasks especially data entry. However, its application on high demanding or more difficult tasks has to be test in future studies.

Further Studies

The present study is a beginning in associating behavioral with neurophysiological measures and explaining the effects of rest breaks using a comprehensive energetical approach. Since the data entry task under study was a VDT task, eye fatigue and visual discomfort would have been occurred and increased across time. However, the use of the subjective fatigue measurement and the chosen neurophysiological variables were not able to reveal eye fatigue. Hence, future study can consider using objective assessment tools such as critical fusional frequency (CFF) and visual acuity to quantify eye fatigue and visual discomfort associated with prolonged VDT engagement. Functional magnetic resonance (fMRI) can also be used to evaluate the visual fatigue related to the task because it allows researchers to reveal the strength of activation in different brain locations. In addition, the present study manipulated only one variable – rest break schedule (the energy regulation). However, it would be possible that some other factors may influence the regulation of energy and/or motivation of the subjects on the task. Interestingly, according to Hawthrone effect (Roethlisberger & Dickson, 1939), workers productivity could be increased by simply paying special attention to the workers such as increase lighting and room temperature. Hence, future study can consider manipulating environmental variables and/or attention to workers, e.g. changing light intensity and noise level, to see how this would affect the results and the relationship among the components in the proposed model. Apart from these, more research can be done to address the effects of different rest schedules on other common office work tasks, such as proofreading. Investigation of task composition throughout an entire workday can also be explored. From the findings of this study, it appears that the task schedule with the less frequent but longer rest break enhances both efficient task performance and energy regulation during the first 3 hours on the task. It is suspected that if an alternative task demanding a totally different type of processing from that of data entry were performed after the 3 hours, the subjects' energy regulation on the alternative task would be very different from that obtained from the data entry task here. In addition, future studies may consider reducing the limitations set out for this study. For example, EEG signals could be captured continuously and at more scalp locations.

REFERENCES

Aasman, J., Mulder, G., & Mulder, L. J. M. (1987). Operator effort and the measurement of heart-rate variability. *Human Factors, 29*(2), 161-170.

Acosta, M. C., Gallar, J., & Belmonte, C. (1999). The influence of eye solutions on blinking and ocular comfort at rest and during work at video display terminals. *Experimental Eye Research, 68*, 663-669.

Adams, J. A. (1987). Historical review and appraisal of research on the learning, retention, and transfer of human motor skills. *Psychological Bulletin, 101*, 41-74.

Ahsberg, E. (2000). Dimensions of fatigue in different working populations. *Scandinavian Journal of Psychology 41*, 231-241.

Ahsberg, E., & Gamberale, F. (1998). Perceived fatigue during physical work: An experimental evaluation of a fatigue inventory. *International Journal of Industrial Ergonomics 21*, 1117-1131.

Ahsberg, E., Gamberale, F., & Gustafsson, K. (2000). Perceived fatigue after mental work: an experimental evaluation of a fatigue inventory. *Ergonomics, 43*(2), 252-268.

Ahsberg, E., Gamberale, F., & Kjellberg, A. (1997). Perceived quality of fatigue during different occupational tasks: Development of a questionnaire. *International Journal of Industrial Ergonomics 20*, 121-135.

Ahsberg, E., Kecklund, G., Akerstedt, T., & Gamberale, F. (2000). Shiftwork and different dimensions of fatigue. *International Journal of Industrial Ergonomics 26*, 457-465.

Akerstedt, T., & Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience, 52*, 29-37.

Allport, A. (1989). Visual Attention. In M. I. Posner (Ed.), *Foundations of cognitive science*. Cambridge, MA: MIT Press.

Bahrick, H. P., & Shelly, C. (1985). Time sharing as an index of automatization. *Journal of Experimental Psychology, 56*, 288-293.

Balci, R., & Aghazadeh, F. (2003). The effect of work-rest schedules and type of task on the discomfort and performance of VDT users. *Ergonomics, 46*(5), 455-465.

Balci, R., & Aghazadeh, F. (2004). Effects of exercise breaks on performance, muscular load, and perceived discomfort in data entry and cognitive tasks. *Computers & Industrial Engineering, 46*, 399-411.

Bargh, J. A. (1992). The ecology of automaticity: Toward establishing the conditions needed to produce automatic processing effects. *American Journal of Psychology, 105*, 181-199.

Beatty, J. (1982). Task-evoked papillary responses, processing load, and the structure of processing resources. *Psychological Bulletin, 91*, 276-292.

Beatty, J. (1986). Computation, control and energetics: A biological perspective. In G. R. J. Hockey, A. W. K. Gaillard & M. G. H. Coles (Eds.), *Energetics and Human Information Processing* (pp. 43-52). Dordrecht: Kluwer Academic.

Bentivoglio, A. R., Bressman, S. B., Cassetta, E., Carretta, D., Tonali, P., & Albanese, A. (1997). Analysis of blink rate patterns in normal subjects. *Movement Disorders, 12*(6), 1028-1034.

Bergqvist, U. O. (1984). Video display terminals and health. *Scandinavian Journal of Work and Environmental Health, 10*, 57-58.

Berntson, G. G., Cacioppo, J. T., & Fieldstone, A. (1996). Illusions, arithmetic, and the bidirection modulation of vagal control of the heart. *Biological Psychology, 44*, 1-17.

Boucsein, W. & Thum, M. (1997). Design of work/rest schedules for computer work based on psychophysiological recovery measures. *International Journal of Industrial Ergonomics, 20*, 51-57.

Boyer, M. J. (1997). *Lippincott's need-to-know ECG facts* (pp. 248). Philadelphia, PA: Lippincott.

Broadbent, D. E. (1971). *Decision and Stress*. London: Academic Press.

Brookings, J. B., Wilson, G. F., & Swain, C. R. (1996). Psychophysiological responses to changes in workload during simulated air traffic control. *Biological Psychology, 42*, 361-377.

Brown, I. D. (1994). Drive fatigue. *Human Factors, 36*(2), 298-314.

Buck-Gengler, C. J., & Healy, A. F. (2001). Processes underlying long-term repetition priming in digit data entry. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 879-888.

Cabon, P., Coblentz, A., Mollard, R., & Fouillot, J. P. (1993). Human vigilance in railway and long-haul flight operation. *Ergonomics, 36*(9), 1019-1033.

Cacioppo, J. T. (2004). Feelings and emotions: roles for electrophysiological markers. *Biological Psychology, 67*, 235-243.

Campagne, A., Pebayle, T., & Muzet, A. (2004). Correlation between driving errors and vigilance level: influence of the driver's age. *Physiology & Behavior, 80*, 515-524.

Carpenter, A. (1948). The rate of blinking during prolonged visual search. *Journal of Experimental Psychology, 38*, 587-591.

Chaffin, D., & Andersson, G. (1984). *Occupational Biomechanics*. New York: Wiley.

Chan C. C. H., Leung, A. W. S., He, J., Yeung, S., Lee, T. M. C., & Hung, J. (2003). Does break schedule augment the fatigue associated with VDT work? *Proceedings of the XVth Triennial Congress of the International Ergonomics Association and the 7th Joint Conference of Ergonomics Society of Korea/ Japan Ergonomics Society* (Vol. 4, pp.154-160).

Carter, J. B., & Banister, E. W. (1994). Musculoskeletal problems in VDT work: a review. *Ergonomics, 37*, 1623-1648.

Chan, C. C. H., & Lee, T. M. C. (1999). Clinical evaluation: From validation to practice. In: K. N. Anchor & T. C. Felicetti (Eds.), *Disability analysis in practice: Framework for an interdisciplinary science* (pp. 357-376). Kendall, Hunt: Dubuque.

Cho, P., Sheng, C., Chan, C., Lee, R., & Tam, J. (2000). Baseline blink rates and the effect of visual task difficulty and position of gaze. *Current Eye Research, 20*(1), 64-70.

Chouinard, S., Briere, M. E., Rainville, C., & Godbout, R. (2003). Correlation between evening and morning waking EEG and spatial orientation. *Brain and Cognition, 53*, 162-165.

Chung, J. W., Wong, C. H., Yang, J.C., & Wong, T. K. (1999). The construction of a pain intensity verbal rating scale in Chinese. *Acta Anaesthesiologica Sinica 37*(2), 65-71.

Chung, J. W. Y., Wong, T. K. S., & Yang, J. C. S. (2000). The Len Model: Assessment of cancer pain in a Chinese context. *Cancer Nursing 23*(6), 454-461.

Coull, J. T. (1998). Neural correlates of attention and arousal: insights from electrophysiology, functional neuroimaging and psychopharmacology. *Progress in Neurobiology, 55*, 343-361.

Craig, A., & Cooper, R. E. (1992). Symptoms of acute and chronic fatigue. In A. P. Smith & D. M. Jones (Eds.), *Handbook of Human Performance. Vol. 3: Trait and state* (pp. 289-339). London: Academic Press.

Crocker, L., & Algina, J. (1986). *Introduction to classical and modern test theory*. Orlando: Rinehart and Winston.

Davidson, R. J., Jackson, D. C. & Larson, C. L. (2000). Human Electroencephalography. In J. T. Cacioppo, L. G. Tassinary & G. G. Berntson (Eds.), *Handbook of Psychophysiology* (2nd ed., pp. 27-52). Cambridge: Cambridge University Press.

Davies, D. R., & Parasuraman, R. (1982). *The psychology of vigilance*. London: Academic Press.

Deutsch, G., Papanicolaou, A. C., Bourbon, W. T., & Eisenberg, H. M. (1987). Cerebral blood flow evidence of right frontal activation in attention demanding tasks. *International Journal Neuroscience, 36*, 23-28.

Dooley, A. (1981). NIOSH issues, CRT Guidelines. *Computerworld, 15*, 1-8.

Duff, E. (1962). *Activation and behavior*. New York: John Wiley & Sons.

Eastman, K. (1983). *Ergonomic Design for People at Work*. Vol. 1. New York: Van Nostrand Reinhold.

Eastman, K. (1986). *Ergonomic Design for People at Work*. Vol. 2. New York: Van Nostrand Reinhold.

Eckberg, D. L., & Sleight, P. (1992). *Human Baroreflexes in Health and Disease*. New York: Oxford University Press.

Eklund, N. H., Boyce, P. R., & Simpson, S. N. (2001). Lighting and sustained performance: modeling data-entry task performance. *Journal of the Illuminating Engineering Society, 30*(2), 126-135.

Ellis, H. C., & Ashbrook, P. W. (1988). Resource allocation model of depressed mood states on memory. In K. Fiedler & J. Forgas (Eds.), *Affect, Cognition and Social Behavior* (pp. 25-43). Toronto: Hogrefe.

Evans, J. (1985). Office conditions influence VDU operator's health. *Health Safety Work, 7*, 34-36.

Fahrbach, P. A., & Chapman, L. J. (1990). VDT work duration and musculoskeletal discomfort. *American Association of Occupational Health Nurses Journal, 38*(1), 32-36.

Fairclough, S. H., & Houston, K. (2004). A metabolic measures of mental effort. *Biological Psychology, 66*, 177-190.

Faucett, J., & Rempel, D. (1996). Musculoskeletal symptoms related to video display terminal use: an analysis of objective and subjective exposure estimates. *American Association of Occupational Health Nurses Journal, 44*(1), 33-39.

Fendrich, D. W., Gesi, A. T., Healy, A. F., & Bourne, L. E., Jr. (1995). The contribution of procedural reinstatement to implicit and explicit memory effects in a motor task. In A. F. Healy & L. E. Bourne, Jr. (Eds.), *Learning and memory of knowledge and skills: Durability and specificity* (pp. 66-94). Thousand Oaks, CA: Sage.

Fendrich, D. W., Healy, A. F., & Bourne, L. E. Jr. (1991). Long-term repetition effects for motoric and perceptual procedures. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 137-151.

Finkelman, J. M. (1994). A large database study of the fatigue associated with work-induced fatigue. *Human Factors, 36*(2), 232-243.

Fisch, B. J. (1991). *Spehlman's EEG Primer* (Second revised and enlarged edition). Amsterdam: Elsevier Science.

Fitts, P. M. (1962). Factors in complex skill training. In R. Glaser (Ed.), *Training research and education* (pp. 177-197). Pittsburgh, PA: University of Pittsburgh Press.

Floru, R., & Cail, F. (1987). Data entry task on VDU: Underload or overload? In B. Knave & G. P. Wideback (Eds.), *Work with Display Units 86*. (pp. 756-767). Amsterdam: Elsevier Science Publishers.

Floru, R., Cail, F., & Elias, R. (1985). Psychophysiological changes during a VDU repetitive task. *Ergonomics, 28*(10), 1455-1468.

Fogarty, C., & Stern, J. A. (1989). Eye movements and blinks: their relationship to higher cognitive processes. *International Journal of Psychophysiology, 8*, 35-42.

Frijda, N. H. (1986). *The Emotions* (pp. 101-116). Cambridge: Cambridge University Press.

Gaillard, A. W. K. (1993). Comparing the concepts of mental load and stress. *Ergonomics, 36*(9), 991-1005.

Gaillard, A. W. K., & Wientjes, C. J. E. (1994). Mental load and work stress asa two types of energy mobilization. *Work & Stress, 8*(2), 141-152.

Galin, D., Johnstone, J., Herron, J. (1978). Effects of task difficulty on EEG measures of cerebral engagement. *Neuropsychologia, 16*, 461-472.

Galinsky, T. L., Swanson, N. G., Sauter, S. L., Hurrell, J. J., & Schleifer, L. M. (2000). A field study of supplementary rest breaks for data-entry operators. *Ergonomics, 43*(5), 622-638.

Gao, C., Lu, D., She, Q., Cai, R., Yang, L., & Zhang, G. (1990). The effects of VDT data entry work on operators. *Ergonomics, 33*(7), 917-924.

Gasser, T., Bacher, P., & Steinberg, H. (1985). Test-retest reliability of spectral parameters of the EEG. *Electroencephaolgraphy and Clinical Neurophysiology, 60*, 312-319.

Gevins, A. S., Remond, A. (1987). *Handbook of electroencephalography and clinical neuropsychology series vol. 1: Methods of analysis of brain electrical and magnetic signals*. Amsterdam: Elsevier.

Gevins, A., & Smith, M. E. (2003). Neurophysiological measures of cognitive workload during human-computer interaction. Theoretical Issues in Ergonomics Science, 4(1-2), 113-131.

Gevins, A., & Smith, M. E. (2000). Neurophysiological measures of working memory and individual differences in cognitive ability and cognitive style. *Cerebral Cortex, 10*(9), 829-839.

Gevins, A., & Smith, M. E. (1999). Detecting transient cognitive impairment with EEG pattern recognition methods. *Aviation, Space, and Environment and Medicine, 70*, 1018-1024.

Gevins, A., Smith, M. E., Leong, H., McEvoy, L., Whitfield, S., Du, R., & Rush, G. (1998). Monitoring working memory load during computer-based tasks with EEG pattern recognition methods. *Human Factors, 40*, 79-91.

Gevins, A., Smith, M. E., McEvoy, L. & Yu, D. (1997). High-resolution EEG mapping of cortical activation related to working memory: Effects of task difficulty, type of processing, and practice. *Cerebral Cortex, 7*, 374-385.

Gevins, A. S., & Schaffer, R. E. (1980). A critical review of electroencephalographic EEG correlates of higher cortical functions. *CRC critical Reviews in Bioengineering, 4*, 113-164.

Gevins, A. S., Zeitlin, G. M., Doyle, J. C., Yingling, C. D., Schaffer, R. E., Callaway, E., & Yeager, C. L. (1979). Electroencephalogram correlates of higher cortical functions. *Science, 203(4381)*, 665-668.

Godnig, E. C., & Hacunda, J. S. (1991). *Computers and Visual Stress: Staying Healthy*. Grand Rapids, MI: Abacus.

Gopher, D, & Donchin, E. (1986). Workload: an examination of the concept. In K. R. Boff, L. Kauffman & J. P. Thomas (Eds.), *Handbook of Perception and Human Performance* (pp. 41-49). New York: Willey.

Grandjean, E. (1988). Fitting the Task to the Man: A textbook of occupational ergonomics. Philadelphia: Taylor & Francis.

Grandjean, E. (1984). *Ergonomics and Health in Modern Offices*. London: Taylor & Francis.

Grier, R. A., Warm, J. S., Dember, W. N., Matthews, G., Galinsky, T. L., Szalma, J. L., & Parasuraman, R. (2003). The vigilance decrement reflects limitations in effortful attention, not mindlessness. *Human Factors, 45*(3), 349-359.

Gundel, A., & Wilson, G. F. (1992). Topographical changes in the ongoing EEG related to the difficulty of mental tasks. *Brain Topography, 5*, 17-25.

Hankins, T. C., & Wilson, G. F. (1998). A comparison of heart rate, eye activity, EEG and subjective measures of pilot mental workload during flight. *Aviation, Space, and Environmental Medicine, 69*(4), 360-367.

Harada, H., Okabe, K., Katsuura, T., & Kikuchi, Y. (1995). Effects of time stress on psychophysiological responses during data entry tasks. *Journal of Physiological Anthropology: Applied Human Science, 14*(6), 279-285.

Hartley, L. R., Arnold, P. K., Smythe, G., Hansen, J. (1994). Indicators of fatigue in truck drivers. *Applied Ergonomics, 25*(3), 143-156.

Hayashi, M., Chikazawa, Y., & Hori, T. (2004). Short nap versus short rest: recuperative effects during VDT work. *Ergonomics, 47*(14), 1549-1560.

He, J., Kinouchi, Y., Yamaquchi, H., Miyamoto, H. (1995). Exercise-induced changes in R wave amplitude and heart rate in normal subjects. *Journal of Electrocardiology, 28*(2), 99-106.

Healy, A. F., Kole, J. A., Buck-Gengler, C. J., & Bourne, L. E., Jr. (2004). Effects of prolonged work on data entry speed and accuracy. *Journal of Experimental Psychology: Applied, 10*(3), 188-199.

Hebb, D. O. (1955). Drives and the CNS (conceptual nervous system). *Psychological Review, 62*, 243-254.

Heckhausen, H., & Beckmann, J. (1990). Intentional action and action slips. *Psychological Review, 97*, 36-48.

Henning, R. A., Alteras-Webb, S. A., Jacques, J., Kissel, G. V., & Sullivan, A. B. (1993). Frequent, short breaks during computer work: The effect on productivity and well-being in a field study. In H. Luczak, A. Cakir & G. Cakir (Eds.), *Work with Display Units 92* (pp. 292-295). Amsterdam: Elsevier-North-Holland.

Henning, R. A., Jacques, P., Kissel, G. V., Sullivan, A. B., & Alteras-Webb, S. M. (1997). Frequent short rest breaks from computer work: effects on productivity and well-being at two field sites. *Ergonomics, 40*(1), 78-91.

Henning, R. A., Kissel, G. V., & Maynard, D. C. (1994). Compensatory rest breaks for VDT operators. *International Journal of Industrial Ergonomics, 14*, 243-249.

Henning, R. A., Sauter, S. L., Salvendy, G., & Krieg, E. F, Jr. (1989). Microbreak length, performance, and stress in a data entry task. *Ergonomics, 32*(7), 855-864.

Hermenau, D. C. (1999). Seating. In K. Jacobs (Ed.), *Ergonomics for Therapists* (2nd ed., pp. 219-237). Woburn, MA: Butterworth-Heinemann.

Higuchi, S., Liu, Y., Yuasa, T., Maeda, A., & Motohashi, Y. (2001). Diurnal variations in alpha power density and subjective sleepiness while performing repeated vigilance tasks. *Clinical Neurophysiology, 112*, 997-1000.

Hockey, G. R. J. (1997). Compensatory control in the regulation of human performance under stress and high workload: A cognitive-energetical framework. *Biological Psychology, 45*, 73-93.

Hockey, G. R. J. (1986). A state control theory of adaptation to stress and individual differences in stress management. In G. R. J. Hockey, A. W. K. Gaillard & M. G. H. Coles (Eds.), *Energetics and Human Information Processing* (pp. 285-298). Dordrecht: Kluwer Academic.

Hockey, G. R. J., Gaillard, A. W. K., & Coles, M. G. H. (1986). *Energetics and Human Information Processing*. Dordrecht: Kluwer Academic

Hockey, G. R. J., Coles, M. G. H., & Gaillard, A. W. K. (1986). Energetical issues in research on human information processing. In G. R. J. Hockey, A. W. K. Gaillard & M. G. H. Coles (Eds.), *Energetics and Human Information Processing* (pp. 3-21). Dordrecht: Kluwer Academic.

Hoffman, A. C. (1946). Eye movements during prolonged reading. *Journal of Experimental Psychology, 36*, 95-118.

Holding, D. H. (1983). Fatigue. In G. R. J. Hockey (Ed.). *Stress and Fatigue in Human Performance* (pp. 145-167). Chichester: John Wiley.

Hong Kong Government Gazette. (1997). *Occupational Safety and Health Ordinance*, Hong Kong: The Government of Hong Kong.

Humphreys, M. A., & Revelle, W. (1984). Personality, motivation and performance: A theory of the relationship between individual differences and information processing. *Psychological Review, 91*, 153-184.

Ignatius, Y. T. S., Yee, T. Y., Yan, L. T. (1993). Self reported musculoskeletal problems among typists and possible risk factors. Journal of Human Ergology, 22, 83-93.

Jausovec, N., & Jausovec, K. (2000). EEG activity during the performance of complex mental problems. *International Journal of Psychophysiology, 36*, 73-88.

Jorna, P. G. A. M. (1992). Spectral analysis of heart rate and psychological state: A review of its validity as a workload index. *Biological Psychology, 34*, 237-257.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.

Kamada, T., Sato, N., Miyake, S., Kumashiro, M., Monou, H. (1992). Power spectral analysis of heart rate variability in type As during solo and competitive mental arithmetic task. *Journal of Psychosomatic Research, 36*(6), 543-551.

Kandel, E. R., Schwartz, J. H., & Jessell, T. M. (2000). *Principles of Neural Science* (4th ed., pp. 961-1013). New York: McGraw-Hill.

Kaneko, K., & Sakamoto, K. (2001). Spontaneous blinks as a criterion of visual fatigue during prolonged work on visual display terminals. *Perceptual and Motor Skills, 92*, 234-250.

Kantowitz, B. H. (1988). Mental workload. In P. A. Hancock (Ed.), *Human Factors Psychology* (pp. 81-121). Amsterdam: Elsevier.

Kantowitz, B. H., & Casper, P. A. (1988). Human mental workload in aviation. In E. L. Wiener & D. C. Ngel (Eds.), *Human Factors in Aviation* (pp. 157-187). San Diego: Academic Press.

Kennard, D. W., & Smyth, G. L. (1963). Interaction of mechanisms causing eye and eyelid movement. *Nature, 197*, 50-52.

Kiroy, V. N., Warsawskaya, L. V., & Voynov, V. B. (1996). EEG after prolonged mental activity. *International Journal of Neuroscience, 85*(1-2), 31-43.

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Research Reviews, 29*, 169-195.

Klimesch, W. (2000). EEG alpha and cognitive processes. In R. Miller (Ed.), Time *and The Brain* (pp. 203-223). Amsterdam: Harwood Academic.

Klimesch, W., Schimke, H., & Schwaiger, J. (1994). Episodic and semantic memory: an analysis in the EEG theta and alpha band. *Electroencephalography and Clinical Neurophysiology, 91*, 428-441.

Kodiath, M. F., & Kodiath, A. (1995). A comparative study of patients who experience chronic malignant pain in India and the United States. *Cancer Nursing 18*(3), 189-96.

Kopardekar, P., & Mital, A. (1994). The effect of different work-rest schedules on fatigue and performance of a simulated directory assistance operator's task. *Ergonomics, 37*(10), 1697-1707.

Krueger, G. P. (1989). Sustained work, fatigue, sleep loss and performance: A review of the issues. *Work & Stress, 3*, 129-141.

LaBerge, D. (1983). Spatial extent of attention to letters and words. *Journal of Experimental Psychology: Human Perception and Performance, 9*, 371-379.

Lal, S. K. L., & Craig, A. (2000). Psychophysiological effects associated with drowsiness: Driver fatigue and electroencephalography. *International Journal of Psychophysiology, 35*, 39.

Lal, S. K. L., & Craig, A. (2001). A critical review of the psychophysiology of drive fatigue. *Biological Psychology, 55*, 173-194.

Lal, S. K. L., & Craig, A. (2002). Driver fatigue: Electroencephalography and psychological assessment. *Psychophysiology, 39*, 313-321.

Lal, S. K. L., & Craig, A. (2005). Reproducibility of the spectral components of the electroencephalogram during driver fatigue. *International Journal of Psychophysiology, 55*, 137-143.

Larson, C. L., Davidson, R. J., Abercrombie, H. C., Ward, R. T., Schaefer, S. M., Jackson, D. C., Holden, J. E., & Perlman, S. B. (1998). Relations between PET-derived measures of thalamic glucose metabolism and EEG alpha power. *Psychophysiology, 35*(2), 162-169.

Leung, A. W. S., Chan, C. C. H., Lee, A. H. S., & Lam, K. W. H. (2004). Visual analogue scale correlates of musculoskeletal fatigue. *Perceptual and Motor Skills, 99*, 235-246.

Leung, A. W. S., Chan, C. C. H., & He, J. (2004). Structural stability and reliability of the Swedish occupational fatigue inventory among Chinese VDT workers. *Applied Ergonomics, 35*, 233-241.

Leung, A. W. S., Chan, C. C. H., Ng, J. J. M., Wong, P. C. C. (2006). Factors contributing to officers' fatigue in high-speed maritime craft operations. *Applied Ergonomics, 37*, 565-576.

Lukiesh, M. (1947). Reading and the rate of blinking. *Journal of Experimental Psychology, 37*, 266-288.

Lundberg, U., Melin, B., Evans, G. W., & Holmberg, L. (1993). Physiological deactivation after two contrasting tasks at a video display terminal: Learning vs repetitive data entry. *Ergonomics, 36*(6), 601-611.

Luria, A. R. (1973). *The Working Brain*. London: Penguin Press.

Mackworth, J. F. (1969). *Vigilance and habituation*. Harmondsworth: Penguim.

Mackworth, N. H. (1950). Researches on the measurement of human performance. *Medical Research Council Special Report Series 268*. London: HMSO.

Makeig, S., & Jung, T. (1996). Tonic, phasic, and transient EEG correlates of auditory awareness in drowsiness. *Cognitive Brain Research, 4*, 15-25.

Matthews, G., Davies, D. R., Westerman, S. J., & Stammers, R. B. (2000). *Human Performance: Cognition, stress and individual differences*. Philadelphia: Taylor & Francis.

McCallum, W. C., Cooper, R., & Pocock, P. V. (1988). Brain slow potential and ERP changes associated with operator load in a visual tracking task. *Electroencephalograhy and Clinical Neurophysiology, 69*, 453-468.

McGregor, D. K., & Stern, J. A. (1996). Time on task and blink effects on saccade duration. *Ergonomics, 39*, 649-660.

McLean, L., Tingley, M., Scott, R. N., & Rickards, J. (2001). Computer terminal work and the benefit of microbreaks. *Applied Ergonomics, 32*, 225-237.

Moray, N. (1967). Where is capacity limited? A survey and a model. *Acta Psychologica*, 27, 84-92.

Mulder, G. (1986). The concept and measurement of mental effort. In G. R. J. Hockey, A. W. K. Gaillard & M. G. H. Coles (Eds.), *Energetics and Human Information Processing* (pp. 175-198). Dordrecht: Kluwer Academic.

Mulder, G. (1988). Assessment if cardiovascular reactivity by means of spectral analysis. Groningen: University of Groningen Press.

Mulholland, T. (1995). Human EEG, behavioral stillness and biofeedback. *International Journal of Psychology, 19*, 263-279.

Murata, K., Araki, S., Kawakami, N., Saito, Y., & Hino, E. (1991). Central nervous system effects and visual fatigue in VDT workers. *International Archives of Occupational and Environmental Health, 63*(2), 109-113.

Muraven, M., & Baumeister, R. F. (2000). Self-regulation and depletion of limited resources: does self-control resemble a muscle? *Psychological Bulletin, 126*(2), 247-259.

Nachreiner, F. (1999). International standards on mental work-load-the ISO 10075 series-. *Industrial Health, 37*, 125-133.

National Institute of Occupational Safety and Health (NIOSH). (1999). *Stress At work* (pp. 99-101). Washington, DC: U. S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

Nelson, N. A., & Silverstein, B. A. (1998). Workplace changes associated with a reduction in musculoskeletal symptoms in office workers. *Human Factors, 40*(2), 337-350.

Neri, D. F., Oyung, R. L., Colletti, L. M., Mallis, M. M., Tam, P. Y., & Dinges, D. F. (2002). Controlled breaks as a fatigue countermeasure on the flight desk. *Aviation, Space, and Environmental Medicine, 73*(7), 654-664.

Neves, D. M., & Anderson, J. R. (1981). Knowledge compilation: Mechanisms for the automatization of cognitive skills. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 57-84). Hillsdale, NJ: Lawrence Erlbaum Associates.

Newsholme, E. A., Blomstrand, E., & Ekblom, B. (1992). Physical and mental fatigue: Metabolic mechanisms and importance of plasma amino acids. *British Medical Bulletin, 48*(3), 477-495.

Norman, D. A. (1891). Categorization of action slips. *Psychological Review, 88*, 1-15.

Norman, D. A. (1988). *The Psychology of Everyday Things*. New York: Basic Books.

Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric theory (3rd Ed.)* New York: McGraw-Hill.

O'Donnell, R. D., & Eggemeier, F. T. (1986). Workload assessment methodology. In K. Boff, L. Kaufman & J. P. Thomas (Eds.), *Handbook of Perception and Human Performance* (pp. 42.1-42.49). New York: Willey.

Ogilvie, R. D., & Simons, I. A. (1992). Falling asleep and waking up: a comparison of EEG spectra. In R. J. Broughton & R. D. Ogilvie (Eds.), *Sleep, arousal, and performance* (pp. 73-87). Boston: Birkhauser.

O'Hanlon, J. F. (1981). Stress in short-cycle repetitive work: general theory and an empirical test. In G. Salvendy & J. Smith (Eds.), *Machine Pacing and Occupational Stress* (pp. 213-222). London: Taylor & Francis.

Okogbaa, O, G., Shell, R. L., & Filipusic, D. (1994). On the investigation of the neurophysiological correlates of knowledge worker mental fatigue using the EEG signal. *Applied Ergonomics, 25*(6), 355-365.

Omori, Y., Miyata, Y., & Yamada, F. (1996). The effects of visibility and memory load on blink rate during visual search task. In K. Shirakura, S. Tsutsui & I. Saito (Eds.), *Current Biofeedback Research in Japan 1995 – 1996* (pp. 1-6). Tokyo: Japanese Society of Biofeedback Research.

Orchard, L. N., & Stern, J. A. (1991). Blinks as an index of cognitive activity during reading. *Integrative Physiological and Behavioral Science, 26*(2), 108-116.

Papanicalaou, A. C., Loring, D. W., Deutsch, G., & Eisenberg, H. M. (1996). Task-related EEG asymmetries: a comparison of alpha blocking and beta enhancement. *International Journal of Neuroscience, 30*, 81-85.

Parasuraman, R., Warm, J. S., & Dember, W. N. (1987). Vigilance: Taxonomy and utility. In L. S. Mark, J. S. Warm & R. L. Huston (Eds.), *Ergonomics and Human Factors: Recent Research* (pp. 11-32). New York: Springer Verlag.

Patel, S., Henderson, R., Bradley, L., Galloway, B., & Hunter, L. (1991). Effect of visual display unit use on blink rate and tear stability. *Optometry & Visual Science, 68*, 888-892.

Parks, R. W., Crockett, D. J., Tuokko, H., Beattie, B. L., Ashford, J. W., Coburn, K. L., Zec, R. F., Becker, R. E., McGeer, P. L., & McGeer, E. G. (1989). Neuropsychological system efficiency' and positron emission topography. *Journal of Neuropsychiatry, 1*, 269-282.

Paus, T., Zatorre, R. J., Hofle, N., & Caramanos, Z. (1997). Time-related changes in neural systems underlying attention and arousal during the performance of an auditory vigilance task. *Journal of Cognitive Neuroscience, 9*(3), 392-408.

Pfaff, H., Fruhstorfer, H., & Peter, J. H. (1976). Changes in eye-blink during and frequency during car driving. *European Journal of Physiology, 362*, R21.

Pfurtscheller, G., Neuper, C., & Mohl, W. (1994). Event-related desynchronization (ERD) during visual processing. *International Journal of Psychophysiology, 16*, 147-153.

Phelps, M. E., Kuhl, D. E., & Mazziotta, J. C. (1981). Metabolic mapping of the brain's response to visual stimulation: Studies in man. *Science, 211*, 1445-1448.

Pickett, C. W., & Lees, R. E. (1991). A cross-sectional study of health complaints among 79 data entry operators using video display terminals. *Journal of Society of Occupational Medicine, 41*(3), 113-116.

Picone, P. (1999). Environmental design. In K. Jacobs (Ed.), *Ergonomics for Therapists* (2nd ed., pp. 135-156). Woburn, MA: Butterworth-Heinemann.

Pinsky, M. (1987). *The VDT Book: A Computer Users Guide to Health and Safety*. New York: New York Committee for Occupational Safety and Health.

Popovich, P. R., & Hachaturyanz, A. F. (1983). Psychophysiological aspects of non-stopped prolonged cosmonaut's work and methods of its optimization. In *Vsesoyuznogo phyiologicheskogo obshestva im. I. P. Pavlova. Baku*, Vol. 1, pp. 405-406. (in Russian).

Portney, L. G., Watkins, M. P., 2000. Foundations of clinical research: Application to practice. Prentice-Hall, New Jersey.

Posner, M. I. (1982). Cummulative development of attentional theory. *American psychologist, 32*, 533-564.

Posner, M. I., & Peterson, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25-42.

Posner, M. I., & Rafal, R. D. (1987). Cognitive theories of attention and the rehabilitation of attentional deficits. In M. J. Meier, A. L. Benton & L. Diller (Eds.), *Neuropsychological Rehabilitation* (pp. 182-201). New York: Churchill Livingstone.

Posner, M. I., & Raichle, M. E. (1997). *Images of Mind*. New York: Scientific American Library.

Posner, M. I., & Rothbart, M. K. (1992). Attentional mechanisms and conscious experience. In D. Milner & M. Rugg (Eds.), *The neuropsychology of consciousness* (pp. 91-111). San Diego, CA: Academic Press.

Posner, M. I., & Rothbart, M. K. (1986). The concept of energy in psychological theory. In G. R. J. Hockey, A. W. K. Gaillard & M. G. H. Coles (Eds.), *Energetics and Human Information Processing* (pp. 23-40). Dordrecht: Kluwer Academic.

Posner, M. I., & Tudela, P. (1997). Imaging resources. *Biological Psychology, 45*, 95-107.

Posner, M. I., Walker, J. A., Friedrich, F., & Rafal, R. D. (1984). Effects of parietal lobe injury on covert orienting of visual attention. *Journal of Neuroscience, 4*, 1863-1874.

Pribram, K. H., & McGuinness, D. (1975). Arousal, activation and effort in the control of attention. *Psychological Review, 82*, 116-149.

Rabbitt, P. M. A. (1978). Detection of errors by skilled typists. *Ergonomics, 21*, 945-958.

Rappelsberger, P., & Petsche, H. (1988). Probability mapping: power and coherence analysis of cognitive processes. *Brain Topography, 1*, 46-54.

Rasmussen, J. (1982). Human errors: a taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents, 4*, 311-333.

Reason, J. T. (1984). Lapses of attention in everyday life. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 515-549). San Diego, CA: Academic Press.

Reason, J. (1979). Actions not as planned: the price of automatization. In G. Underwood & R. Stevens (Eds.), *Aspects of consciousness, Vol. 1: Psychological issues* (pp. 67-89). Chichester, UK: Wiley.

Reason, J. T. (1990). *Human Error*. Cambridge: Cambridge University Press.

Reason, J., & Mycielska (1982). *Absent-minded? The psychology of mental lapses and everyday errors* (pp. 1-37). Englewood Cliff, NJ: Prentice-Hall.

Rechichi, C., De Moja, C., & Scullica, L. (1996). Psychology of computer use: 36 visual discomfort and different types of work at video display terminals. *Perceptual and Motor Skills, 82*, 935-938.

Rockstroh, B., Elbert, T., Canavan, A., Lutzenberger, W., & Birbaumer, N. (1989). *Slow cortical potentials and behavior*. Baltimore: Urban & Schwarzenberg.

Robbins, T. W. (1997). Arousal systems and attentional processes. *Biological Psychology, 45*, 57-71.

Robbins, T. W. (1986). Psychopharmacological and neurobiological aspects of the energetics of information processing. In G. R. J. Hockey, A. W. K. Gaillard & M. G. H. Coles (Eds.), *Energetics and Human Information Processing* (pp. 71-90). Dordrecht: Kluwer Academic.

Rodahl, K.,1989. The physiology of work. Taylor & Francis, London.

Roethlisberger, F. J., & Dickson, W. (1939). *Management and the worker: an account of a research program conducted by the Western electric company.* Cambridge, MA: Harvard University Press.

Roscoe, A. H. (1992). Assessing pilot workload. Why measure heart rate, HRV and respiration? *Biological Psychology, 34*, 259-287.

Rugg, M. D., & Dickens, A. M. (1982). Dissociation of alpha and theta activity as a function of verbal and visual-spatial tasks. *Electroencephalography and Clinical Neurophysiology, 51*, 201-207.

Rumelhart, D. E., & Norman, D. A. (1982). Simulating a skilled typist: A study of skilled cognitive-motor performance. *Cognitive Science, 6*, 1-36.

Sammer, G. (1998). Heart period variability and respiratory changes associated with physical and mental load: non-linear analysis. *Ergonomics, 41*(5), 746-755.

Sanders, A. F. (1997). A summary of resource theories from a behavioral perspective. *Biological Psychology, 45*, 5-18.

Sanders, A. F. (1983). Towards a model of stress and human performance. *Acta Psychologica, 53*, 61-97.

Santamaria, J., & Chiappa, K. H. (1987). The EEG of drowsiness in normal adults. *Journal of Clinical Neurophysiology, 4*, 327-382.

Sauter, S. L. (1991). Work postures, workstation design and musculoskeletal discomfort in a VDT entry task. *Human Factors, 33*(2), 151-167.

Schellekens, J. M. H., Sijtsma, G. J., Vegter, E., & Meijman, T. F. (2000). Immediate and delayed after-effects of long lasting mentally demanding work. *Biological Psychology, 53*, 37-56.

Schier, M. A. (2000). Changes in EEG alpha power during simulated driving: a demonstration. *International Journal of Psychophysiology, 37*, 155-162.

Schleifer, L. M., & Ley, R. (1994). End-tidal PCO_2 as an index of psychophysiological activity during VDT data-entry work and relaxation. *Ergonomics, 37*(2), 245-254.

Schleifer, L. M., & Okogbaa, O. G. (1990). System response time and method of pay: cardiovascular stress effects in computer-based tasks. *Ergonomics, 33*(12), 1495-1509.

Schleifer, L. M., Sauter, S. L., Smith, R. J., & Knutson, S. (1990). Ergonomics predictors of visual system complaints in VDT data entry. *Behavior and Information Technology, 9*(4), 273-282.

Schlote, T., Kadner, G., & Freudenthaler, N. (2004). Marked reduction and distinct patterns of eye blinking in patients with moderately dry eyes during video display terminal use. *Graefe's Archive for Clinical and Experimental Ophthalmology, 242*(4), 306-312.

Schneider, W., & Fisk, A. D. (1982). Concurrent automatic and controlled visual search: Can processing occur without resource cost? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*, 261-278.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search and attention. *Psychological Review, 84*, 1-66.

Shallice, T., & Burgess, P. (1993). Supervisory control of action and thought selection. In A. D. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, awareness, and control: a tribute to Donald Broadbent*. Oxford: Oxford University Press.

Sharpless, S., & Jaspers, H. (1956). Habituation of the arousal reaction. *Brain, 79*, 655-680.

Sheer, D. E. (1989). Sensory and cognitive 40 Hz event-related potentials: Behavioral correlates, brain function, and clinical application. In E. Basar & T. H. Bullock (Eds.), *Brain Dynamics, vol. 2* (pp. 339-374). Berlin: Springer.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84*, 127-190.

Siu, Z. K. F., Chan, C. C. H., Wong, L. T. L., & Hung, L. K. (1999). Work-related psychological factors and musculoskeletal discomfort among VDT workers. In *Proceedings of work stress & health '99: Organization of work in a global economy* (pp. 207). Baltimore: American Psychological Association and National Institute for Occupational Safety and Health.

Steptoe, A., Fieldman, G., & Evans, O. (1993). An experimental study of the effects of control over work pace on cardiovascular responsivity. *Journal of Psychophysiology, 7*, 290-300.

Sterman, M. B., & Mann, C. A. (1995). Concepts and applications of EEG analysis in aviation performance evaluation. *Biological Psychology, 40*, 115-130.

Sterman, M. B., Mann, C. A., & Kaiser, D. A. (1992). Quantitative EEG patterns of differential in-flight workload. *Space Operations Applications and Research Proceedings*, pp. 466-473.

Stern, R. M., Ray, W. J., & Quigley, K. S. (2001). *Psychophysiological Recording*. (2nd ed.). New York: Oxford University Press.

Stern, J. A., Walrath, L. C., & Goldstein, R. (1984). The endogenous eyeblink. *Psychophysiology, 21*(1), 22-33.

Stuss, D. T., & Benson, D. F. (1984). Neuropsychological studies of the frontal lobes. *Psychological Bulletin, 95*, 3-28.

Stuss, D. T., & Benson, D. F. (1986). *The Frontal Lobes*. New York: Raven Press.

Tanaka, Y., & Yamaoka, K. (1993). Blink activity and task difficulty. *Perceptual & Motor Skills, 77*, 55-66

Task Force of The European Society if Cardiology and The North American Society of Pacing and Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal, 17*, 354-381.

Tinker, M. A. (1946). Validity of frequency of blinking as a criterion of readability. *Journal of Experimental Psychology, 36*, 453-460.

Tucker, P. (2003). The impact of rest breaks upon accident risk, fatigue and performance: a review. *Work & Stress, 17*(2), 123-137.

Ursin, H. (1986). Energetics and the self regulation of activation. In G. R. J. Hockey, A. W. K. Gaillard & M. G. H. Coles (Eds.), *Energetics and Human Information Processing* (pp. 53-70). Dordrecht: Kluwer Academic.

Van Orden, K. F., Limbert, W., Makeig, S., & Jung, T. P. (2001). Eye activity correlates of workload during a visuospatial memory task. *Human Factors, 43*(1), 111-121.

Van Winsum, W., Sergeant, J., & Geuze, R. (1984). The functional significance of event related desynchronization of alpha rhythm in attentional and activating tasks. *Electroencephalograhy & Clinical Neurophysiology, 58*, 519-524.

Vasseljen, O., & Westgaard, R. H. (1997). Arm and trunk posture during work in relation to shoulder and neck pain and trapezius activity. *Clinical Biomechanics 12*(1), 22-31.

Veltman, J. A. & Gaillard, A. W. K. (1996). Physiological indices of workload in a simulated flight task. *Biological Psychology, 42*, 323-342.

Veltman, J. A. & Gaillard, A. W. K. (1998). Physiological workload reactions to increasing levels of task difficulty. *Ergonomics, 41*(5), 656-669.

Vicente, K. J., Thornton, D. C., & Moray, N. (1987). Spectral analysis of sinus arrhythmia: A measure of mental effort. *Human Factors, 29*(2), 171-182.

Walsh, F. B., Hoyt, W. F. (1969). *Clinical Neuro-Ophthalmology* (3rd ed.). Baltimore: Williams & Wilkins.

Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and workload in automated systems. In R. Parasuraman & M. Mouloua (Eds.), *Automation and Human Performance: Theory and applications* (pp. 183-200). New Jersey: Lawrence Erlbaum Associates.

Westgaard, R. H., & Aaras, A. (1984). Postural muscle strain as a causal factor in the development of musculo-skeletal illness. *Applied Ergonomics 15*(3), 162-174.

Wickens, C. D. (1984). Processing resources in attention. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 63-102). New York, NY: Academic Press.

Wickens, C. D., & Hollands, J. G. (2000). Engineering Psychology and Human Performance (3rd ed.). New Jersey: Prentice-Hall.

Wiethoff, M., & Hockey, G. R. J. (1996). Intra-individual analysis of the demand-strain relationship: a multi-level field study of the impact of natural variations in the workload of junior doctors. Applied Psychology: An international review.

Wilson, G. F., Swain, C. R., & Ullsperger, P. (1999). EEG power changes during multiple level memory retention task. *International Journal of Psychophysiology, 32*, 107-118.

Wood, J. G., & Hassett, J. (1983). Eyeblinking during problem solving: The effect of problem difficulty and internally vs externally directed attention. *Psychophysiology, 20*(1), 18-20.

Wright, N., & McGown, A. (2001). Vigilance on the civil flight deck: incidence of sleepiness and sleep during long-haul flights and associated changes in physiological parameters. *Ergonomics, 44*(1), 82-106.

Yamada, F. (1998). Frontal midline theta rhythm and eyeblinking activity during a VDT task and a video game. *Ergonomics, 41*, 678-688.

Yamamoto, S., & Matsuoka, S. (1990). Topographic EEG study of visual display terminal (VDT) performance with special reference to frontal midline theta waves. *Brain Topography, 2*(4), 257-267.

Zomeren, A. H., & Brouwer, W. H. (1994). *Clinical Neuropsychology of Attention* (pp. 39-62). New York: Oxford University Press.

APPENDICES

Appendix I : Descriptions of the Items and Subscales of the SOFI-C

The items in each subscale are listed below.
(extracted from the article: Ahsberg E, Gamberale F, Kjellberg A. (1997), Perceived quality of fatigue during different occupational tasks: Development of a questionnaire. *International Journal of Indutrial Ergonomics*, 20, 121-135.

Subscale 1: Physical exertion
- Items: Palpitation
  - Sweaty
  - Warm
  - Out of breath
  - Breathing heavily

Subscale 2: Physical discomfort
- Items: Tense muscle
  - Numbness
  - Stiff joints
  - Hurting
  - Aching

Subscale 3: Lack of energy
- Items: Worn out
  - Exhausted
  - Spent
  - Drained
  - Overworked

Subscale 4: Lack of motivation
- Items: Lack of concern
  - Listless
  - Passive
  - Indifferent
  - Uninterested

Subscale 5: Sleepiness
- Items: Lazy
  - Falling asleep
  - Drowsy
  - Yawning
  - Sleepy

Appendix II : The Chinese version of the Swedish Occupational Fatigue Inventory (SOFI-C)

瑞典職業疲勞評估表
中文版

試想想現在你的疲勞感覺。以下的詞語在什麼程度上正確地形容你現在的感覺？請隨你自己的意願圈出相當於你現在感覺的程度的數字。數字由 0 (程度極少) 至 10 (程度極大) 排列。

	程度極少										程度極大
	0	1	2	3	4	5	6	7	8	9	10
心跳急速 Palpitation	0	1	2	3	4	5	6	7	8	9	10
不感關注 Lack of concern	0	1	2	3	4	5	6	7	8	9	10
懶惰 Lazy	0	1	2	3	4	5	6	7	8	9	10
筋疲力竭 Worn out	0	1	2	3	4	5	6	7	8	9	10
肌肉繃緊 Tense muscle	0	1	2	3	4	5	6	7	8	9	10
痲痺 Numbness	0	1	2	3	4	5	6	7	8	9	10
冒汗 Sweaty	0	1	2	3	4	5	6	7	8	9	10
精力耗盡 Exhausted	0	1	2	3	4	5	6	7	8	9	10
沒精打彩 Listless	0	1	2	3	4	5	6	7	8	9	10
打瞌睡 Falling asleep	0	1	2	3	4	5	6	7	8	9	10
體力耗盡 Spent	0	1	2	3	4	5	6	7	8	9	10
昏昏欲睡 Drowsy	0	1	2	3	4	5	6	7	8	9	10
消極被動 Passive	0	1	2	3	4	5	6	7	8	9	10
關節僵硬 Stiff joints	0	1	2	3	4	5	6	7	8	9	10
發暖 Warm	0	1	2	3	4	5	6	7	8	9	10
漠不關心 Indifferent	0	1	2	3	4	5	6	7	8	9	10
痛苦 Hurting	0	1	2	3	4	5	6	7	8	9	10
喘不過氣 Out of breath	0	1	2	3	4	5	6	7	8	9	10
打呵欠 Yawning	0	1	2	3	4	5	6	7	8	9	10
體力衰竭 Drained	0	1	2	3	4	5	6	7	8	9	10
渴睡 Sleepy	0	1	2	3	4	5	6	7	8	9	10
操勞過度 Overworked	0	1	2	3	4	5	6	7	8	9	10
疼痛 Aching	0	1	2	3	4	5	6	7	8	9	10
呼吸沉重 Breathing heavily	0	1	2	3	4	5	6	7	8	9	10
枯燥乏味 Uninterested	0	1	2	3	4	5	6	7	8	9	10

Translated from the Swedish Occupational Fatigue Inventory (SOFI); extracted from Ahsberg E, Kecklund G, Akerstedt T, Gamberale F. Shiftwork and different dimensions of fatigue. *Int J of Ind Ergo* 2000; 26: 457-465.

Appendix III:Complete Set of Questionnaire on the Occupational Fatigue Survey

編號.: ____________

電腦終端機操作員之職業疲勞問卷調查

Occupational fatigue survey on VDT workers

問卷
Questionnaire

請細閱及簽署同意書 (第 2-3 頁)

問卷共兩部份，請用大約十分鐘完成問卷。

第一部份 – 職業疲勞之評估
請依照指示填寫 "瑞典職業疲勞評估表"。
(第 4 頁)

第二部份 – 個人資料
(第 5-7 頁)

第三部份 – 職業疲勞之評估
(第 8 頁) 有待研究員的指引才填寫

Please read and sign the consent form (refer to page 2-3)

The questionnaire consisted of two parts. It will take you about 10 minutes for completion.

Part I – Occupational fatigue assessment
Please complete "The Swedish Occupational Fatigue Inventory"
(Refer to page 4)

Part II – Demographic Characteristics
(Refer to page 5-7)

Part III – Occupational fatigue assessment
(Refer to page 8) No need to fill in until announcement by staff.

Consent form (English version) Page 2

Consent Form

Research project: Occupational fatigue on VDT users

Project title: Validation of the Swedish Occupational Fatigue Inventory (SOFI) for VDT workers

Investigators: Ada W.S. Leung
Research student, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University.

Dr. Chetwyn C.H. Chan
Associate Professor, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University.

Aim of study: This study is to validate Chinese version of the Swedish Occupational Fatigue Inventory for assessing fatigue among VDT users in Hong Kong.

I agree to participate in the field test and fill in questionnaires. I will be asked on Information regarding my work and personal data. In this study, I will be requested to evaluate my occupational fatigue for several times which include the one that I did yesterday by filling in the 'Swedish Occupational Fatigue Inventory'. Therefore, I will be requested to evaluate my occupational fatigue again during the talk today.

I understand that the study carries no risks to me. There will be no direct benefits for me. My name will not appear in any document or report. All information collected in this study will be kept in confidential. Results obtained from the study may be used as reports or contribute in academic teaching. My participation in this study is completely voluntary. I am free to withdraw my consent and stop participating at any time without penalty. If I have any inquiries regarding the study, I can direct them to the researchers for clarification.

I __________________________ have read this form, understood my involvement in the study and voluntarily agreed to participate.

______________________________ ____________________________
Signature of Participant Date

Consent form (Chinese version) Page 3

同意書

研究計劃：電腦終端機操作員之職業疲勞
研究項目：核準 “瑞典職業疲勞評估表”
研究生：梁詠思, 香港理工大學復康治療學系研究生
研究顧問：陳智軒博士, 副教授, 香港理工大學復康治療學系研究主任
研究目的：研究中文版之 “瑞典職業疲勞評估表” 對評估香港電腦終端機操作員之職業疲勞的適用性。

本人願意接受問卷調查並參加現場訪問。本人會被要請填寫問卷並透露個人及工作資料。在此項研究中，本人會多次被要求評估自己的職業疲勞指數，包括作天已填寫了一次的評估表。故此在講座裏，本人將會再被要請使用 “瑞典職業疲勞評估表” 來評估自己的職業疲勞指數。

本人明白此項研究對我沒有傷害，也沒有直接得益。在這研究所取得的一切資料會絕對保密。本人的名字也不會出現於任何的資料庫，而研究的結果會可能用作整體的報告，或教學及學術的用途。本人明白參與此項研究純屬自願性質。在過程中，本人可以隨時停止提供資料及退出參與此項研究。如對是項研究有任何疑問，本人可向在場的研究員查詢或致電梁詠思(電話:27667090)。

本人己經明白研究的原因及過程，並同意參與。

本人 ____________________ 巳閱讀此同意書，明白其內容並願意參與此項研究。

____________________________ ____________________
參加者簽署 日期

Part I

瑞典職業疲勞評估表
中文版

試想想現在你的疲勞感覺。以下的詞語在什麼程度上正確地形容你現在的感覺？請隨你自己的意願圈出相當於你現在感覺的程度的數字。數字由 0 (程度極少) 至 10 (程度極大) 排列。

	程度極少										程度極大
	0	1	2	3	4	5	6	7	8	9	10
心跳急速 Palpitation	0	1	2	3	4	5	6	7	8	9	10
不感關注 Lack of concern	0	1	2	3	4	5	6	7	8	9	10
懶惰 Lazy	0	1	2	3	4	5	6	7	8	9	10
筋疲力竭 Worn out	0	1	2	3	4	5	6	7	8	9	10
肌肉繃緊 Tense muscle	0	1	2	3	4	5	6	7	8	9	10
痲痺 Numbness	0	1	2	3	4	5	6	7	8	9	10
冒汗 Sweaty	0	1	2	3	4	5	6	7	8	9	10
精力耗盡 Exhausted	0	1	2	3	4	5	6	7	8	9	10
沒精打彩 Listless	0	1	2	3	4	5	6	7	8	9	10
打瞌睡 Falling asleep	0	1	2	3	4	5	6	7	8	9	10
體力耗盡 Spent	0	1	2	3	4	5	6	7	8	9	10
昏昏欲睡 Drowsy	0	1	2	3	4	5	6	7	8	9	10
消極被動 Passive	0	1	2	3	4	5	6	7	8	9	10
關節僵硬 Stiff joints	0	1	2	3	4	5	6	7	8	9	10
發暖 Warm	0	1	2	3	4	5	6	7	8	9	10
漠不關心 Indifferent	0	1	2	3	4	5	6	7	8	9	10
痛苦 Hurting	0	1	2	3	4	5	6	7	8	9	10
喘不過氣 Out of breath	0	1	2	3	4	5	6	7	8	9	10
打呵欠 Yawning	0	1	2	3	4	5	6	7	8	9	10
體力衰竭 Drained	0	1	2	3	4	5	6	7	8	9	10
渴睡 Sleepy	0	1	2	3	4	5	6	7	8	9	10
操勞過度 Overworked	0	1	2	3	4	5	6	7	8	9	10
疼痛 Aching	0	1	2	3	4	5	6	7	8	9	10
呼吸沉重 Breathing heavily	0	1	2	3	4	5	6	7	8	9	10
枯燥乏味 Uninterested	0	1	2	3	4	5	6	7	8	9	10

Translated from the Swedish Occupational Fatigue Inventory (SOFI); extracted from Ahsberg E, Kecklund G, Akerstedt T, Gamberale F. Shiftwork and different dimensions of fatigue. *Int J of Ind Ergo* 2000; 26: 457-465.

END OF PART I

編號：____________ page 5

第二部份 – 個人資料
Part II – Demographic Characteristics

請於適當方格內加✓號
Please answer by putting a tick in the appropriate box.

1. Please indicate your sex 你的性別是
   - □ Male 男
   - □ Female 女

2. Please indicate your age 你的年齡是介乎在下列那一個範圍？
   - □ Below 21 二十一歲以下
   - □ 21 – 25 二十一至二十五歲
   - □ 26 – 30 二十六至三十歲
   - □ 31 – 35 三十一至三十五歲
   - □ 36 – 40 三十六至四十歲
   - □ 41 – 45 四十一至四十五歲
   - □ 46 – 50 四十六至五十歲
   - □ 50 or above 五十歲或以上

3. Are you right-handed or left-handed? 那是你的慣用手？
   - □ Right-handed 右手
   - □ Left-handed 左手
   - □ Ambidextrous 左、右手均用

4. Please indicate your martial status. 你的婚姻狀況是
   - □ Never married 未婚
   - □ Married 已婚
   - □ Others 其他: ________________________

5. Do you have child/children? 你有沒有孩子？
   - □ Yes 有 (Please indicate the number 請列明數目 : _____________
   - □ No 沒有

6. Please indicate your highest educational attainment.你的教育程度是
   - □ Below form 3 中三以下
   - □ Completed form 3 中三畢業
   - □ Secondary (Complete form 5) 中學畢業 (完成中五)
   - □ Matriculation 預科畢業或專業訓練
   - □ Post secondary 大專畢業
   - □ University or above 大學畢業或以上

7. Have you ever had any vocational training? 你曾否接受過職業訓練？

☐ Yes 有 (Please specify 請詳細列明: ____________________________)
☐ No 沒有

8. Do you have the following chronic illnesses at present?
你現在是否患有以下的慢性疾病？

☐ Chronic Obstructive Pulmonary Disease 慢性阻塞性肺病
☐ Chronic Renal Failure 慢性腎功能衰竭
☐ Hypertension 高血壓
☐ Rheumatoid arthritis 類風濕性關節炎
☐ Cumulative Trauma Disorder 累積性肌肉勞捐疾病
☐ None 沒有任何慢性疾病
☐ Others 其他
(Please indicate 請詳細列明: ____)

9. For how many years have you been working on visual display terminal?
你已從事電腦終端機操作的工作共有多久？

☐ Less than 1 year 少過一年
☐ 1 to <5 years 一至少過五年
☐ 5 to <10 years 五至少過十年
☐ 10 to <15 years 十至少過十五年
☐ 15 years or above 十五年或以上

10. How many hours do you work in a day at the present job?
你在現時工作崗位裏每天工作多少個小時？
__________________________ Hour(s) 小時

11. Please indicate the total number of hours in a working day that you have to work on the visual display terminal at the present job.
請指出在你現時的工作崗位裏，你每天使用雹腦終端機操作多少個小時。

☐ 0 to <2 hours 零至少過兩小時
☐ 2 to <4 hours 兩至少過四小時
☐ 4 to <6 hours 四至少過六小時
☐ 6 to <8 hours 六至少過八小時
☐ ≥8 hours 八小時或以上

12. Did you also have to deal with keyboard operation in previous job? If so, please indicate the total number of hours spent on keyboard operation in a working day.
在你以往受僱的職位，你是否需要使用電腦終端機操作？如有需要，請指出每需要使用電腦終端機操作多少個小時？

☐ Yes 有需要 ☐ No 沒有需要 ☐ Not applicable 不適用
☐ 0 to <2 hours 零至少過兩小時
☐ 2 to <4 hours 兩至少過四小時
☐ 4 to <6 hours 四至少過六小時
☐ 6 to <8 hours 六至少過八小時

☐ ≥8 hours 八小時或以上

13. Is there any rest break during working hours at the present job (excluding lunch hours). If yes, please indicate the frequency and average duration of the break in a working day.
你在現時工作崗位裏有沒有小休時間 (午飯時間不計在內)? 如有，請註明每天工作裏小休的次數及平均每次小休的持續。
☐ Yes 有 Rest break(s) in a working day 小休的次數:_______________
Average duration of a break 平均每次小休的持續: _____min 分鐘
☐ No 沒有

14. What kind of activities you often engage for relaxation after a day of work? (can tick one or more)
在一天的工作後，你會用那些方法來消除疲勞？(可選一項或以上)
☐ Watch TV 看電視
☐ Listen to music 聽音樂
☐ Physical fitness exercise 健體運動
☐ Watch movies 看電影
☐ Read books 看書
☐ Others (please specify) 其他 (請註明): ____________________________

15. What body parts you often feel most discomfort in working on Visual display terminal? (Choose 3 only)
在工作崗位裏操作電腦終端機時，你覺得身體那些部位最不舒服？ (請選擇下列其中三項)
☐ Head 頭
☐ Eye 眼
☐ Neck 頸
☐ Shoulder 肩膀
☐ Elbow 手肘
☐ Wrist 手腕
☐ Low back 下背
☐ Leg 腳

16. Have you ever sought medical consultation because of the discomfort?
你曾否就那些肌肉骨骼的不適而去求診？
☐ Yes 有
☐ No 沒有

END OF PART II

第三部份

Part III

瑞典職業疲勞評估表
中文版

試想想現在你的疲勞感覺。以下的詞語在什麼程度上正確地形容你現在的感覺？請隨你自己的意願圈出相當於你現在感覺的程度的數字。數字由 0 (程度極少) 至 10 (程度極大) 排列。

	程度極少										程度極大
	0	1	2	3	4	5	6	7	8	9	10
操勞過度 Overworked	0	1	2	3	4	5	6	7	8	9	10
痛苦 Hurting	0	1	2	3	4	5	6	7	8	9	10
精力耗盡 Exhausted	0	1	2	3	4	5	6	7	8	9	10
肌肉繃緊 Tense muscle	0	1	2	3	4	5	6	7	8	9	10
發暖 Warm	0	1	2	3	4	5	6	7	8	9	10
渴睡 Sleepy	0	1	2	3	4	5	6	7	8	9	10
心跳急速 Palpitation	0	1	2	3	4	5	6	7	8	9	10
體力衰竭 Drained	0	1	2	3	4	5	6	7	8	9	10
冒汗 Sweaty	0	1	2	3	4	5	6	7	8	9	10
枯燥乏味 Uninterested	0	1	2	3	4	5	6	7	8	9	10
不感關注 Lack of concern	0	1	2	3	4	5	6	7	8	9	10
筋疲力竭 Worn out	0	1	2	3	4	5	6	7	8	9	10
疼痛 Aching	0	1	2	3	4	5	6	7	8	9	10
打呵欠 Yawning	0	1	2	3	4	5	6	7	8	9	10
消極被動 Passive	0	1	2	3	4	5	6	7	8	9	10
喘不過氣 Out of breath	0	1	2	3	4	5	6	7	8	9	10
打瞌睡 Falling asleep	0	1	2	3	4	5	6	7	8	9	10
懶惰 Lazy	0	1	2	3	4	5	6	7	8	9	10
漠不關心 Indifferent	0	1	2	3	4	5	6	7	8	9	10
關節僵硬 Stiff joints	0	1	2	3	4	5	6	7	8	9	10
昏昏欲睡 Drowsy	0	1	2	3	4	5	6	7	8	9	10
體力耗盡 Spent	0	1	2	3	4	5	6	7	8	9	10
呼吸沉重 Breathing heavily	0	1	2	3	4	5	6	7	8	9	10
痲痺 Numbness	0	1	2	3	4	5	6	7	8	9	10
沒精打彩 Listless	0	1	2	3	4	5	6	7	8	9	10

Translated from the Swedish Occupational Fatigue Inventory (SOFI); extracted from Ahsberg E, Kecklund G, Akerstedt T, Gamberale F. Shiftwork and different dimensions of fatigue. *Int J of Ind Ergo* 2000; 26: 457-465.

END OF QUESTIONNAIRE THANK YOU

Appendix IV : Statistical Table

Sample size for correlational analysis (5% level, two-tailed test) (Extracted from Kraemer & Thiemann (1987). How *many subjects?: Statistical power analysis in research*. California: Stage Publications, pp. 110)

5% level, Two tailed test											
Δ	99	95	90	80	70	60	50	40	30	20	10
0.22	369	261	212	158	125	99	78	60	43	27	11
0.24	308	218	177	133	105	83	66	50	36	23	10
0.26	261	185	150	112	89	71	56	43	31	20	-
0.28	223	159	128	96	76	61	48	37	27	17	-
0.30	193	137	111	83	66	53	42	32	23	15	-
0.32	169	120	97	73	58	46	36	28	21	13	-
0.34	148	105	85	64	51	41	32	25	18	12	-
0.36	131	93	75	57	45	36	29	22	16	11	-
0.38	116	83	67	51	40	32	26	20	15	10	-
0.40	104	74	60	45	36	29	23	18	13	-	-
0.45	80	57	46	35	28	22	18	14	11	-	-
0.50	62	45	36	27	22	18	14	11	-	-	-
0.55	50	35	29	22	18	14	12	-	-	-	-
0.60	40	29	23	18	14	12	10	-	-	-	-
0.65	32	23	19	15	12	10	-	-	-	-	-
0.70	26	19	15	12	10	-	-	-	-	-	-
0.75	21	15	13	10	-	-	-	-	-	-	-
0.80	17	12	10	-	-	-	-	-	-	-	-
0.85	13	10	-	-	-	-	-	-	-	-	-
0.90	10	-	-	-	-	-	-	-	-	-	-

Appendix V : A Sample of Data Entry Worksheet

Data Sheet G01

10	33	79	73	76	29	70
62	29	73	71	82	77	42
53	65	37	15	89	49	23
26	74	65	55	90	45	32
94	70	28	26	79	17	42
83	46	88	47	76	10	36
67	46	51	39	38	41	69
53	64	54	52	62	25	46
47	74	22	68	83	22	73
32	99	50	36	23	25	80
22	83	43	71	59	55	34
84	87	39	74	97	56	61
21	38	37	86	69	25	13
30	16	56	30	49	45	13
10	86	92	24	77	74	12
78	71	25	98	10	80	57
85	89	90	58	56	88	77
84	95	65	87	66	41	70
36	88	77	70	38	61	58
13	33	24	45	63	87	24

Appendix VI : Check list of Body Anthropometry at the Workstation

Baseline measurement of seating posture

		Length (cm)
	Teach correct sitting posture (using sheet)	
	Fixed monitor, keyboard & mouse pad position	
	Angle of elbow to hands (90^o)	
	Choose comfortable distance	
	Monitor & keyboard distance (if adjusted)	
	Eye & monitor distance (horizontal)	
	Ear lobe & monitor distance (horizontal)	
	Elbow & keyboard top distance	
	Monitor top to table height	
	First line cursor to table height	
	Keyboard top to table height	
	Adjust sit height	
	Eye to floor height	
	Seat to floor height	
	Popliteal fossa to floor height	

* Work table height: 72 cm

Appendix VII : Information Sheet

Title of Project : Mental fatigue: Level of information processing, rest schedule and task composition for sedentary work

Principle Investigator : Dr. Chetwyn C. H. Chan, Associate Professor

Student : Leung Wing Sze, Ada

Co-investigators : Mr. Simon Yeung, Assistant Professor
Dr. M. C. Lee, Associate Professor
Dr. Jufang He, Assistant Professor
Dr. Paul Yung, Assistant Professor

Background information:
The study is a multi-disciplinary project on investigating the effect of task design on mental fatigue, which is one of the major risk factors of stress at work. The research team is composed of two psychologists and a neuropsychologist, an ergonomist, and a research scientist at The Hong Kong Polytechnic University and The University of Hong Kong. The present study aims to explore the effect off work-simulated tasks on producing mental fatigue and hence stress among a group of young adults.

Design:
The design of the six experimental task conditions is based on the combination of information processing level of task, frequency and duration of rest break, and task composition. The dependent variables of mental fatigue include subjective fatigue, physiological, neurophysiological measures as well as task performance. All the participants will be randomly assigned to one of the six experimental task trials.

Experimental protocol:
The experimental task trials will require each participant to perform at his/ her maximum effort either on a proof reading or data entry task, or both, in a 6-hour workday. The workday schedule is composed of either three 50-minute or five 30-minute task sessions with a different combination of either four 10-minute or eight 5-minute rest breaks schedule and either monotonous or alternative task composition.

Total time engaged and remuneration:
The overall experiment will last for approximately 8 hours. A remuneration of $240 will be given to the participants for participating the study and a bonus of up to $100, as an incentive, will also be offered for showing maximum effort on work speed and accuracy. The purpose of giving monetary token to the participants is both to remunerate for the time spent on the experiment and to motivate their active participation during the experiment.

Appendix VIII : Consent Form Used in the Experiment

Consent form

Title of project : Mental fatigue: Level of information processing, rest schedule and task composition for sedentary work

Principle Investigator : Dr. Chetwyn C. H. Chan, Associate Professor

Student : Leung Wing Sze, Ada

Co-investigators : Mr. Simon Yeung, Assistant Professor
Dr. M. C. Lee, Associate Professor
Dr. Jufang He, Assistant Professor
Dr. Paul Yung, Assistant Professor

You are participating in a study concerning the simulated Visual Display Terminal (VDT) tasks. You will be instructed to complete an information processing task in a computer workstation. You will be required to perform several neurophysiological measures without inducing any side effect. You will also be videotaped at anytime throughout the study.

Your participation will take approximately 8 hours. You will receive $240 as remuneration for participating in the study. You may receive up to $100 as the bonus for showing maximum effort on work speed and accuracy. Your anonymity will be maintained. Your name will be known only to the experimenter, and neither it nor any identifying information will be revealed in the results.

Your participation in this study is completely voluntary. You may withdraw fro the study at any time before its completion without penalty. If you have any inquires, please address to the research team of the Ergonomics and Human Performance Laboratory of The Hong Kong Polytechnic University (Rm. FJ 502; Tel: 2766-). Or, you could contact Ada Leung at 2766- or Joanne Hung at 2857- .

Signing this form indicates that you have read and understood this information, and you have voluntarily consented to participate in this study.

Name of Participant	Name of Witness
Signature	Signature
Date	Date

Appendix IX : Demographic Questionnaire

Demographic Questionnaire

(Reference from the Physical Health Questionnaire)

Code: __________________
Name: __________________ Contact phone no.: ___________________

The date of inquiry: ______________________
Age/Sex:___________________
Weight:_______________kg
Height:_______________cm
Right-handed/ Left-handed: ___________________

1. Do you have any chronic illness at present e.g. cumulative trauma disorder, rheumatoid arthritis, hypertension etc.?
   Yes/ No If yes, please specify:__________________________

2. Have you wear glasses or contact lens at present? Yes (glasses/ contact lens)/ No.

3. Do you need working night shift? Yes/ No.

4. Are you having prescriptive medication at present? Yes/ No.
   If yes, please specify:________________________

5. How many sleeping hours do you have last bight? ________________hours

6. How many hours do you use computer a day? _________________hours

7. What body parts indicated below do you often feel discomfort in operating computer? Please circle three.
   Head, Eye, Neck, Shoulder, Elbow, Wrist, Low back, Leg

8. Have you ever sought medical consultation because of the discomfort? Yes/ No.

9. Do you experience excessive overload in recent week? Yes/ No.

10. Do you experience long working hours in recent week? Yes/ No.

11. Do you experience high cognitive demands in recent week? Yes/ No. Please specify the task(s) of high cognitive demands that you work on:____.

12. What kind of activities you often engage for relaxation after a day of work? (Examples are: watch TV, listen to music, physical fitness exercise, watch movies, read books, etc.)____.

13. D you have vigorous exercise in recent week? Yes/ No. If yes, please specify:____.

Appendix X : Record Sheet for the Measurement of the Eye Blink Rate and Neurophysiological Variables

LM schedule - Randomization pattern 1

		Time in minutes							
Session	Time Start session	**w**	ECG EEG	Eye blink video	**w**	ECG EEG	**w**	Time end session	Time Start measure
1a		**3**	5	2				----------	
1b	--------			2	**1**	5	**2**		
2				2	**2**	5	**1**		
3				2	**3**	5	**0**		
4a		**3**	5	2				----------	
4b	--------			2	**3**	5	**0**		
5				2	**1**	5	**2**		
6				2	**2**	5	**1**		

Key: S = Session
w = wait

LM schedule - Randomization pattern 2

		Time in minutes							
Session	Time Start session	**w**	ECG EEG	Eye blink video	**w**	ECG EEG	**w**	Time end session	Time Start measure
1a		**3**	5	2				----------	
1b	--------			2	**1**	5	**2**		
2				2	**3**	5	**0**		
3				2	**2**	5	**1**		
4a		**3**	5	2				----------	
4b	--------			2	**2**	5	**1**		
5				2	**2**	5	**1**		
6				2	**1**	5	**2**		

Key: S = Session
w = wait

SM schedule - Randomization pattern 1

		Time in minutes							
Session	Time Start session	**w**	ECG EEG	Eye blink video	**w**	ECG EEG	**w**	Time end session	Time Start measure
1a		**3**	5	2				----------	
1b	--------			2	**1**	5	**2**		
2				2	**2**	5	**1**		
3				2	**3**	5	**0**		
4				2	**2**	5	**1**		
5				2	**3**	5	**0**		
6a		**3**	5	2				----------	
6b	--------			2	**1**	5	**2**		
7				2	**2**	5	**1**		
8				2	**1**	5	**2**		
9				2	**2**	5	**1**		
10				2	**3**	5	**0**		

Key: S = Session
w = wait

SM schedule - Randomization pattern 2

		Time in minutes							
Session	Time Start session	**w**	ECG EEG	Eye blink video	**w**	ECG EEG	**w**	Time end session	Time Start measure
1a		**3**	5	2				----------	
1b	--------			2	**1**	5	**2**		
2				2	**3**	5	**0**		
3				2	**2**	5	**1**		
4				2	**1**	5	**2**		
5				2	**1**	5	**2**		
6a		**3**	5	2				----------	
6b	--------			2	**2**	5	**1**		
7				2	**2**	5	**1**		
8				2	**1**	5	**2**		
9				2	**2**	5	**1**		
10				2	**1**	5	**2**		

Key: S = Session
w = wait

Appendix XI : Follow-up Study

The appendix summarizes the follow-up study that was conducted to examine whether there were significant changes in the subjects' typing speed across each 10-minute subsession in any task session. It replicated the longer and less frequent rest schedule (LM) of the data entry task. The reason for replicating the LM schedule, which was composed of 50-minute task sessions, instead of the shorter and more frequent rest schedule (SM), which was composed of 30-minute task sessions, was that the nonsignificant results from the LM schedule, if obtained, could be more readily generalized to the SM schedule.

Twenty university students with a mean age 21.0±1.1 years participated in the follow-up study. The subjects were given the same instructions as those in the main study and were reminded to perform as quickly and accurately as possible. In this study, only the behavioral variables on performance on the task were measured. The variables (typing speed and error rate) and their measurement methods were the same as those described in Chapters V and VII. To accurately reflect the subjects' typing speed every 10 minutes on task, a new macro program was constructed for the Excel spreadsheet. This macro program ran concurrently with the subjects' keying in of the two-digit numbers. The total number of data entered and errors committed within each 10-minute time interval were captured after the subjects completed the task. Since this study was done after the main study was completed, the experimental workstation was made as similar as possible to that used in the main study. The main study made the assumption that there were no significant differences in typing speed across the 10-minute subsessions in any task session. The results obtained in this follow-up study were targeted to verify this assumption.

Table 12.1 summarizes the descriptive statistics of the speed of data entry across each 10-minute segment of the data entered. A three-way repeated measures ANOVA (2 Blocks × 3 Sessions × 5 Subsessions) revealed non-significant main effects on Block, $F(1,19) = 3.52$, $p = 0.076$; Session, $F(1.32,25.10) = 2.96$, $p = 0.088$; and Subsession, $F(1.96,37.40) = 3.12$, $p = 0.056$; but significant Block × Session, $F(2,38) = 17.02$, $p < 0.001$; Block × Subsession, $F(2.62,49.85) = 8.28$, $p < 0.001$; and Session × Subsession interaction effects, $F(4.09,77.62) = 14.18$, $p < 0.001$.

Although there were significant interaction effects between sessions and subsessions, the emphasis of the analysis rests on the main effect of Subsession. As the main effect of Subsession was found marginal in its significance, post-hoc comparisons were performed on this main effect using a one-way repeated measures ANOVA across the subsessions in each task session. A Bonferroni adjustment was applied to control for the repeated measures. Significant differences were found in the typing speed of subsessions in S1, $F(2.64,56.57) = 4.13$, $p = 0.014$; S5, $F(1.98,37.61) = 6.56$, $p = 0.004$; and S6, $F(2.76,52.52) = 8.61$, $p < 0.001$. In S1, the typing speed in the first subsession was significantly slower than in the second subsession ($p = 0.034$); in S5, the typing speed in the first subsession was significantly faster than in all other subsessions ($p = 0.013$ to 0.014); and in S6, the typing speed in the first subsession was significantly faster than in the last subsession ($p = 0.001$). It appears that the slower typing speed of subjects in the first 10 minutes of the S1 (first session) was likely due to learning of the rules and skills of the task. For the significant differences in S5 and S6, it appears that the subjects performed significantly faster only in the first 10 minutes. Nevertheless, the differences obtained from the subsession differences are subtle, and no systematic pattern across task sessions is noted. Therefore, it is reasonable to assume that the typing speed across the subsessions did not vary.

Table 12.1. *Mean (SD) of the speed of data entry in each 10-minute task segment*

Block	Session (S)	Speed of subsession data entry (data entered per minute)				
		1	2	3	4	5
Morning	S1	25.70 (3.36)	28.99 (5.29)	27.89 (5.72)	28.66 (6.87)	28.42 (6.91)
	S2	29.31 (5.23)	28.68 (5.27)	28.69 (6.59)	30.40 (6.21)	28.76 (4.75)
	S3	30.69 (6.57)	30.84 (8.47)	30.01 (5.77)	30.52 (6.71)	29.36 (6.88)
Afternoon	S4	30.68 (6.49)	31.50 (7.07)	30.44 (7.20)	31.38 (5.94)	30.78 (5.94)
	S5	32.90 (5.50)	30.09 (7.29)	29.98 (5.69)	30.58 (5.68)	29.84 (7.38)
	S6	31.77 (6.66)	29.46 (4.88)	33.45 (7.52)	28.96 (6.46)	27.52 (7.04)

[1] Each subsession was a 10-minute segment

The subjects' typing speed within the entire task session of this follow-up study was analyzed to compare the results with those obtained in the main study. Table 12.2 summarizes the descriptive statistics of the speed of data entry across each 50-minute task session of the data entry task. A two-way repeated measures ANOVA (2 Blocks × 3 Sessions) revealed a significant main effect on Block, $F(1,19) = 4.55$, $p = 0.046$, and Block × Session, $F(2,38) = 19.61$, $p < 0.001$ interaction effects, but nonsignificant main effects on Session, $F(1.35,13.37) = 3.69$, $p = 0.055$. A further one-way repeated measures ANOVA on the three morning sessions revealed that the subjects' typing speed increased significantly from S1 to S2 ($p = 0.001$), and then from S2 to S3 ($p = 0.004$), and that the speed in S3 was also faster than in S1 ($p < 0.001$). In the afternoon, however, there were no significant differences across the three task sessions (S4 to S6) ($p > 0.20$). It appears that the subjects' typing speed increased only across the morning sessions, not those of the afternoon. This finding is the same as that of the main study, except that the subjects in the main study showed no significant increase in typing speed from S2 to S3.

Table 12.2. *Mean (SD) of the speed of data entry in each task session*

Block	Session (S)	Speed of data entry (data entered per minute)
Morning	S1	27.31 (5.71)
	S2	28.90 (5.67)
	S3	30.07 (6.22)
Afternoon	S4	30.85 (6.41)
	S5	30.41 (6.39)
	S6	29.78 (6.08)

The results on error rates are presented for reference, although they are not the main focus of this report. Table 12.3 summarizes the descriptive statistics of the error rate across each 10-minute data entry task. A three-way repeated measures ANOVA (2 Blocks × 3 Sessions × 5 Subsessions) revealed nonsignificant main effects on Block, $F(1,19) = 1.46$, $p = 0.242$; Session, $F(1.19,22.60) = 0.81$, $p = 0.398$; and Subsession, $F(2.80,53.25) = 1.19$, $p = 0.322$; and nonsignificant Block × Session, $F(2,38) = 3.40$, $p = 0.056$; Block × Subsession, $F(2.80,53.22) = 1.09$, $p = 0.360$; Session × Subsession, $(3.49,66.25) = 2.56$, $p = 0.054$; and Block × Session × Subsession, $F(2.37,44.97) = 1.13$, $p = 0.338$ interaction effects.

In addition, the subjects' error rates across the entire task session of this follow-up study were also analyzed. Table 12.4 summarizes the descriptive statistics of the error rate across each 50-minute task session of the data entry task. A two-way repeated measures ANOVA (2 Blocks × 3 Sessions) revealed nonsignificant main effects on Block, $F(1,19) = 1.67$, $p = 0.212$; Session, $F(1.19,22.66) = 0.84$, $p = 0.390$; and Block × Session, $F(1.60,30.34) = 3.55$, $p = 0.051$ interaction effects. A further one-way repeated measures ANOVA on the three morning (S1 to S3) and three afternoon sessions (S4 to S6) revealed no significant results ($p > 0.10$). These findings concur with those obtained in the main study, except that the subjects in the main study showed significantly more errors in S1 than in S4.

Table 12.3. *Mean (SD) of error rates in each 10-minute task segment*

Block	Session (S)	Error rate of subsessions[1] (%)				
		1	2	3	4	5
Morning	S1	0.45 (0.94)	0.44 (0.85)	0.66 (1.27)	0.61 (0.75)	0.29 (0.43)
	S2	0.35 (0.42)	0.44 (0.99)	0.45 (0.84)	0.21 (0.27)	0.35 (0.65)
	S3	0.51 (0.48)	0.44 (0.56)	0.24 (0.26)	0.24 (0.35)	0.57 (1.20)
Afternoon	S4	0.23 (0.27)	0.29 (0.66)	0.29 (0.41)	0.41 (0.49)	0.24 (4.00)
	S5	0.17 (0.32)	0.45 (0.48)	0.31 (0.31)	0.47 (0.68)	0.56 (0.78)
	S6	0.12 (0.27)	0.19 (0.28)	0.47 (0.67)	0.04 (0.11)	0.41 (1.00)

[1] Each subsession was a 10-minute segment

Table 12.4. *Mean (SD) of error rates in each task session*

Block	Session (S)	Error rate of subsessions[1] (%)
Morning	S1	0.50 (0.79)
	S2	0.36 (0.48)
	S3	0.40 (0.44)
Afternoon	S4	0.29 (0.30)
	S5	0.39 (0.23)
	S6	0.24 (0.28)

[1] Each subsession was a 10-minute segment

Appendix XII : Complete Lists of Correlations

Correlations Between SOFI-C and EEG Spectral Power

Table 13.1. *Correlations between the SOFI-C measured at the end of morning and the EEG spectral power in S2 and S3 of the* ***LM schedule***

			Normalized EEG spectral power			
			Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
S2	SL	δ	*r* = -0.21, *p* = 0.378	*r* = -0.07, *p* = 0.757	*r* = -0.23, *p* = 0.684	*r* = -0.10, *p* = 0.684
		θ	*r* = -0.34, *p* = 0.147	*r* = -0.19, *p* = 0.425	*r* = -0.34, *p* = 0.145	*r* = -0.35, *p* = 0.135
		α_1	*r* = -0.12, *p* = 0.624	*r* = -0.11, *p* = 0.644	*r* = -0.42, *p* = 0.063	*r* = 0.45, *p* = 0.049
		α_2	*r* = -0.12, *p* = 0.611	*r* = -0.07, *p* = 0.772	*r* = -0.51, *p* = 0.022	*r* = -0.52, *p* = 0.019
		β_1	*r* = -0.07, *p* = 0.779	*r* = -0.08, *p* = 0.743	*r* = -0.58, *p* = 0.007**	*r* = -0.60, *p* = 0.005**
		β_2	*r* = -0.10, *p* = 0.687	*r* = -0.24, *p* = 0.295	*r* = -0.55, *p* = 0.012**	*r* = -0.62, *p* = 0.004**
		β_3	*r* = -0.08, *p* = 0.744	*r* = -0.26, *p* = 0.265	*r* = -0.58, *p* = 0.007**	*r* = -0.65, *p* = 0.002**
	PD	δ	*r* = -0.05, *p* = 0.829	*r* = -0.06, *p* = 0.811	*r* = -0.09, *p* = 0.705	*r* = -0.13, *p* = 0.584
		θ	*r* = -0.23, *p* = 0.328	*r* = -0.04, *p* = 0.862	*r* = -0.26, *p* = 0.275	*r* = -0.26, *p* = 0.262
		α_1	*r* = -0.13, *p* = 0.597	*r* = -0.01, *p* = 0.987	*r* = -0.40, *p* = 0.082	*r* = -0.50, *p* = 0.024
		α_2	*r* = -0.21, *p* = 0.373	*r* = -0.05, *p* = 0.829	*r* = -0.53, *p* = 0.017**	*r* = -0.52, *p* = 0.020
		β_1	*r* = -0.29, *p* = 0.208	*r* = -0.07, *p* = 0.764	*r* = -0.57, *p* = 0.009**	*r* = -0.60, *p* = 0.010**
		β_2	*r* = -0.27, *p* = 0.247	*r* = -0.23, *p* = 0.328	*r* = -0.57, *p* = 0.009**	*r* = -0.57, *p* = 0.008**
		β_3	*r* = -0.25, *p* = 0.283	*r* = -0.20, *p* = 0.398	*r* = -0.58, *p* = 0.007**	*r* = -0.64, *p* = 0.003**
	LM	δ	*r* = -0.27, *p* = 0.253	*r* = 0.06, *p* = 0.795	*r* = -0.24, *p* = 0.316	*r* = -0.16, *p* = 0.492
		θ	*r* = -0.36, *p* = 0.120	*r* = -0.18, *p* = 0.456	*r* = -0.39, *p* = 0.087	*r* = -0.35, *p* = 0.136
		α_1	*r* = -0.29, *p* = 0.217	*r* = -0.09, *p* = 0.712	*r* = -0.35, *p* = 0.130	*r* = -0.34, *p* = 0.138
		α_2	*r* = -0.42, *p* = 0.069	*r* = -0.04, *p* = 0.858	*r* = -0.39, *p* = 0.089	*r* = -0.38, *p* = 0.099
		β_1	*r* = -0.44, *p* = 0.054	*r* = -0.23, *p* = 0.340	*r* = -0.45, *p* = 0.047	*r* = -0.46, *p* = 0.040
		β_2	*r* = -0.47, *p* = 0.036	*r* = -0.39, *p* = 0.087	*r* = -0.41, *p* = 0.074	*r* = -0.46, *p* = 0.043
		β_3	*r* = -0.42, *p* = 0.064	*r* = -0.39, *p* = 0.086	*r* = -0.45, *p* = 0.045	*r* = -0.53, *p* = 0.016**
	LE	δ	*r* = -0.34, *p* = 0.146	*r* = 0.01, *p* = 0.982	*r* = -0.18, *p* = 0.46	*r* = -0.15, *p* = 0.533
		θ	*r* = -0.47, *p* = 0.036	*r* = -0.26, *p* = 0.278	*r* = -0.45, *p* = 0.047	*r* = -0.39, *p* = 0.086
		α_1	*r* = -0.30, *p* = 0.195	*r* = -0.11, *p* = 0.630	*r* = -0.36, *p* = 0.122	*r* = -0.33, *p* = 0.160
		α_2	*r* = -0.48, *p* = 0.031	*r* = -0.11, *p* =0.649	*r* = -0.42, *p* = 0.066	*r* = -0.43, *p* = 0.058
		β_1	*r* = -0.36, *p* = 0.122	*r* = -0.08, *p* = 0.741	*r* = -0.50, *p* = 0.024	*r* = -0.52, *p* = 0.018
		β_2	*r* = -0.37, *p* = 0.108	*r* = -0.21, *p* = 0.367	*r* = -0.48, *p* = 0.032	*r* = -0.49, *p* = 0.028
		β_3	*r* = -0.32, *p* = 0.172	*r* = -0.25, *p* = 0.291	*r* = -0.49, *p* = 0.029	*r* = -0.55, *p* = 0.012**
	PE	δ	*r* = 0.11, *p* = 0.640	*r* = 0.08, *p* = 0.724	*r* = 0.12, *p* = 0.615	*r* = 0.20, *p* = 0.403
		θ	*r* = 0.25, *p* = 0.289	*r* = 0.38, *p* = 0.099	*r* = 0.20, *p* = 0.398	*r* = 0.26, *p* = 0.271
		α_1	*r* = -0.01, *p* = 0.996	*r* = 0.11, *p* = 0.632	*r* = -0.16, *p* = 0.503	*r* = -0.15, *p* = 0.517
		α_2	*r* = -0.11, *p* = 0.649	*r* = -0.04, *p* = 0.879	*r* = -0.24, *p* = 0.303	*r* = -0.24, *p* = 0.302
		β_1	*r* = -0.05, *p* = 0.852	*r* = 0.27, *p* = 0.256	*r* = -0.29, *p* = 0.223	*r* = -0.24, *p* = 0.320
		β_2	*r* = -0.06, *p* = 0.793	*r* = 0.13, *p* = 0.577	*r* = -0.29, *p* = 0.212	*r* = -0.20, *p* = 0.409
		β_3	*r* = -0.01, *p* = 0.983	*r* = 0.16, *p* = 0.507	*r* = -0.20, *p* = 0.407	*r* = -0.21, *p* = 0.379
S3	SL	δ	*r* = -0.14, *p* = 0.570	*r* = 0.33, *p* = 0.158	*r* = -0.16, *p* = 0.945	*r* = 0.11, *p* = 0.639
		θ	*r* = -0.15, *p* = 0.528	*r* = 0.14, *p* = 0.545	*r* = -0.13, *p* = 0.583	*r* = -0.11, *p* = 0.640
		α_1	*r* = -0.05, *p* = 0.834	*r* = 0.23, *p* = 0.321	*r* = 0.05, *p* = 0.831	*r* = -0.05, *p* = 0.835
		α_2	*r* = -0.02, *p* = 0.951	*r* = 0.25, *p* = 0.293	*r* = -0.07, *p* = 0.756	*r* = -0.20, *p* = 0.396
		β_1	*r* = 0.07, *p* = 0.763	*r* = 0.22, *p* = 0.358	*r* = -0.12, *p* = 0.600	*r* = -0.21, *p* = 0.382
		β_2	*r* = 0.01, *p* = 0.977	*r* = 0.09, *p* = 0.703	*r* = 0.14, *p* = 0.557	*r* = 0.02, *p* = 0.927
		β_3	*r* = 0.05, *p* = 0.830	*r* = 0.07, *p* = 0.762	*r* = 0.08, *p* = 0.724	*r* = -0.08, *p* = 0.724
	PD	δ	*r* = -0.14, *p* = 0.549	*r* = 0.15, *p* = 0.528	*r* = -0.18, *p* = 0.458	*r* = -0.12, *p* = 0.607
		θ	*r* = -0.22, *p* = 0.342	*r* = -0.05, *p* = 0.833	*r* = -0.19, *p* = 0.412	*r* = -0.18, *p* = 0.450
		α_1	*r* = -0.13, *p* = 0.576	*r* = 0.21, *p* = 0.382	*r* = 0.02, *p* = 0.948	*r* = -0.11, *p* = 0.649
		α_2	*r* = -0.18, *p* = 0.439	*r* = 0.18, *p* = 0.438	*r* = -0.14, *p* = 0.545	*r* = -0.16, *p* = 0.505
		β_1	*r* = -0.15, *p* = 0.529	*r* = 0.16, *p* = 0.503	*r* = -0.19, *p* = 0.431	*r* = -0.20, *p* = 0.389

		β_2	$r = -0.14, p = 0.571$	$r = 0.13, p = 0.578$	$r = -0.03, p = 0.916$	$r = -0.03, p = 0.906$
		β_3	$r = -0.11, p = 0.644$	$r = 0.12, p = 0.608$	$r = -0.07, p = 0.759$	$r = -0.11, p = 0.633$
	LM	δ	$r = -0.34, p = 0.141$	$r = 0.07, p = 0.775$	$r = -0.21, p = 0.376$	$r = -0.17, p = 0.486$
		θ	$r = -0.40, p = 0.082$	$r = -0.17, p = 0.466$	$r = -0.34, p = 0.138$	$r = -0.30, p = 0.207$
		α_1	$r = -0.33, p = 0.156$	$r = -0.01, p = 0.961$	$r = -0.11, p = 0.637$	$r = -0.18, p = 0.451$
		α_2	$r = -0.38, p = 0.098$	$r = 0.02, p = 0.936$	$r = -0.18, p = 0.452$	$r = -0.24, p = 0.319$
		β_1	$r = -0.33, p = 0.157$	$r = -0.05, p = 0.822$	$r = -0.23, p = 0.328$	$r = -0.34, p = 0.149$
		β_2	$r = -0.38, p = 0.102$	$r = -0.13, p = 0.580$	$r = -0.02, p = 0.940$	$r = -0.13, p = 0.573$
		β_3	$r = -0.32, p = 0.176$	$r = -0.10, p = 0.689$	$r = -0.13, p = 0.597$	$r = -0.31, p = 0.180$
	LE	δ	$r = -0.24, p = 0.320$	$r = 0.28, p = 0.227$	$r = -0.11, p = 0.64$	$r = -0.05, p = 0.821$
		θ	$r = -0.29, p = 0.224$	$r = 0.01, p = 0.987$	$r = -0.30, p = 0.205$	$r = -0.24, p = 0.312$
		α_1	$r = -0.18, p = 0.446$	$r = 0.18, p = 0.444$	$r = -0.13, p = 0.579$	$r = -0.16, p = 0.511$
		α_2	$r = -0.21, p = 0.371$	$r = 0.27, p = 0.246$	$r = -0.23, p = 0.337$	$r = -0.27, p = 0.250$
		β_1	$r = -0.19, p = 0.425$	$r = 0.18, p = 0.455$	$r = -0.26, p = 0.263$	$r = -0.32, p = 0.167$
		β_2	$r = -0.27, p = 0.246$	$r = 0.03, p = 0.915$	$r = -0.08, p = 0.753$	$r = -0.10, p = 0.673$
		β_3	$r = -0.22, p = 0.360$	$r = 0.04, p = 0.858$	$r = -0.12, p = 0.619$	$r = -0.26, p = 0.266$
	PE	δ	$r = 0.02, p = 0.924$	$r = 0.32, p = 0.172$	$r = 0.05, p = 0.847$	$r = 0.09, p = 0.706$
		θ	$r = 0.04, p = 0.863$	$r = 0.46, p = 0.043$	$r = 0.14, p = 0.550$	$r = 0.20, p = 0.399$
		α_1	$r = 0.05, p = 0.833$	$r = 0.46, p = 0.044$	$r = -0.19, p = 0.424$	$r = -0.07, p = 0.760$
		α_2	$r = 0.01, p = 0.996$	$r = 0.48, p = 0.048$	$r = -0.36, p = 0.124$	$r = -0.14, p = 0.562$
		β_1	$r = -0.05, p = 0.837$	$r = 0.52, p = 0.018$	$r = -0.32, p = 0.175$	$r = -0.07, p = 0.758$
		β_2	$r = -0.01, p = 0.977$	$r = 0.44, p = 0.051$	$r = -0.23, p = 0.327$	$r = 0.07, p = 0.778$
		β_3	$r = -0.01, p = 0.973$	$r = 0.42, p = 0.067$	$r = -0.10, p = 0.668$	$r = 0.12, p = 0.623$

SL = sleepiness; PD = Physical Discomfort; LM = Lack of Motivation; LE = Lack of Energy; PE = Physical Exertion

** adjusted significant p level at $p \leq 0.017$

Table 13.2. *Correlations between the SOFI-C measured at the end of afternoon and the EEG spectral power in S5 and S6 of the* ***LM schedule***

			Normalized EEG spectral power			
			Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
S5	SL	δ	$r = 0.53, p = 0.016$ **	$r = -0.14, p = 0.543$	$r = 0.23, p = 0.321$	$r = 0.23, p = 0.339$
		θ	$r = 0.59, p = 0.007$**	$r = 0.03, p = 0.912$	$r = 0.31, p = 0.187$	$r = 0.29, p = 0.217$
		α_1	$r = 0.50, p = 0.024$	$r = -0.05, p = 0.827$	$r = 0.15, p = 0.537$	$r = 0.16, p = 0.494$
		α_2	$r = 0.40, p = 0.080$	$r = -0.13, p = 0.596$	$r = 0.19, p = 0.416$	$r = 0.21, p = 0.367$
		β_1	$r = -0.11, p = 0.655$	$r = -0.47, p = 0.038$	$r = 0.10, p = 0.679$	$r = 0.10, p = 0.677$
		β_2	$r = -0.30, p = 0.199$	$r = -0.49, p = 0.027$	$r = -0.05, p = 0.820$	$r = -0.13, p = 0.597$
		β_3	$r = -0.28, p = 0.230$	$r = -0.40, p = 0.083$	$r = -0.07, p = 0.781$	$r = -0.09, p = 0.711$
	PD	δ	$r = 0.31, p = 0.179$	$r = 0.15, p = 0.530$	$r = 0.17, p = 0.479$	$r = 0.17, p = 0.470$
		θ	$r = 0.38, p = 0.096$	$r = 0.21, p = 0.367$	$r = 0.17, p = 0.476$	$r = 0.22, p = 0.356$
		α_1	$r = 0.25, p = 0.283$	$r = 0.03, p = 0.901$	$r = -0.08, p = 0.731$	$r = -0.13, p = 0.579$
		α_2	$r = 0.22, p = 0.350$	$r = -0.004, p = 0.987$	$r = -0.02, p = 0.936$	$r = -0.13, p = 0.572$
		β_1	$r = -0.07, p = 0.758$	$r = -0.14, p = 0.558$	$r = -0.25, p = 0.288$	$r = -0.37, p = 0.111$
		β_2	$r = -0.09, p = 0.696$	$r = -0.12, p = 0.611$	$r = -0.28, p = 0.230$	$r = -0.44, p = 0.053$
		β_3	$r = -0.09, p = 0.710$	$r = -0.17, p = 0.473$	$r = -0.28, p = 0.236$	$r = -0.45, p = 0.049$
	LM	δ	$r = 0.05, p = 0.848$	$r = 0.21, p = 0.367$	$r = 0.12, p = 0.601$	$r = -0.08, p = 0.746$
		θ	$r = 0.58, p = 0.008$**	$r = 0.31, p = 0.181$	$r = 0.08, p = 0.735$	$r = 0.003, p = 0.990$
		α_1	$r = 0.48, p = 0.035$	$r = 0.28, p = 0233$	$r = -0.06, p = 0.800$	$r = -0.13, p = 0.576$
		α_2	$r = 0.66, p = 0.002$**	$r = 0.17, p = 0.481$	$r = 0.05, p = 0.849$	$r = -0.04, p = 0.859$
		β_1	$r = 0.31, p = 0.187$	$r = -0.06, p = 0.817$	$r = -0.02, p = 0.945$	$r = -0.21, p = 0.384$
		β_2	$r = 0.19, p = 0.420$	$r = -0.10, p = 0.674$	$r = -0.05, p = 0.845$	$r = -0.26, p = 0.260$

		β_3	r = 0.21, p = 0.375	r = -0.02, p = 0.944	r = -0.02, p = 0.929	r = -0.23, p = 0.328
	LE	δ	r = 0.46, p = 0.040	r = 0.15, p = 0533	r = 0.08, p = 0.746	r = 0.07, p = 0.774
		θ	r = 0.45, p = 0.047	r = 0.16, p = 0.503	r = 0.26, p = 0.264	r = 0.22, p = 0.347
		α_1	r = 0.29, p = 0.213	r = -0.02, p = 0.950	r = 0.27, p = 0.253	r = 0.05, p = 0.852
		α_2	r = 0.43, p = 0.056	r = 0.01, p = 0.959	r = 0.28, p = 0.228	r =0.001, p = 0.999
		β_1	r = 0.14, p = 0.562	r = 0.06, p = 0.810	r = 0.29, p = 0.218	r = -0.06, p = 0.807
		β_2	r = 0.06, p = 0.816	r = 0.08, p = 0.739	r = 0.26, p = 0.264	r = -0.07, p = 0.772
		β_3	r = 0.14, p = 0.564	r = 0.21, p = 0.380	r = 0.25, p = 0.298	r = -0.06, p = 0.803
	PE	δ	r = 0.09, p = 0.701	r = -0.19, p = 0.431	r = 0.06, p = 0.816	r = 0.02, p = 0.939
		θ	r = -0.17, p = 0.470	r = -0.24, p = 0.300	r = -0.03, p = 0.899	r = -0.04, p = 0.871
		α_1	r = -0.03, p = 0.917	r = -0.25, p = 0.282	r = -0.08, p = 0.730	r = -0.28, p = 0.227
		α_2	r = -0.02, p = 0.944	r = -0.29, p = 0.222	r = -0.07, p = 0.764	r = -0.20, p = 0.408
		β_1	r = -0.09, p = 0.701	r = -0.09, p = 0.719	r = -0.08, p = 0.734	r = -0.20, p = 0.397
		β_2	r = -0.03, p = 0.898	r = -0.02, p = 0.939	r = -0.05, p = 0.822	r = -0.26, p = 0.262
		β_3	r = -0.02, p = 0.924	r = -0.09, p = 0.719	r = -0.03, p = 0.916	r = -0.12, p = 0.619
S6	SL	δ	r = 0.70, p = 0.001**	r = 0.21, p = 0.370	r = 0.12, p = 0.605	r = 0.17, p = 0.468
		θ	r = 0.54, p = 0.014**	r = 0.15, p = 0.536	r = 0.12, p = 0.620	r = -0.02, p = 0.930
		α_1	r = 0.39, p = 0.092	r = 0.07, p = 0.776	r = 0.06, p = 0.815	r = -0.03, p = 0.910
		α_2	r = 0.11, p = 0.660	r = 0.11, p = 0.641	r = -0.08, p = 0.735	r = -0.12, p = 0.602
		β_1	r = -0.10, p = 0.679	r = -0.01, p = 0.967	r = -0.07, p = 0.759	r = -0.15, p = 0.530
		β_2	r = -0.18, p = 0.444	r = -0.01, p = 0.958	r = -0.13, p = 0.596	r = -0.22, p = 0.351
		β_3	r = -0.13, p = 0.582	r = -0.08, p = 0.744	r = -0.17, p = 0.465	r = -0.19, p = 0.422
	PD	δ	r = 0.35, p = 0.133	r = -0.03, p = 0.910	r = 0.10, p = 0.683	r = 0.10, p = 0.668
		θ	r = 0.22, p = 0.350	r = -0.10, p = 0.688	r = -0.10, p = 0.670	r = -0.12, p = 0.605
		α_1	r = 0.31, p = 0.185	r = -0.12, p = 0.606	r = 0.08, p = 0.747	r = -0.11, p = 0.659
		α_2	r = -0.01, p = 0.978	r = -0.17, p = 0.465	r =-0.002, p = 0.995	r = -0.24, p = 0.313
		β_1	r = -0.06, p = 0.790	r = -0.24, p = 0.305	r = -0.18, p = 0.455	r = -0.39, p = 0.090
		β_2	r = -0.29, p = 0.903	r = -0.25, p = 0.281	r = -0.10, p = 0.662	r = -0.36, p = 0.118
		β_3	r = -0.04, p = 0.880	r = -0.25, p = 0.282	r = -0.11, p = 0.635	r = -0.36, p = 0.114
	LM	δ	r = 0.49, p = 0.029	r = 0.16, p = 0.494	r = 0.19, p = 0.422	r = 0.19, p = 0.428
		θ	r = 0.57, p = 0.009**	r = 0.33, p = 0.154	r = 0.23, p = 0.340	r = 0.23, p = 0.335
		α_1	r = 0.53, p = 0.018	r = 0.32, p = 0.168	r = 0.11, p = 0.655	r = 0.17, p = 0.468
		α_2	r = 0.35, p = 0.133	r = 0.26, p = 0.265	r = 0.05, p = 0.828	r = 0.10, p = 0.678
		β_1	r = 0.30, p = 0.154	r = 0.16, p = 0.510	r = 0.07, p = 0.765	r = 0.11, p = 0.638
		β_2	r = 0.29, p = 0.221	r = 0.08, p = 0.744	r = 0.06, p = 0.816	r = 0.20, p = 0.402
		β_3	r = 0.30, p = 0.195	r = 0.10, p = 0.688	r = -0.02, p = 0.940	r = 0.12, p = 0.602
	LE	δ	r = 0.66, p = 0.001**	r = 0.43, p = 0.062	r = 0.07, p = 0.764	r = 0.18, p = 0.453
		θ	r = 0.58, p = 0.008**	r = 0.31, p = 0.187	r = 0.22, p = 0.348	r = 0.19, p = 0.431
		α_1	r = 0.42, p = 0.066	r = 0.07, p = 0.784	r = 0.20, p = 0.392	r = 0.07, p = 0.770
		α_2	r = 0.24, p = 0.313	r = 0.04, p = 0.862	r = 0.07, p = 0.777	r = -0.10, p = 0.672
		β_1	r = 0.09, p = 0.699	r = 0.16, p = 0.492	r = 0.12, p = 0.602	r = -0.08, p = 0.748
		β_2	r = 0.11, p = 0.653	r = 0.13, p = 0.581	r = 0.10, p = 0.684	r = -0.10, p = 0.680
		β_3	r = 0.18, p = 0.445	r = 0.30, p = 0.194	r = 0.04, p = 0.855	r = -0.10, p = 0.686
	PE	δ	r = -0.01, p = 0.971	r = 0.14, p = 0.569	r = -0.37, p = 0.111	r = -0.17, p = 0.475
		θ	r = -0.09, p = 0.714	r = 0.14, p = 0.549	r = -0.16, p = 0.508	r = -0.12, p = 0.611
		α_1	r = 0.01, p = 0.968	r = 0.18, p = 0.457	r = -0.19, p = 0.422	r = -0.19, p = 0.432
		α_2	r = -0.28, p =0.228	r = 0.10, p = 0.684	r = -0.19, p = 0.418	r = -0.22, p = 0.359
		β_1	r = -0.35, p = 0.134	r = 0.15, p = 0.534	r = -0.23, p = 0.341	r = -0.20, p = 0.395
		β_2	r = -0.30, p = 0.192	r = 0.12, p = 0.617	r = -0.15, p = 0.518	r = -0.18, p = 0.450
		β_3	r = -0.27, p = 0.259	r = 0.23, p = 0.331	r = -0.16, p = 0.509	r = -0.10, p = 0.688

SL = sleepiness; PD = Physical Discomfort; LM = Lack of Motivation; LE = Lack of Energy; PE = Physical Exertion

** adjusted significant p level at $p \leq 0.017$

Table 13.3. *Correlations between the SOFI-C measured at the end of morning and the EEG spectral power in s3, s4, and s5 of the* ***SM schedule***

			Normalized EEG spectral power			
			Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
s3	SL	δ	$r = 0.45, p = 0.045$	$r = 0.11, p = 0.641$	$r = -0.01, p = 0.985$	$r = 0.28, p = 0.907$
		θ	$r = 0.43, p = 0.057$	$r = 0.06, p = 0.820$	$r = 0.11, p = 0.659$	$r = -0.05, p = 0.821$
		α_1	$r = 0.24, p = 0.299$	$r = -0.31, p = 0.168$	$r = 0.02, p = 0.932$	$r = -0.34, p = 0.142$
		α_2	$r = 0.10, p = 0.677$	$r = -0.25, p = 0.291$	$r = 0.04, p = 0.864$	$r = -0.19, p = 0.436$
		β_1	$r = 0.10, p = 0.670$	$r = -0.08, p = 0.724$	$r = 0.33, p = 0.159$	$r = -0.03, p = 0.916$
		β_2	$r = 0.07, p = 0.766$	$r = 0.04, p = 0.866$	$r = 0.34, p = 0.137$	$r = -0.06, p = 0.979$
		β_3	$r = 0.16, p = 0.503$	$r = 0.15, p = 0.541$	$r = 0.39, p = 0.089$	$r = 0.05, p = 0.820$
	PD	δ	$r = 0.28, p = 0.234$	$r = 0.14, p = 0.570$	$r = 0.44, p = 0.054$	$r = 0.56, p = 0.010$**
		θ	$r = 0.45, p = 0.047$	$r = 0.37, p = 0.114$	$r = 0.69, p = 0.001$**	$r = 0.65, p = 0.002$**
		α_1	$r = 0.27, p = 0.258$	$r = 0.03, p = 0.910$	$r = 0.54, p = 0.015$	$r = 0.40, p = 0.082$
		α_2	$r = 0.23, p = 0.325$	$r = 0.03, p = 0.888$	$r = 0.68, p = 0.001$**	$r = 0.53, p = 0.017$
		β_1	$r = 0.28, p = 0.241$	$r = 0.14, p = 0.566$	$r = 0.60, p = 0.005$**	$r = 0.44, p = 0.05$
		β_2	$r = 0.32, p = 0.165$	$r = 0.21, p = 0.384$	$r = 0.62, p = 0.004$**	$r = 0.42, p = 0.067$
		β_3	$r = 0.38, p = 0.101$	$r = 0.29, p = 0.209$	$r = 0.59, p = 0.006$**	$r = 0.38, p = 0.096$
	LM	δ	$r = 0.53, p = 0.017$	$r = 0.22, p = 0.345$	$r = 0.26, p = 0.271$	$r = 0.31, p = 0.177$
		θ	$r = 0.52, p = 0.020$	$r = 0.22, p = 0.355$	$r = 0.32, p = 0.170$	$r = 0.19, p = 0.432$
		α_1	$r = 0.39, p = 0.093$	$r = -0.08, p = 0.725$	$r = 0.22, p = 0.352$	$r = -0.06, p = 0.795$
		α_2	$r = 0.22, p = 0.341$	$r = -0.07, p = 0.786$	$r = 0.40, p = 0.083$	$r = 0.19, p = 0.427$
		β_1	$r = 0.16, p = 0.511$	$r = 0.02, p = 0.928$	$r = 0.44, p = 0.050$	$r = 0.16, p = 0.508$
		β_2	$r = 0.16, p = 0.497$	$r = 0.11, p = 0.638$	$r = 0.47, p = 0.035$	$r = 0.21, p = 0.381$
		β_3	$r = 0.23, p = 0.321$	$r = 0.22, p = 0.363$	$r = 0.47, p = 0.036$	$r = 0.22, p = 0.356$
	LE	δ	$r = 0.14, p = 0.555$	$r = 0.22, p = 0.349$	$r = 0.19, p = 0.424$	$r = 0.30, p = 0.193$
		θ	$r = 0.19, p = 0.412$	$r = 0.11, p = 0.639$	$r = 0.27, p = 0.255$	$r = 0.23, p = 0.331$
		α_1	$r = 0.11, p = 0.632$	$r = -0.18, p = 0.440$	$r = 0.27, p = 0.256$	$r = 0.07, p = 0.759$
		α_2	$r = -0.03, p = 0.913$	$r = -0.30, p = 0.200$	$r = 0.38, p = 0.103$	$r = 0.15, p = 0.530$
		β_1	$r = 0.12, p = 0.602$	$r = -0.16, p = 0.491$	$r = 0.40, p = 0.082$	$r = 0.15, p = 0.525$
		β_2	$r = 0.22, p = 0.343$	$r = 0.09, p = 0.712$	$r = 0.48, p = 0.031$	$r = 0.18, p = 0.455$
		β_3	$r = 0.30, p = 0.197$	$r = 0.21, p = 0.375$	$r = 0.50, p = 0.024$	$r = 0.20, p = 0.389$
	PE	δ	$r = 0.29, p = 0.210$	$r = 0.24, p = 0.317$	$r = 0.29, p = 0.219$	$r = 0.42, p = 0.063$
		θ	$r = 0.30, p = 0.195$	$r = 0.05, p = 0.820$	$r = 0.24, p = 0.300$	$r = 0.21, p = 0.380$
		α_1	$r = 0.31, p = 0.177$	$r = 0.08, p = 0.750$	$r = 0.27, p = 0.259$	$r = 0.09, p = 0.701$
		α_2	$r = 0.30, p = 0.197$	$r = 0.07, p = 0.783$	$r = 0.50, p = 0.026$	$r = 0.29, p = 0.209$
		β_1	$r = 0.37, p = 0.106$	$r = 0.18, p = 0.453$	$r = 0.56, p = 0.011$	$r = 0.32, p = 0.167$
		β_2	$r = 0.39, p = 0.093$	$r = 0.28, p = 0.229$	$r = 0.52, p = 0.019$	$r = 0.28, p = 0.240$
		β_3	$r = 0.43, p = 0.062$	$r = 0.42, p = 0.066$	$r = 0.48, p = 0.032$	$r = 0.25, p = 0.284$
s4	SL	δ	$r = 0.53, p = 0.017$	$r = 0.28, p = 0.241$	$r = 0.23, p = 0.320$	$r = 0.23, p = 0.323$
		θ	$r = 0.38, p = 0.097$	$r = -0.01, p = 0.955$	$r = 0.05, p = 0.851$	$r = 0.04, p = 0.857$
		α_1	$r = 0.14, p = 0.571$	$r = -0.36, p = 0.117$	$r = -0.17, p = 0.479$	$r = -0.19, p = 0.435$
		α_2	$r = 0.16, p = 0.498$	$r = -0.23, p = 0.321$	$r = -0.08, p = 0.724$	$r = 0.03, p = 0.906$
		β_1	$r = 0.11, p = 0.637$	$r = -0.05, p = 0.844$	$r = 0.05, p = 0.830$	$r = 0.20, p = 0.394$
		β_2	$r = 0.06, p = 0.792$	$r = -0.04, p = 0.877$	$r = 0.06, p = 0.810$	$r = 0.24, p = 0.311$
		β_3	$r = 0.12, p = 0.626$	$r = 0.05, p = 0.846$	$r = 0.10, p = 0.671$	$r = 0.21, p = 0.375$
	PD	δ	$r = 0.15, p = 0.525$	$r = -0.04, p = 0.860$	$r = 0.17, p = 0.466$	$r = 0.18, p = 0.443$
		θ	$r = 0.18, p = 0.456$	$r = 0.09, p = 0.705$	$r = 0.32, p = 0.176$	$r = 0.36, p = 0.122$
		α_1	$r = -0.09, p = 0.695$	$r = -0.39, p = 0.088$	$r = 0.23, p = 0.320$	$r = 0.28, p = 0.230$
		α_2	$r = -0.14, p = 0.540$	$r = -0.46, p = 0.041$	$r = 0.28, p = 0.228$	$r = 0.36, p = 0.117$
		β_1	$r = -0.05, p = 0.838$	$r = -0.24, p = 0.319$	$r = 0.19, p = 0.432$	$r = 0.28, p = 0.237$
		β_2	$r = -0.01, p = 0.963$	$r = -0.22, p = 0.359$	$r = 0.22, p = 0.350$	$r = 0.41, p = 0.074$
		β_3	$r = -0.05, p = 0.830$	$r = -0.14, p = 0.559$	$r = 0.18, p = 0.459$	$r = 0.30, p = 0.197$
	LM	δ	$r = 0.50, p = 0.026$	$r = 0.12, p = 0.606$	$r = 0.18, p = 0.438$	$r = 0.18, p = 0.448$
		θ	$r = 0.29, p = 0.218$	$r = -0.11, p = 0.648$	$r = -0.06, p = 0.795$	$r = 0.02, p = 0.946$
		α_1	$r = 0.04, p = 0.853$	$r = -0.45, p = 0.046$	$r = -0.24, p = 0.306$	$r = -0.17, p = 0.469$

		α_2	$r = -0.04, p = 0.873$	$r = -0.35, p = 0.135$	$r = -0.13, p = 0.597$	$r = 0.05, p = 0.836$
		β_1	$r = -0.09, p = 0.708$	$r = -0.09, p = 0.693$	$r = -0.14, p = 0.570$	$r = 0.03, p = 0.918$
		β_2	$r = -0.08, p = 0.726$	$r = -0.06, p = 0.803$	$r = -0.12, p = 0.613$	$r = 0.16, p = 0.492$
		β_3	$r = -0.08, p = 0.731$	$r = 0.02, p = 0.948$	$r = -0.12, p = 0.615$	$r = 0.11, p = 0.650$
	LE	δ	$r = 0.11, p = 0.658$	$r = 0.11, p = 0.657$	$r = 0.08, p = 0.739$	$r = 0.15, p = 0.530$
		θ	$r = 0.01, p = 0.998$	$r = -0.07, p = 0.778$	$r = 0.09, p = 0.717$	$r = 0.10, p = 0.677$
		α_1	$r = -0.23, p = 0.337$	$r = -0.37, p = 0.113$	$r = 0.01, p = 0.972$	$r = -0.17, p = 0.462$
		α_2	$r = -0.28, p = 0.224$	$r = -0.50, p = 0.025$	$r = 0.14, p = 0.544$	$r = -0.02, p = 0.949$
		β_1	$r = -0.15, p = 0.536$	$r = -0.28, p = 0.230$	$r = 0.19, p = 0.422$	$r = 0.02, p = 0.924$
		β_2	$r = -0.07, p = 0.770$	$r = -0.17, p = 0.480$	$r = 0.22, p = 0.360$	$r = 0.01, p = 0.985$
		β_3	$r = -0.05, p = 0.852$	$r = -0.12, p = 0.606$	$r = 0.19, p = 0.428$	$r = -0.03, p = 0.890$
	PE	δ	$r = 0.34, p = 0.148$	$r = 0.30, p = 0.195$	$r = 0.21, p = 0.368$	$r = 0.36, p = 0.116$
		θ	$r = 0.25, p = 0.283$	$r = 0.16, p = 0.490$	$r = 0.38, p = 0.104$	$r = 0.26, p = 0.272$
		α_1	$r = 0.20, p = 0.398$	$r = 0.13, p = 0.585$	$r = 0.34, p = 0.149$	$r = 0.06, p = 0.819$
		α_2	$r = 0.24, p = 0.315$	$r = -0.05, p = 0.840$	$r = 0.43, p = 0.059$	$r = 0.19, p = 0.433$
		β_1	$r = 0.26, p = 0.266$	$r = -0.06, p = 0.813$	$r = 0.59, p = 0.006$**	$r = 0.35, p = 0.128$
		β_2	$r = 0.27, p = 0.249$	$r = -0.02, p = 0.929$	$r = 0.57, p = 0.009$**	$r = 0.24, p = 0.312$
		β_3	$r = 0.27, p = 0.251$	$r = 0.07, p = 0.786$	$r = 0.47, p = 0.037$	$r = 0.05, p = 0.845$
s5	SL	δ	$r = 0.47, p = 0.035$	$r = 0.20, p = 0.406$	$r = 0.32, p = 0.171$	$r = 0.28, p = 0.235$
		θ	$r = 0.45, p = 0.045$	$r = 0.05, p = 0.837$	$r = 0.08, p = 0.727$	$r = 0.18, p = 0.458$
		α_1	$r = 0.16, p = 0.503$	$r = -0.29, p = 0.214$	$r = -0.25, p = 0.294$	$r = -0.18, p = 0.439$
		α_2	$r = 0.11, p = 0.640$	$r = -0.22, p = 0.347$	$r = -0.10, p = 0.668$	$r = 0.04, p = 0.857$
		β_1	$r = 0.01, p = 0.987$	$r = -0.04, p = 0.860$	$r = 0.05, p = 0.841$	$r = 0.21, p = 0.383$
		β_2	$r = -0.10, p = 0.667$	$r = -0.09, p = 0.702$	$r = 0.10, p = 0.681$	$r = 0.29, p = 0.210$
		β_3	$r = -0.01, p = 0.968$	$r = -0.02, p = 0.948$	$r = 0.08, p = 0.741$	$r = 0.24, p = 0.309$
	PD	δ	$r = 0.36, p = 0.116$	$r = -0.08, p = 0.730$	$r = 0.38, p = 0.100$	$r = 0.20, p = 0.394$
		θ	$r = 0.70, p = 0.001$**	$r = 0.18, p = 0.438$	$r = 0.62, p = 0.004$**	$r = 0.64, p = 0.002$**
		α_1	$r = 0.09, p = 0.699$	$r = -0.37, p = 0.107$	$r = 0.19, p = 0.430$	$r = 0.43, p = 0.060$
		α_2	$r = -0.02, p = 0.929$	$r = -0.12, p =0.630$	$r = 0.16, p = 0.494$	$r = 0.43, p = 0.058$
		β_1	$r = 0.09, p = 0.701$	$r = -0.04, p = 0.885$	$r = 0.15, p = 0.524$	$r = 0.52, p = 0.018$
		β_2	$r = 0.09, p = 0.720$	$r = 0.01, p = 0.990$	$r = 0.14, p = 0.550$	$r = 0.42, p = 0.064$
		β_3	$r = 0.09, p = 0.695$	$r = 0.06, p = 0.797$	$r = 0.16, p = 0.497$	$r = 0.48, p = 0.030$
	LM	δ	$r = 0.56, p = 0.010$**	$r = 0.14, p = 0.546$	$r = 0.42, p = 0.067$	$r = 0.30, p = 0.193$
		θ	$r = 0.71, p = 0.001$**	$r = 0.13, p = 0.586$	$r = 0.28, p = 0.230$	$r = 0.49, p = 0.030$
		α_1	$r = 0.22, p = 0.351$	$r = -0.25, p = 0.282$	$r = -0.23, p = 0.334$	$r = 0.16, p = 0.499$
		α_2	$r = 0.09, p = 0.696$	$r = -0.21, p =0.384$	$r = -0.12, p = 0.617$	$r = 0.30, p = 0.201$
		β_1	$r = 0.01, p = 0.953$	$r = 0.01, p = 0.980$	$r = -0.10, p = 0.063$	$r = 0.42, p = 0.060$
		β_2	$r = -0.06, p = 0.796$	$r = -0.01, p = 0.966$	$r = -0.04, p = 0.856$	$r = 0.46, p = 0.042$
		β_3	$r = -0.01\ p = 0.975$	$r = 0.06, p = 0.812$	$r = -0.04, p = 0.879$	$r = 0.43, p = 0.060$
	LE	δ	$r = 0.10, p = 0.674$	$r = 0.01, p = 0.992$	$r = 0.11, p = 0.646$	$r = 0.11, p = 0.659$
		θ	$r = 0.48, p = 0.033$	$r = 0.13, p = 0.590$	$r = 0.40, p = 0.080$	$r = 0.34, p = 0.147$
		α_1	$r = -0.06, p = 0.792$	$r = -0.24, p= 0.302$	$r = 0.12, p = 0.629$	$r = 0.01, p = 0.964$
		α_2	$r = -0.15, p = 0.540$	$r = -0.04, p =0.880$	$r = 0.25, p = 0.294$	$r = 0.16, p = 0.503$
		β_1	$r = 0.11, p = 0.657$	$r = 0.01, p = 0.973$	$r = 0.29, p = 0.209$	$r = 0.28, p = 0.235$
		β_2	$r = 0.03, p = 0.899$	$r = 0.07, p = 0.782$	$r = 0.28, p = 0.228$	$r = 0.25, p = 0.295$
		β_3	$r = 0.08, p = 0.749$	$r = 0.08, p = 0.735$	$r = 0.30, p = 0.203$	$r = 0.33, p = 0.159$
	PE	δ	$r = 0.13, p = 0.586$	$r = -0.02, p = 0.920$	$r = -0.17, p = 0.466$	$r = 0.01, p = 0.975$
		θ	$r = 0.23, p = 0.328$	$r = 0.12, p = 0.959$	$r = 0.30, p = 0.202$	$r = 0.01, p = 0.996$
		α_1	$r = 0.25, p = 0.284$	$r = -0.07, p = 0.778$	$r = 0.19, p = 0.415$	$r = -0.39, p = 0.089$
		α_2	$r = 0.29, p = 0.224$	$r = 0.04, p = 0.864$	$r = 0.37, p = 0.105$	$r = -0.13, p = 0.597$
		β_1	$r = 0.32, p = 0.173$	$r = 0.01, p = 0.978$	$r = 0.59, p = 0.006$	$r = 0.01, p = 0.979$
		β_2	$r = 0.20, p = 0.406$	$r = -0.01, p = 0.973$	$r = 0.48, p = 0.032$	$r = -0.04, p = 0.861$
		β_3	$r = 0.21, p = 0.375$	$r = 0.09, p = 0.721$	$r = 0.47, p = 0.035$	$r = -0.02, p = 0.949$

SL = sleepiness; PD = Physical Discomfort; LM = Lack of Motivation; LE = Lack of Energy; PE = Physical Exertion

** adjusted significant p level at $p \leq 0.010$

Table 13.4. *Correlations between the SOFI-C measured at the end of afternoon and the EEG spectral power in s8, s9, and s10 of the* ***SM schedule***

			Normalized EEG spectral power			
			Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
s8	SL	δ	$r = 0.09, p = 0.704$	$r = -0.26, p = 0.272$	$r = -0.15, p = 0.517$	$r = -0.17, p = 0.465$
		θ	$r = 0.03, p = 0.901$	$r = -0.34, p = 0.138$	$r = -0.24, p = 0.308$	$r = -0.42, p = 0.064$
		α_1	$r = -0.20, p = 0.395$	$r = -0.30, p = 0.206$	$r = 0.10, p = 0.968$	$r = -0.26, p = 0.265$
		α_2	$r = -0.07, p = 0.758$	$r = -0.20, p = 0.404$	$r = -0.01, p = 0.973$	$r = -0.19, p = 0.433$
		β_1	$r = -0.12, p = 0.611$	$r = -0.12, p = 0.603$	$r = 0.11, p = 0.638$	$r = -0.05, p = 0.825$
		β_2	$r = -0.05, p = 0.851$	$r = -0.01, p = 0.963$	$r = 0.20, p = 0.388$	$r = 0.07, p = 0.780$
		β_3	$r = -0.20, p = 0.918$	$r = -0.01, p = 0.956$	$r = 0.23, p = 0.321$	$r = 0.15, p = 0.530$
	PD	δ	$r = 0.23, p = 0.922$	$r = -0.34, p = 0.137$	$r = -0.34, p = 0.148$	$r = -0.40, p = 0.082$
		θ	$r = 0.14, p = 0.555$	$r = -0.23, p = 0.329$	$r = -0.12, p = 0.615$	$r = -0.16, p = 0.514$
		α_1	$r = -0.25, p = 0.290$	$r = -0.34, p = 0.141$	$r = -0.16, p = 0.513$	$r = -0.27, p = 0.253$
		α_2	$r = -0.15, p = 0.533$	$r = -0.29, p = 0.216$	$r = -0.21, p = 0.387$	$r = -0.30, p = 0.195$
		β_1	$r = -0.03, p = 0.898$	$r = -0.17, p = 0.469$	$r = -0.06, p = 0.799$	$r = -0.19, p = 0.412$
		β_2	$r = -0.08, p = 0.733$	$r = -0.09, p = 0.696$	$r = -0.07, p = 0.758$	$r = 0.21, p = 0.367$
		β_3	$r = -0.07, p = 0.785$	$r = -0.05, p = 0.837$	$r = -0.03, p = 0.898$	$r = -0.12, p = 0.602$
	LM	δ	$r = -0.05, p = 0.833$	$r = -0.35, p = 0.131$	$r = -0.25, p = 0.297$	$r = -0.29, p = 0.214$
		θ	$r = 0.18, p = 0.938$	$r = -0.34, p = 0.138$	$r = -0.25, p = 0.298$	$r = -0.38, p = 0.094$
		α_1	$r = -0.29, p = 0.213$	$r = -0.37, p = 0.105$	$r = -0.12, p = 0.606$	$r = -0.38, p = 0.104$
		α_2	$r = -0.10, p = 0.677$	$r = -0.24, p = 0.312$	$r = -0.07, p = 0.766$	$r = -0.26, p = 0.263$
		β_1	$r = -0.09, p = 0.698$	$r = -0.14, p = 0.544$	$r = 0.03, p = 0.887$	$r = -0.16, p = 0.489$
		β_2	$r = -0.08, p = 0.743$	$r = -0.03, p = 0.903$	$r = 0.08, p = 0.728$	$r = -0.13, p = 0.592$
		β_3	$r = -0.07, p = 0.765$	$r = 0.02, p = 0.945$	$r = 0.08, p = 0.736$	$r = -0.07, p = 0.777$
	LE	δ	$r = -0.003, p = 0.989$	$r = -0.38, p = 0.103$	$r = -0.39, p = 0.091$	$r = -0.46, p = 0.039$
		θ	$r = 0.15, p = 0.517$	$r = -0.31, p = 0.182$	$r = -0.22, p = 0.346$	$r = -0.31, p = 0.192$
		α_1	$r = -0.26, p = 0.265$	$r = -0.35, p = 0.131$	$r = -0.18, p = 0.454$	$r = -0.16, p = 0.492$
		α_2	$r = -0.28, p = 0.240$	$r = -0.25, p = 0.288$	$r = -0.10, p = 0.679$	$r = -0.06, p = 0.796$
		β_1	$r = -0.31, p = 0.185$	$r = -0.21, p = 0.371$	$r = -0.01, p = 0.953$	$r = 0.03, p = 0.910$
		β_2	$r = -0.29, p = 0.208$	$r = -0.15, p = 0.541$	$r = -0.07, p = 0.770$	$r = 0.003, p = 0.990$
		β_3	$r = -0.27, p = 0.258$	$r = -0.08, p = 0.730$	$r = 0.03, p = 0.892$	$r = 0.10, p = 0.669$
	PE	δ	$r = -0.10, p = 0.673$	$r = -0.40, p = 0.083$	$r = -0.45, p = 0.046$	$r = -0.48, p = 0.031$
		θ	$r = -0.10, p = 0.680$	$r = -0.36, p = 0.123$	$r = -0.46, p = 0.042$	$r = -0.44, p = 0.055$
		α_1	$r = -0.25, p = 0.291$	$r = -0.45, p = 0.049$	$r = -0.36, p = 0.120$	$r = -0.31, p = 0.182$
		α_2	$r = -0.09, p = 0.699$	$r = -0.29, p = 0.209$	$r = -0.23, p = 0.322$	$r = -0.21, p = 0.385$
		β_1	$r = -0.06, p = 0.790$	$r = -0.16, p = 0.501$	$r = -0.25, p = 0.282$	$r = -0.18, p = 0.448$
		β_2	$r = -0.06, p = 0.790$	$r = -0.06, p = 0.812$	$r = -0.35, p = 0.133$	$r = -0.20, p = 0.391$
		β_3	$r = -0.05, p = 0.824$	$r = 0.06, p = 0.806$	$r = -0.21, p = 0.382$	$r = -0.10, p = 0.676$
s9	SL	δ	$r = -0.10, p = 0.681$	$r = -0.56, p = 0.010$**	$r = -0.20, p = 0.390$	$r = -0.21, p = 0.369$
		θ	$r = -0.13, p = 0.592$	$r = -0.60, p = 0.006$**	$r = -0.18, p = 0.454$	$r = -0.27, p = 0.248$
		α_1	$r = -0.38, p = 0.095$	$r = -0.46, p = 0.043$	$r = 0.06, p = 0.816$	$r = -0.04, p = 0.869$
		α_2	$r = -0.15, p = 0.521$	$r = -0.19, p = 0.432$	$r = 0.05, p = 0.846$	$r = 0.04, p = 0.884$
		β_1	$r = -0.003, p = 0.991$	$r = 0.09, p = 0.716$	$r = 0.15, p = 0.525$	$r = 0.13, p = 0.580$
		β_2	$r = 0.20, p = 0.389$	$r = 0.23, p = 0.328$	$r = 0.26, p = 0.275$	$r = 0.32, p = 0.166$
		β_3	$r = 0.13, p = 0.599$	$r = 0.19, p = 0.412$	$r = 0.28, p = 0.233$	$r = 0.32, p = 0.164$
	PD	δ	$r = 0.01, p = 0.968$	$r = -0.34, p = 0.145$	$r = -0.08, p = 0.726$	$r = -0.17, p = 0.471$
		θ	$r = -0.22, p = 0.353$	$r = -0.36, p = 0.122$	$r = -0.23, p = 0.335$	$r = -0.19, p = 0.414$
		α_1	$r = -0.12, p = 0.602$	$r = -0.23, p = 0.342$	$r = -0.11, p = 0.634$	$r = -0.02, p = 0.921$
		α_2	$r = -0.19, p = 0.423$	$r = -0.06, p = 0.817$	$r = -0.17, p = 0.479$	$r = -0.11, p = 0.646$
		β_1	$r = 0.12, p = 0.614$	$r = 0.18, p = 0.444$	$r = -0.01, p = 0.958$	$r = 0.06, p = 0.801$
		β_2	$r = 0.13, p = 0.577$	$r = 0.22, p = 0.348$	$r = 0.03, p = 0.901$	$r = 0.18, p = 0.459$
		β_3	$r = 0.11, p = 0.636$	$r = 0.23, p = 0.329$	$r = 0.04, p = 0.878$	$r = 0.15, p = 0.525$
	LM	δ	$r = -0.10, p = 0.683$	$r = -0.62, p = 0.003$**	$r = -0.26, p = 0.262$	$r = -0.29, p = 0.214$
		θ	$r = -0.20, p = 0.408$	$r = -0.62, p = 0.004$**	$r = -0.26, p = 0.265$	$r = -0.31, p = 0.178$
		α_1	$r = -0.35, p = 0.134$	$r = -0.45, p = 0.048$	$r = -0.07, p = 0.786$	$r = -0.15, p = 0.533$

		α_2	$r = -0.23, p = 0.325$	$r = -0.20, p = 0.403$	$r = -0.05, p = 0.841$	$r = -0.08, p = 0.742$
		β_1	$r = -0.03, p = 0.887$	$r = 0.11, p = 0.653$	$r = 0.06, p = 0.803$	$r = 0.02, p = 0.934$
		β_2	$r = 0.12, p = 0.606$	$r = 0.23, p = 0.337$	$r = 0.13, p = 0.584$	$r = 0.17, p = 0.470$
		β_3	$r = 0.02, p = 0.923$	$r = 0.20, p = 0.388$	$r = 0.13, p = 0.599$	$r = 0.13, p = 0.599$
	LE	δ	$r = 0.02, p = 0.920$	$r = -0.42, p = 0.069$	$r = -0.28, p = 0.232$	$r = -0.34, p = 0.147$
		θ	$r = -0.04, p = 0.883$	$r = -0.38, p = 0.103$	$r = -0.23, p = 0.330$	$r = -0.26, p = 0.268$
		α_1	$r = -0.16, p = 0.502$	$r = -0.16, p = 0.495$	$r = -0.07, p = 0.767$	$r = -0.04, p = 0.881$
		α_2	$r = -0.12, p = 0.623$	$r = 0.08, p = 0.746$	$r = -0.02, p = 0.939$	$r = 0.09, p = 0.695$
		β_1	$r = 0.01, p = 0.980$	$r = 0.17, p = 0.464$	$r = 0.04, p = 0.866$	$r = 0.13, p = 0.577$
		β_2	$r = 0.13, p = 0.572$	$r = 0.29, p = 0.219$	$r = 0.05, p = 0.850$	$r = 0.25, p = 0.289$
		β_3	$r = 0.06, p = 0.799$	$r = 0.31, p = 0.190$	$r = 0.10, p = 0.686$	$r = 0.25, p = 0.281$
	PE	δ	$r = 0.15, p = 0.542$	$r = -0.13, p = 0.591$	$r = -0.07, p = 0.775$	$r = -0.13, p = 0.573$
		θ	$r = -0.10, p = 0.691$	$r = -0.19, p = 0.419$	$r = -0.44, p = 0.050$	$r = -0.42, p = 0.068$
		α_1	$r = -0.06, p = 0.795$	$r = -0.08, p = 0.724$	$r = -0.33, p = 0.161$	$r = -0.21, p = 0.380$
		α_2	$r = -0.08, p = 0.735$	$r = 0.10, p = 0.661$	$r = -0.28, p = 0.229$	$r = 0.17, p = 0.468$
		β_1	$r = 0.06, p = 0.816$	$r = 0.20, p = 0.392$	$r = -0.26, p = 0.263$	$r = -0.10, p = 0.683$
		β_2	$r = 0.10, p = 0.967$	$r = 0.19, p = 0.435$	$r = -0.27, p = 0.257$	$r = -0.04, p = 0.882$
		β_3	$r = 0.05, p = 0.820$	$r = 0.21, p = 0.375$	$r = -0.21, p = 0.367$	$r = -0.01, p = 0.953$
s10	SL	δ	$r = -0.17, p = 0.480$	$r = -0.50, p = 0.026$	$r = -0.53, p = 0.017$	$r = -0.49, p = 0.028$
		θ	$r = -0.10, p = 0.666$	$r = -0.58, p = 0.007$**	$r = -0.20, p = 0.401$	$r = -0.13, p = 0.586$
		α_1	$r = -0.37, p = 0.112$	$r = -0.42, p = 0.066$	$r = 0.02, p = 0.926$	$r = 0.10, p = 0.675$
		α_2	$r = -0.34, p = 0.144$	$r = -0.26, p = 0.278$	$r = 0.07, p = 0.771$	$r = 0.10, p = 0.687$
		β_1	$r = -0.18, p = 0.443$	$r = 0.02, p = 0.939$	$r = 0.21, p = 0.370$	$r = 0.25, p = 0.283$
		β_2	$r = 0.04, p = 0.873$	$r = 0.22, p = 0.353$	$r = 0.26, p = 0.262$	$r = 0.34, p = 0.139$
		β_3	$r = 0.04, p = 0.876$	$r = 0.14, p = 0.570$	$r = 0.25, p = 0.295$	$r = 0.35, p = 0.136$
	PD	δ	$r = 0.07, p = 0.774$	$r = -0.27, p = 0.254$	$r = -0.31, p = 0.188$	$r = -0.31, p = 0.181$
		θ	$r = -0.38, p = 0.097$	$r = -0.59, p = 0.010$	$r = -0.51, p = 0.022$	$r = -0.38, p = 0.101$
		α_1	$r = -0.22, p = 0.360$	$r = -0.44, p = 0.054$	$r = -0.06, p = 0.805$	$r = 0.07, p = 0.761$
		α_2	$r = -0.27, p = 0.246$	$r = -0.29, p = 0.208$	$r = -0.14, p = 0.571$	$r = -0.03, p = 0.912$
		β_1	$r = 0.13, p = 0.597$	$r = 0.03, p = 0.910$	$r = -0.04, p = 0.858$	$r = 0.08, p = 0.728$
		β_2	$r = 0.18, p = 0.439$	$r = 0.06, p = 0.805$	$r = -0.05, p = 0.840$	$r = 0.06, p = 0.808$
		β_3	$r = 0.27, p = 0.259$	$r = 0.05, p = 0.838$	$r = -0.07, p = 0.786$	$r = 0.06, p = 0.791$
	LM	δ	$r = -0.06, p = 0.816$	$r = -0.47, p = 0.039$	$r = -0.49, p = 0.029$	$r = -0.46, p = 0.042$
		θ	$r = -0.17, p = 0.481$	$r = -0.63, p = 0.003$**	$r = -0.36, p = 0.117$	$r = -0.32, p = 0.174$
		α_1	$r = -0.29, p = 0.208$	$r = -0.50, p = 0.026$	$r = -0.08, p = 0.736$	$r = -0.10, p = 0.966$
		α_2	$r = -0.35, p = 0.131$	$r = -0.33, p = 0.163$	$r = -0.04, p = 0.866$	$r = -0.03, p = 0.888$
		β_1	$r = -0.06, p = 0.799$	$r = 0.04, p = 0.878$	$r = 0.05, p = 0.845$	$r = 0.08, p = 0.744$
		β_2	$r = 0.12, p = 0.608$	$r = 0.20, p = 0.407$	$r = 0.09, p = 0.699$	$r = 0.11, p = 0.654$
		β_3	$r = 0.09, p = 0.709$	$r = 0.13, p = 0.580$	$r = 0.05, p = 0.835$	$r = 0.10, p = 0.681$
	LE	δ	$r = -0.08, p = 0.750$	$r = -0.48, p = 0.032$	$r = -0.54, p = 0.015$	$r = -0.59, p = 0.006$**
		θ	$r = -0.13, p = 0.582$	$r = -0.42, p = 0.065$	$r = -0.28, p = 0.228$	$r = -0.29, p = 0.217$
		α_1	$r = -0.28, p = 0.239$	$r = -0.34, p = 0.146$	$r = 0.06, p = 0.787$	$r = 0.12, p = 0.623$
		α_2	$r = -0.38, p = 0.100$	$r = -0.06, p = 0.816$	$r = 0.11, p = 0.640$	$r = 0.16, p = 0.494$
		β_1	$r = -0.05, p = 0.826$	$r = 0.13, p = 0.577$	$r = 0.21, p = 0.365$	$r = 0.25, p = 0.296$
		β_2	$r = 0.05, p = 0.822$	$r = 0.26, p = 0.266$	$r = 0.21, p = 0.368$	$r = 0.24, p = 0.314$
		β_3	$r = 0.11, p = 0.636$	$r = 0.29, p = 0.224$	$r = 0.18, p = 0.440$	$r = 0.25, p = 0.299$
	PE	δ	$r = 0.17, p = 0.469$	$r = -0.18, p = 0.461$	$r = -0.16, p = 0.502$	$r = -0.20, p = 0.388$
		θ	$r = -0.16, p = 0.512$	$r = -0.20, p = 0.396$	$r = -0.38, p = 0.104$	$r = -0.15, p = 0.539$
		α_1	$r = -0.16, p = 0.502$	$r = -0.30, p = 0.205$	$r = -0.13, p = 0.574$	$r = 0.16, p = 0.513$
		α_2	$r = -0.13, p = 0.593$	$r = -0.03, p = 0.909$	$r = -0.06, p = 0.801$	$r = 0.23, p = 0.336$
		β_1	$r = 0.11, p = 0.660$	$r = 0.17, p = 0.485$	$r = -0.05, p = 0.834$	$r = 0.26, p = 0.266$
		β_2	$r = 0.11, p = 0.655$	$r = 0.16, p = 0.515$	$r = -0.18, p = 0.455$	$r = 0.11, p = 0.660$
		β_3	$r = 0.20, p = 0.408$	$r = 0.15, p = 0.517$	$r = -0.18, p = 0.460$	$r = 0.08, p = 0.726$

SL = sleepiness; PD = Physical Discomfort; LM = Lack of Motivation; LE = Lack of Energy; PE = Physical Exertion

** adjusted significant p level at $p \leq 0.010$

Correlations Between SOFI-C and Mental Effort (0.1 Hz HRV × -1)

Table 13.5. *Correlations between the SOFI-C measured at the end of morning and afternoon and the mental effort (0.1 Hz HRV × -1) in S2 and S3 for the morning block, and S5 and S6 for the afternoon block of the* ***LM schedule***

		Morning			Afternoon
		0.1 Hz HRV × -1			0.1 Hz HRV × -1
S2	SL	$r = -0.25, p = 0.279$	S5	SL	$r = 0.02, p = 0.925$
	PD	$r = -0.22, p = 0.355$		PD	$r = -0.37, p = 0.109$
	LM	$r = 0.05, p = 0.837$		LM	$r = -0.09, p = 0.716$
	LE	$r = -0.04, p = 0.881$		LE	$r = -0.07, p = 0.756$
	PE	$r = -0.07, p = 0.777$		PE	$r = -0.29, p = 0.217$
S3	SL	$r = -0.11, p = 0.631$	S6	SL	$r = 0.08, p = 0.726$
	PD	$r = -0.09, p = 0.700$		PD	$r = -0.14, p = 0.556$
	LM	$r = -0.11, p = 0.648$		LM	$r = -0.16, p = 0.497$
	LE	$r = -0.12, p = 0.609$		LE	$r = -0.13, p = 0.575$
	PE	$r = -0.26, p = 0.273$		PE	$r = -0.23, p = 0.330$

SL = sleepiness; PD = Physical Discomfort; LM = Lack of Motivation; LE = Lack of Energy; PE = Physical Exertion

** adjusted significant p level at $p \leq 0.017$

Table 13.6. *Correlations between the SOFI-C measured at the end of morning and afternoon and the mental effort (0.1 Hz HRV × -1) in s3, s4 and s5 for the morning block, and s8, s9, and s10 for the afternoon block of the* ***SM schedule***

		Morning			Afternoon
		0.1 Hz HRV × -1			0.1 Hz HRV × -1
s3	SL	$r = -0.14, p = 0.567$	s8	SL	$r = -0.12, p = 0.605$
	PD	$r = 0.16, p = 0.511$		PD	$r = -0.13, p = 0.578$
	LM	$r = -0.01, p = 0.976$		LM	$r = -0.16, p = 0.948$
	LE	$r = 0.30, p = 0.197$		LE	$r = -0.21, p = 0.367$
	PE	$r = 0.05, p = 0.834$		PE	$r = -0.21, p = 0.369$
s4	SL	$r = -0.11, p = 0.642$	s9	SL	$r = -0.02, p = 0.930$
	PD	$r = 0.19, p = 0.433$		PD	$r = 0.01, p = 0.953$
	LM	$r = 0.03, p = 0.890$		LM	$r = 0.13, p = 0.574$
	LE	$r = 0.18, p = 0.460$		LE	$r = -0.05, p = 0.841$
	PE	$r = 0.15, p = 0.528$		PE	$r = 0.04, p = 0.856$
s5	SL	$r = -0.26, p = 0.273$	s10	SL	$r = -0.41, p = 0.074$
	PD	$r = 0.07, p = 0.757$		PD	$r = -0.33, p = 0.151$
	LM	$r = -0.20, p = 0.938$		LM	$r = -0.32, p = 0.173$
	LE	$r = 0.22, p = 0.346$		LE	$r = -0.22, p = 0.351$
	PE	$r = -0.03, p = 0.888$		PE	$r = -0.06, p = 0.806$

SL = sleepiness; PD = Physical Discomfort; LM = Lack of Motivation; LE = Lack of Energy; PE = Physical Exertion

** adjusted significant p level at $p < 0.010$

Correlations Between Speed of Data Entry and EEG Spectral Power

Table 13.7. *Correlations between speed of data entry in the last 10-minute session and the EEG spectral power of the **LM schedule***

		Normalized EEG spectral power			
		Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
S1	δ	$r = 0.34, p = 0.140$	$r = 0.43, p = 0.060$	$r = 0.08, p = 0.746$	$r = 0.27, p = 0.250$
	θ	$r = 0.18, p = 0.461$	$r = 0.40, p = 0.080$	$r = 0.41, p = 0.069$	$r = 0.40, p = 0.083$
	α_1	$r = 0.28, p = 0.225$	$r = 0.31, p = 0.190$	$r = 0.14, p = 0.552$	$r = 0.11, p = 0.643$
	α_2	$r = 0.25, p = 0.299$	$r = 0.37, p = 0.106$	$r = 0.16, p = 0.512$	$r = 0.02, p = 0.940$
	β_1	$r = 0.30, p = 0.205$	$r = 0.52, p = 0.019$	$r = 0.20, p = 0.390$	$r = 0.17, p = 0.472$
	β_2	$r = 0.32, p = 0.164$	$r = 0.39, p = 0.086$	$r = 0.20, p = 0.410$	$r = 0.12, p = 0.937$
	β_3	$r = 0.33, p = 0.161$	$r = 0.43, p = 0.059$	$r = 0.20, p = 0.395$	$r = 0.03, p = 0.891$
S2	δ	$r = 0.09, p = 0.695$	$r = -0.03, p = 0.901$	$r = 0.17, p = 0.476$	$r = 0.19, p = 0.424$
	θ	$r = -0.03, p = 0.901$	$r = 0.02, p = 0.942$	$r = 0.18, p = 0.459$	$r = 0.08, p = 0.726$
	α_1	$r = 0.13, p = 0.588$	$r = -0.11, p = 0.659$	$r = 0.10, p = 0.685$	$r = 0.02, p = 0.948$
	α_2	$r = 0.26, p = 0.270$	$r = -0.09, p = 0.706$	$r = 0.10, p = 0.676$	$r = 0.06, p = 0.818$
	β_1	$r = 0.53, p = 0.017$	$r = 0.34, p = 0.141$	$r = 0.05, p = 0.823$	$r = 0.07, p = 0.777$
	β_2	$r = 0.57, p = 0.008$	$r = 0.40, p = 0.079$	$r = 0.02, p = 0.923$	$r = -0.002, p = 0.994$
	β_3	$r = 0.55, p = 0.013$	$r = 0.35, p = 0.132$	$r = 0.05, p = 0.826$	$r = 0.05, p = 0.841$
S3	δ	$r = 0.16, p = 0.506$	$r = 0.34, p = 0.142$	$r = 0.44, p = 0.052$	$r = 0.51, p = 0.022$
	θ	$r = 0.15, p = 0.524$	$r = 0.46, p = 0.039$	$r = 0.45, p = 0.046$	$r = 0.42, p = 0.068$
	α_1	$r = 0.24, p = 0.313$	$r = 0.31, p = 0.191$	$r = 0.48, p = 0.032$	$r = 0.36, p = 0.115$
	α_2	$r = 0.34, p = 0.141$	$r = 0.23, p = 0.340$	$r = 0.52, p = 0.020$	$r = 0.36, p = 0.115$
	β_1	$r = 0.54, p = 0.014$	$r = 0.36, p = 0.116$	$r = 0.53, p = 0.015$	$r = 0.53, p = 0.017$
	β_2	$r = 0.57, p = 0.009$	$r = 0.35, p = 0.136$	$r = 0.59, p = 0.006$**	$r = 0.51, p = 0.021$
	β_3	$r = 0.50, p = 0.024$	$r = 0.34, p = 0.140$	$r = 0.59, p = 0.006$**	$r = 0.53, p = 0.016$
S4	δ	$r = 0.05, p = 0.839$	$r = -0.14, p = 0.550$	$r = 0.03, p = 0.890$	$r = 0.04, p = 0.881$
	θ	$r = 0.16, p = 0.510$	$r = 0.03, p = 0.899$	$r = 0.15, p = 0.525$	$r = 0.12, p = 0.614$
	α_1	$r = 0.06, p = 0.811$	$r = 0.14, p = 0.561$	$r = 0.10, p = 0.667$	$r = 0.17, p = 0.475$
	α_2	$r = -0.05, p = 0.835$	$r = 0.24, p = 0.303$	$r = 0.02, p = 0.936$	$r = 0.12, p = 0.608$
	β_1	$r = -0.09, p = 0.709$	$r = 0.10, p = 0.690$	$r = 0.03, p = 0.908$	$r = 0.14, p = 0.566$
	β_2	$r = -0.08, p = 0.752$	$r = 0.08, p = 0.738$	$r = 0.001, p = 0.996$	$r = 0.15, p = 0.543$
	β_3	$r = -0.09, p = 0.722$	$r = -0.002, p = 0.994$	$r = -0.08, p = 0.738$	$r = 0.12, p = 0.614$
S5	δ	$r = 0.23, p = 0.336$	$r = -0.60, p = 0.005$**	$r = 0.08, p = 0.743$	$r = 0.04, p = 0.861$
	θ	$r = 0.10, p = 0.691$	$r = -0.38, p = 0.099$	$r = 0.06, p = 0.808$	$r = 0.05, p = 0.837$
	α_1	$r = 0.09, p = 0.710$	$r = -0.42, p = 0.067$	$r = -0.08, p = 0.731$	$r = 0.05, p = 0.845$
	α_2	$r = -0.13, p = 0.599$	$r = -0.39, p = 0.090$	$r = -0.12, p = 0.617$	$r = 0.07, p = 0.767$
	β_1	$r = -0.27, p = 0.254$	$r = -0.56, p = 0.010$	$r = -0.10, p = 0.663$	$r = 0.12, p = 0.621$
	β_2	$r = -0.43, p = 0.062$	$r = -0.48, p = 0.032$	$r = -0.25, p = 0.280$	$r = -0.11, p = 0.631$
	β_3	$r = -0.43, p = 0.057$	$r = -0.47, p = 0.037$	$r = -0.26, p = 0.267$	$r = -0.03, p = 0.887$
S6	δ	$r = 0.21, p = 0.372$	$r = -0.06, p = 0.812$	$r = -0.06, p = 0.802$	$r = -0.21, p = 0.365$
	θ	$r = 0.12, p = 0.623$	$r = -0.11, p = 0.636$	$r = 0.01, p = 0.964$	$r = -0.14, p = 0.545$
	α_1	$r = -0.03, p = 0.888$	$r = -0.10, p = 0.688$	$r = -0.11, p = 0.649$	$r = -0.05, p = 0.824$
	α_2	$r = -0.16, p = 0.509$	$r = -0.06, p = 0.794$	$r = -0.24, p = 0.317$	$r = -0.16, p = 0.499$
	β_1	$r = -0.26, p = 0.270$	$r = -0.07, p = 0.762$	$r = -0.13, p = 0.585$	$r = -0.10, p = 0.691$
	β_2	$r = -0.34, p = 0.148$	$r = -0.09, p = 0.693$	$r = -0.21, p = 0.370$	$r = -0.27, p = 0.245$
	β_3	$r = -0.33, p = 0.153$	$r = -0.20, p = 0.399$	$r = -0.20, p = 0.404$	$r = -0.19, p = 0.429$

** adjusted significant p level at $p \leq 0.0056$

Table 13.8. *Correlations between speed of data entry in the last 10-minute session and the EEG spectral power of the* ***SM schedule***

		Normalized EEG spectral power			
		Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
s1	δ	r = 0.15, p = 0.541	r = -0.05, p = 0.820	r = -0.18, p = 0.457	r = -0.07, p = 0.759
	θ	r = -0.11, p = 0.654	r = -0.16, p = 0.492	r = -0.04, p = 0.854	r = -0.04, p = 0.858
	α_1	r = 0.16, p = 0.515	r = -0.09, p = 0.699	r = 0.30, p = 0.196	r = 0.08, p = 0.729
	α_2	r = 0.29, p = 0.208	r = 0.02, p = 0.930	r = 0.07, p = 0.757	r = -0.10, p = 0.661
	β_1	r = 0.28, p = 0.238	r = 0.06, p = 0.790	r = 0.38, p = 0.104	r = 0.21, p = 0.377
	β_2	r = 0.25, p = 0.287	r = 0.04, p = 0.858	r = 0.29, p = 0.216	r = 0.13, p = 0.581
	β_3	r = 0.35, p = 0.136	r = 0.11, p = 0.633	r = 0.34, p = 0.148	r = 0.20, p = 0.400
s2	δ	r = -0.02, p = 0.942	r = 0.12, p = 0.609	r = -0.27, p = 0.242	r = -0.07, p = 0.785
	θ	r = -0.22, p = 0.361	r = 0.05, p = 0.843	r = 0.01, p = 0.984	r = -0.01, p = 0.969
	α_1	r = -0.27, p = 0.255	r = -0.14, p = 0.555	r = 0.17, p = 0.466	r = 0.12, p = 0.606
	α_2	r = -0.10, p = 0.671	r = -0.12, p = 0.626	r = 0.34, p = 0.147	r = 0.30, p = 0.195
	β_1	r = -0.03, p = 0.917	r = 0.09, p = 0.705	r = 0.35, p = 0.133	r = 0.29, p = 0.218
	β_2	r = 0.07, p = 0.782	r = 0.03, p = 0.887	r = 0.31, p = 0.192	r = 0.19, p = 0.422
	β_3	r = 0.12, p = 0.625	r = 0.12, p = 0.935	r = 0.21, p = 0.376	r = 0.22, p = 0.357
s3	δ	r = -0.23, p = 0.327	r = -0.17, p = 0.609	r = -0.31, p = 0.178	r = -0.32, p = 0.170
	θ	r = -0.24, p = 0.304	r = 0.01, p = 0.980	r = 0.05, p = 0.980	r = -0.01, p = 0.971
	α_1	r = -0.11, p = 0.654	r = 0.17, p = 0.466	r = 0.28, p = 0.228	r = 0.17, p = 0.480
	α_2	r = 0.18, p = 0.449	r = 0.36, p = 0.117	r = 0.03, p = 0.890	r = -0.01, p = 0.969
	β_1	r = 0.25, p = 0.288	r = 0.41, p = 0.075	r = 0.14, p = 0.564	r = 0.02, p = 0.939
	β_2	r = 0.24, p = 0.314	r = 0.35, p = 0.135	r = 0.17, p = 0.472	r = -0.03, p = 0.887
	β_3	r = 0.23, p = 0.334	r = 0.22, p = 0.347	r = 0.18, p = 0.455	r = 0.07, p = 0.764
s4	δ	r = -0.38, p = 0.103	r = -0.04, p = 0.882	r = -0.48, p = 0.033	r = -0.39, p = 0.091
	θ	r = -0.37, p = 0.110	r = -0.01, p = 0.958	r = -0.14, p = 0.551	r = -0.20, p = 0.396
	α_1	r = -0.12, p = 0.601	r = 0.37, p = 0.109	r = 0.22, p = 0.344	r = 0.12, p = 0.614
	α_2	r = 0.06, p = 0.815	r = 0.31, p = 0.184	r = 0.19, p = 0.411	r = 0.14, p = 0.545
	β_1	r = 0.15, p = 0.534	r = 0.39, p = 0.091	r = 0.27, p = 0.260	r = 0.21, p = 0.367
	β_2	r = 0.27, p = 0.247	r = 0.36, p = 0.122	r = 0.23, p = 0.339	r = 0.12, p = 0.610
	β_3	r = 0.20, p = 0.390	r = 0.24, p = 0.303	r = 0.13, p = 0.599	r = 0.05, p = 0.828
s5	δ	r = 0.15, p = 0.529	r = 0.37, p = 0.107	r = 0.04, p = 0.875	r = 0.17, p = 0.468
	θ	r = -0.08, p = 0.752	r = 0.20, p = 0.402	r = 0.05, p = 0.834	r = 0.12, p = 0.626
	α_1	r = -0.23, p = 0.338	r = 0.09, p = 0.716	r = 0.07, p = 0.786	r = 0.15, p = 0.523
	α_2	r = -0.06, p = 0.815	r = 0.01, p = 0.973	r = -0.15, p = 0.543	r = -0.04, p = 0.865
	β_1	r = -0.09, p = 0.693	r = 0.32, p = 0.167	r = -0.15, p = 0.539	r = -0.10, p = 0.665
	β_2	r =-0.003, p = 0.991	r = 0.28, p = 0.233	r = -0.03, p = 0.893	r = 0.00, p = 1.000
	β_3	r = 0.07, p = 0.768	r = 0.25, p = 0.283	r = -0.05, p = 0.820	r = 0.01, p = 0.975
s6	δ	r = -0.11, p = 0.638	r = 0.05, p = 0.847	r = 0.13, p = 0.584	r = 0.11, p = 0.638
	θ	r = 0.09, p = 0.722	r = 0.21, p = 0.384	r = 0.33, p = 0.162	r = 0.24, p = 0.314
	α_1	r = 0.39, p = 0.090	r = 0.03, p = 0.897	r = 0.47, p = 0.038	r = 0.31, p = 0.183
	α_2	r = 0.20, p = 0.408	r = -0.02, p = 0.939	r = 0.37, p = 0.109	r = 0.27, p = 0.251
	β_1	r = 0.32, p = 0.177	r = 0.01, p = 0.963	r = 0.45, p = 0.046	r = 0.38, p = 0.096
	β_2	r = 0.07, p = 0.771	r = -0.26, p = 0.269	r = 0.35, p = 0.133	r = 0.21, p = 0.372
	β_3	r = 0.10, p = 0.682	r = -0.32, p = 0.171	r = 0.31, p = 0.178	r = 0.21, p = 0.368
s7	δ	r = -0.02, p = 0.937	r = -0.05, p = 0.841	r = -0.06, p = 0.792	r = -0.14, p = 0.554
	θ	r = 0.20, p = 0.388	r = 0.05, p = 0.846	r = 0.28, p = 0.233	r = 0.15, p = 0.534
	α_1	r = 0.33, p = 0.153	r = 0.04, p = 0.877	r = 0.48, p = 0.032	r = 0.29, p = 0.217
	α_2	r = 0.14, p = 0.551	r = 0.02, p = 0.919	r = 0.36, p = 0.115	r = 0.36, p = 0.117
	β_1	r = 0.07, p = 0.761	r = -0.01, p = 0.971	r = 0.49, p = 0.028	r = 0.45, p = 0.045
	β_2	r = 0.04, p = 0.854	r = -0.05, p = 0.822	r = 0.36, p = 0.122	r = 0.28, p = 0.238
	β_3	r = -0.02, p = 0.951	r = -0.02, p = 0.943	r = 0.30, p = 0.193	r = 0.24, p = 0.319
s8	δ	r = -0.47, p = 0.036	r = 0.01, p = 0.954	r =-0.001, p =0.997	r = -0.05, p = 0.851
	θ	r = -0.07, p = 0.758	r = 0.16, p = 0.506	r = 0.18, p = 0.246	r = 0.11, p = 0.633
	α_1	r = -0.29, p = 0.224	r = 0.04, p = 0.862	r = 0.30, p = 0.207	r = 0.14, p = 0.570

	α_2	$r = -0.06, p = 0.791$	$r = 0.19, p = 0.426$	$r = 0.40, p = 0.083$	$r = 0.29, p = 0.224$
	β_1	$r = 0.18, p = 0.444$	$r = 0.13, p = 0.590$	$r = 0.27, p = 0.258$	$r = 0.27, p = 0.251$
	β_2	$r = -0.26, p = 0.277$	$r = 0.00, p = 0.999$	$r = 0.17, p = 0.484$	$r = 0.17, p = 0.484$
	β_3	$r = -0.30, p = 0.201$	$r = -0.04, p = 0.880$	$r = 0.09, p = 0.698$	$r = 0.04, p = 0.879$
s9	δ	$r = -0.16, p = 0.507$	$r = -0.05, p = 0.831$	$r = 0.02, p = 0.924$	$r = 0.04, p = 0.857$
	θ	$r = 0.26, p = 0.277$	$r = 0.35, p = 0.132$	$r = 0.57, p = 0.009$	$r = 0.51, p = 0.021$
	α_1	$r = 0.33, p = 0.155$	$r = 0.20, p = 0.395$	$r = 0.51, p = 0.022$	$r = 0.56, p = 0.010$
	α_2	$r = 0.18, p = 0.461$	$r = 0.05, p = 0.831$	$r = 0.47, p = 0.035$	$r = 0.54, p = 0.015$
	β_1	$r = 0.05, p = 0.849$	$r = -0.05, p = 0.829$	$r = 0.29, p = 0.211$	$r = 0.32, p = 0.171$
	β_2	$r = -0.13, p = 0.578$	$r = -0.02, p = 0.616$	$r = 0.21, p = 0.376$	$r = 0.12, p = 0.601$
	β_3	$r = -0.12, p = 0.604$	$r = -0.13, p = 0.599$	$r = 0.17, p = 0.464$	$r = 0.07, p = 0.777$
s10	δ	$r = -0.31, p = 0.182$	$r = -0.30, p = 0.198$	$r = -0.05, p = 0.829$	$r = 0.03, p = 0.908$
	θ	$r = -0.33, p = 0.157$	$r = -0.09, p = 0.709$	$r = 0.12, p = 0.611$	$r = 0.14, p = 0.568$
	α_1	$r = -0.05, p = 0.843$	$r = -0.02, p = 0.936$	$r = 0.70, p = 0.001$**	$r = 0.60, p = 0.005$
	α_2	$r = -0.02, p = 0.949$	$r = -0.04, p = 0.877$	$r = 0.64, p = 0.002$**	$r = 0.56, p = 0.010$
	β_1	$r = 0.07, p = 0.777$	$r = -0.04, p = 0.860$	$r = 0.52, p = 0.019$	$r = 0.50, p = 0.024$
	β_2	$r = 0.08, p = 0.751$	$r = -0.07, p = 0.761$	$r = 0.40, p = 0.081$	$r = 0.45, p = 0.048$
	β_3	$r = 0.15, p = 0.522$	$r = -0.08, p = 0.748$	$r = 0.34, p = 0.146$	$r = 0.35, p = 0.128$

** adjusted significant p level at $p \leq 0.002$

Correlations Between Speed of Data Entry and Mental Effort (0.1 Hz HRV × -1)

Table 13.9. *Correlations between speed of data entry in the last 10-minute session and the mental effort (0.1 Hz HRV × -1) of the* ***LM schedule***

		0.1 Hz HRV × -1
Morning	S1	$r = -0.07, p = 0.763$
	S2	$r = 0.44, p = 0.051$
	S3	$r = 0.22, p = 0.346$
Afternoon	S4	$r = -0.20, p = 0.404$
	S5	$r = 0.15, p = 0.529$
	S6	$r = -0.27, p = 0.257$

** adjusted significant p level at $p \leq 0.0056$

Table 13.10. *Correlations between speed of data entry in the last 10-minute session and the mental effort (0.1 Hz HRV × -1) of the* ***SM schedule***

		0.1 Hz HRV × -1
Morning	s1	$r = 0.34, p = 0.137$
	s2	$r = -0.01, p = 0.959$
	s3	$r = 0.14, p = 0.551$
	s4	$r = 0.23, p = 0.332$
	s5	$r = 0.07, p = 0.766$
Afternoon	s6	$r = -0.10, p = 0.665$
	s7	$r = -0.10, p = 0.662$
	s8	$r = -0.10, p = 0.690$
	s9	$r = 0.23, p = 0.334$
	s10	$r = 0.13, p = 0.576$

** adjusted significant p level at $p \leq 0.002$

Correlations Between Error Rate and EEG Spectral Power

Table 13.11. *Correlations between error rate in the last 10-minute session and the EEG spectral power of the* ***LM schedule***

		Normalized EEG spectral power			
		Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
S1	δ	$r = 0.23, p = 0.329$	$r = -0.33, p = 0.160$	$r = -0.08, p = 0.731$	$r = -0.18, p = 0.457$
	θ	$r = 0.04, p = 0.877$	$r = -0.32, p = 0.175$	$r = -0.35, p = 0.133$	$r = -0.30, p = 0.193$
	α_1	$r = 0.12, p = 0.618$	$r = -0.09, p = 0.708$	$r = -0.25, p = 0.286$	$r = -0.01, p = 0.962$
	α_2	$r = 0.05, p = 0.821$	$r = -0.06, p = 0.806$	$r = -0.21, p = 0.371$	$r = 0.08, p = 0.726$
	β_1	$r = -0.18, p = 0.441$	$r = -0.004, p = 0.987$	$r = -0.21, p = 0.375$	$r = -0.07, p = 0.786$
	β_2	$r = -0.20, p = 0.407$	$r = -0.03, p = 0.912$	$r = -0.23, p = 0.331$	$r = 0.06, p = 0.810$
	β_3	$r = -0.29, p = 0.210$	$r = -0.08, p = 0.731$	$r = -0.33, p = 0.156$	$r = -0.12, p = 0.618$
S2	δ	$r = -0.07, p = 0.778$	$r = -0.44, p = 0.055$	$r = -0.03, p = 0.904$	$r = -0.04, p = 0.858$
	θ	$r = -0.06, p = 0.788$	$r = -0.38, p = 0.100$	$r = -0.18, p = 0.447$	$r = -0.26, p = 0.270$
	α_1	$r = 0.23, p = 0.335$	$r = -0.02, p = 0.922$	$r = -0.17, p = 0.462$	$r = -0.28, p = 0.237$
	α_2	$r = 0.11, p = 0.646$	$r = -0.21, p = 0.386$	$r = -0.19, p = 0.414$	$r = -0.17, p = 0.469$
	β_1	$r = -0.31, p = 0.830$	$r = -0.53, p = 0.017$	$r = -0.23, p = 0.338$	$r = 0.29, p = 0.219$
	β_2	$r = -0.37, p = 0.108$	$r = -525, p = 0.017$	$r = -0.35, p = 0.134$	$r = -0.29, p = 0.212$
	β_3	$r = -0.42, p = 0.063$	$r = -0.51, p = 0.022$	$r = -0.42, p = 0.066$	$r = -0.33, p = 0.152$
S3	δ	$r = 0.07, p = 0.790$	$r = -0.03, p = 0.903$	$r = -0.07, p = 0.774$	$r = -0.07, p = 0.769$
	θ	$r = -0.10, p = 0.672$	$r = -0.30, p = 0.204$	$r = -0.26, p = 0.268$	$r = -0.24, p = 0.299$
	α_1	$r = -0.06, p = 0.792$	$r = -0.03, p = 0.916$	$r = 0.10, p = 0.687$	$r = 0.10, p = 0.684$
	α_2	$r = -0.15, p = 0.536$	$r = 0.20, p = 0.399$	$r = 0.13, p = 0.581$	$r = 0.08, p = 0.741$
	β_1	$r = -0.27, p = 0.242$	$r = 0.03, p = 0.909$	$r = 0.08, p = 0.751$	$r = -0.16, p = 0.499$
	β_2	$r = -0.37, p = 0.112$	$r = -0.05, p = 0.830$	$r = 0.51, p = 0.830$	$r = -0.03, p = 0.886$
	β_3	$r = -0.25, p = 0.280$	$r = 0.01, p = 0.960$	$r = -0.08, p = 0.725$	$r = -0.25, p = 0.288$
S4	δ	$r = 0.38, p = 0.099$	$r = 0.29, p = 0.211$	$r = 0.26, p = 0.269$	$r = 0.28, p = 0.234$
	θ	$r = 0.07, p = 0.755$	$r = 0.04, p = 0.861$	$r = 0.18, p = 0.461$	$r = 0.13, p = 0.599$
	α_1	$r = 0.18, p = 0.447$	$r = 0.03, p = 0.889$	$r = 0.30, p = 0.206$	$r = 0.25, p = 0.299$
	α_2	$r = 0.14, p = 0.556$	$r = -0.02, p = 0.947$	$r = 0.24, p = 0.316$	$r = 0.30, p = 0.205$
	β_1	$r = 0.07, p = 0.781$	$r = 0.12, p = 0.617$	$r = 0.06, p = 0.791$	$r = 0.12, p = 0.961$
	β_2	$r = 0.03, p = 0.891$	$r = 0.05, p = 0.827$	$r = -0.004, p = 0.988$	$r = -0.03, p = 0.917$
	β_3	$r = -0.02, p = 0.927$	$r = -0.05, p = 0.841$	$r = -0.004, p = 0.987$	$r = -0.11, p = 0.631$
S5	δ	$r = -0.09, p = 0.713$	$r = -0.11, p = 0.633$	$r = -0.14, p = 0.559$	$r = -0.16, p = 0.511$
	θ	$r = 0.19, p = 0.434$	$r = 0.01, p = 0.967$	$r = 0.02, p = 0.931$	$r = 0.10, p = 0.676$
	α_1	$r = -0.10, p = 0.679$	$r = -0.03, p = 0.894$	$r = -0.11, p = 0.644$	$r = 0.12, p = 0.602$
	α_2	$r = -0.11, p = 0.634$	$r = 0.11, p = 0.644$	$r = -0.08, p = 0.743$	$r = 0.07, p = 0.783$
	β_1	$r = -0.33, p = 0.150$	$r = -0.29, p = 0.224$	$r = -0.13, p = 0.588$	$r = -0.02, p = 0.933$
	β_2	$r = -0.40, p = 0.084$	$r = -0.33, p = 0.160$	$r = -0.18, p = 0.439$	$r = -0.02, p = 0.950$
	β_3	$r = -0.53, p = 0.018$	$r = -0.57, p = 0.009$	$r = -0.18, p = 0.460$	$r = -0.004, p = 0.985$
S6	δ	$r = -0.24, p = 0.301$	$r = 0.002, p = 0.994$	$r = -0.18, p = 0.444$	$r = 0.15, p = 0.541$
	θ	$r = -0.37, p = 0.107$	$r = -0.08, p = 0.750$	$r = -0.16, p = 0.499$	$r = -0.12, p = 0.619$
	α_1	$r = -0.36, p = 0.115$	$r = 0.01, p = 0.962$	$r = -0.28, p = 0.237$	$r = -0.35, p = 0.127$
	α_2	$r = -0.06, p = 0.790$	$r = -0.05, p = 0.827$	$r = -0.11, p = 0.648$	$r = -0.18, p = 0.460$
	β_1	$r = -0.13, p = 0.592$	$r = 0.09, p = 0.719$	$r = -0.03, p = 0.912$	$r = -0.09, p = 0.694$
	β_2	$r = -0.03, p = 0.898$	$r = 0.09, p = 0.717$	$r = -0.05, p = 0.834$	$r = -0.26, p = 0.275$
	β_3	$r = -0.05, p = 0.850$	$r = 0.22, p = 0.354$	$r = 0.08, p = 0.734$	$r = -0.08, p = 0.731$

** adjusted significant p level at $p < 0.0056$

Table 13.12. *Correlations between error rate in the last 10-minute session and the EEG spectral power of the* ***SM schedule***

		Normalized EEG spectral power			
		Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
s1	δ	$r = 0.32, p = 0.171$	$r =-0.003, p = 0.988$	$r = 0.05, p = 0.820$	$r = 0.11, p = 0.654$
	θ	$r = 0.12, p = 0.607$	$r = -0.11, p = 0.644$	$r = 0.04, p = 0.875$	$r = 0.04, p = 0.882$
	α_1	$r = 0.34, p = 0.147$	$r = 0.12, p = 0.624$	$r = 0.24, p = 0.308$	$r = 0.29, p = 0.208$
	α_2	$r = 0.31, p = 0.181$	$r = 0.12, p = 0.607$	$r = 0.23, p = 0.327$	$r = 0.23, p = 0.325$
	β_1	$r = 0.08, p = 0.731$	$r = 0.02, p = 0.934$	$r = 0.25, p = 0.298$	$r = 0.17, p = 0.469$
	β_2	$r = 0.09, p = 0.702$	$r = 0.03, p = 0.889$	$r = 0.25, p = 0.298$	$r = 0.20, p = 0.394$
	β_3	$r = 0.12, p = 0.947$	$r = -0.09, p = 0.718$	$r = 0.13, p = 0.592$	$r = 0.03, p = 0.901$
s2	δ	$r = 0.38, p = 0.096$	$r = 0.10, p = 0.666$	$r = 0.12, p = 0.618$	$r = 0.12, p = 0.620$
	θ	$r = 0.50, p = 0.025$	$r = -0.13, p = 0.596$	$r = 0.21, p = 0.373$	$r = 0.18, p = 0.449$
	α_1	$r = 0.40, p = 0.081$	$r = 0.05, p = 0.850$	$r = -0.06, p = 0.793$	$r = 0.06, p = 0.801$
	α_2	$r = 0.34, p = 0.144$	$r = 0.13, p = 0.578$	$r = 0.08, p = 0.724$	$r = 0.09, p = 0.693$
	β_1	$r = 0.10, p = 0.671$	$r = 0.10, p = 0.680$	$r = 0.18, p = 0.458$	$r = 0.13, p = 0.583$
	β_2	$r = 0.20, p = 0.400$	$r = 0.14, p = 0.566$	$r = 0.24, p = 0.319$	$r = 0.20, p = 0.389$
	β_3	$r = 0.15, p = 0.522$	$r = 0.23, p = 0.330$	$r = 0.19, p = 0.419$	$r = 0.05, p = 0.832$
s3	δ	$r = 0.33, p = 0.154$	$r = 0.30, p = 0.198$	$r = 0.20, p = 0.407$	$r = 0.30, p = 0.193$
	θ	$r = 0.41, p = 0.071$	$r = 0.43, p = 0.060$	$r = 0.42, p = 0.069$	$r = 0.38, p = 0.100$
	α_1	$r = 0.39, p = 0.088$	$r = 0.55, p = 0.012$	$r = 0.60, p = 0.005$	$r = 0.31, p = 0.187$
	α_2	$r = 0.36, p = 0.119$	$r = 0.39, p = 0.091$	$r = 0.46, p = 0.043$	$r = 0.15, p = 0.540$
	β_1	$r = 0.29, p = 0.219$	$r = 0.26, p = 0.273$	$r = 0.63, p = 0.002$**	$r = 0.24, p = 0.314$
	β_2	$r = 0.22, p = 0.353$	$r = 0.19, p = 0.434$	$r = 0.54, p = 0.015$	$r = 0.09, p = 0.717$
	β_3	$r = 0.24, p = 0.318$	$r = 0.23, p = 0.327$	$r = 0.47, p = 0.035$	$r = 0.07, p = 0.775$
s4	δ	$r = 0.49, p = 0.027$	$r = 0.26, p = 0.278$	$r = 0.27, p = 0.259$	$r = 0.39, p = 0.089$
	θ	$r = 0.44, p = 0.051$	$r = 0.48, p = 0.031$	$r = 0.48, p = 0.034$	$r = 0.39, p = 0.091$
	α_1	$r = 0.51, p = 0.023$	$r = 0.58, p = 0.008$	$r = 0.55, p = 0.012$	$r = 0.34, p = 0.137$
	α_2	$r = 0.40, p = 0.080$	$r = 0.31, p = 0.177$	$r = 0.43, p = 0.059$	$r = 0.19, p = 0.420$
	β_1	$r = 0.24, p = 0.311$	$r = -0.01\ p = 0.960$	$r = 0.62, p = 0.002$**	$r = 0.35, p = 0.126$
	β_2	$r = 0.17, p = 0.481$	$r = -0.08, p = 0.744$	$r = 0.45, p = 0.044$	$r = 0.05, p = 0.834$
	β_3	$r = 0.15, p = 0.535$	$r = -0.08, p = 0.744$	$r = 0.36, p = 0.120$	$r = -0.11, p = 0.655$
s5	δ	$r = 0.27, p = 0.260$	$r = 0.16, p = 0.513$	$r = 0.30, p = 0.203$	$r = 0.20, p = 0.399$
	θ	$r = 0.24, p = 0.305$	$r = 0.06, p = 0.811$	$r = 0.23, p = 0.345$	$r = 0.12, p = 0.613$
	α_1	$r = 0.15, p = 0.526$	$r = 0.05, p = 0.842$	$r = 0.17, p = 0.481$	$r = 0.14, p = 0.571$
	α_2	$r = 0.11, p = 0.632$	$r = 0.10, p = 0.690$	$r = 0.25, p = 0.296$	$r = 0.30, p = 0.207$
	β_1	$r = -0.36, p = 0.125$	$r = -0.17, p = 0.468$	$r = 0.21, p = 0.380$	$r = 0.15, p = 0.531$
	β_2	$r = -0.31, p = 0.183$	$r = -0.23, p = 0.330$	$r = 0.26, p = 0.273$	$r = 0.22, p = 0.342$
	β_3	$r = -0.28, p = 0.236$	$r = -0.18, p = 0.452$	$r = 0.21, p = 0.380$	$r = 0.13, p = 0.588$
s6	δ	$r = 0.13, p = 0.578$	$r = 0.25, p = 0.285$	$r = 0.27, p = 0.249$	$r = 0.23, p = 0.340$
	θ	$r = 0.39, p = 0.091$	$r = 0.36, p = 0.149$	$r = 0.40, p = 0.078$	$r = 0.35, p = 0.103$
	α_1	$r = -0.12, p = 0.610$	$r = 0.12, p = 0.630$	$r =0.004, p = 0.987$	$r = -0.06, p = 0.793$
	α_2	$r = -0.07, p = 0.761$	$r = -0.01, p = 0.974$	$r = 0.03, p = 0.910$	$r = -0.23, p = 0.924$
	β_1	$r = -0.15, p = 0.522$	$r = 0.08, p = 0.732$	$r = -0.05, p = 0.837$	$r = -0.30, p = 0.201$
	β_2	$r = -0.06, p = 0.808$	$r = -0.04, p = 0.869$	$r = -0.09, p = 0.722$	$r = -0.36, p = 0.124$
	β_3	$r = -0.15, p = 0.523$	$r = -0.09, p = 0.712$	$r = -0.14, p = 0.570$	$r = -0.42, p = 0.068$
s7	δ	$r = -0.02, p = 0.950$	$r = 0.10, p = 0.690$	$r = 0.07, p = 0.775$	$r = 0.05, p = 0.827$
	θ	$r = 0.27, p = 0.255$	$r = 0.28, p = 0.237$	$r = 0.29, p = 0.214$	$r = 0.49, p = 0.029$
	α_1	$r = -0.18, p = 0.437$	$r = 0.03, p = 0.904$	$r = 0.11, p = 0.641$	$r = 0.37, p = 0.111$
	α_2	$r = -0.36, p = 0.121$	$r = -0.22, p = 0.348$	$r = 0.21, p = 0.369$	$r = 0.33, p = 0.157$
	β_1	$r = -0.49, p = 0.028$	$r = -0.37, p = 0.111$	$r = 0.15, p = 0.528$	$r = 0.32, p = 0.168$
	β_2	$r = -0.51, p = 0.023$	$r = -0.48, p = 0.032$	$r = 0.02, p = 0.936$	$r = 0.27, p = 0.247$
	β_3	$r = -0.46, p = 0.040$	$r = -0.45, p = 0.047$	$r = 0.04, p = 0.883$	$r = 0.13, p = 0.574$
s8	δ	$r = 0.26, p = 0.274$	$r = 0.05, p = 0.820$	$r = -0.01, p = 0.963$	$r = -0.06, p = 0.803$
	θ	$r = 0.11, p = 0.646$	$r = 0.03, p = 0.911$	$r = -0.26, p = 0.269$	$r = -0.22, p = 0.354$
	α_1	$r = 0.24, p = 0.307$	$r = 0.05, p = 0.832$	$r = -0.24, p = 0.318$	$r = -0.09, p = 0.708$

	α_2	$r = -0.05$, $p = 0.836$	$r = -0.07$, $p = 0.759$	$r = -0.14$, $p = 0.556$	$r = -0.11$, $p = 0.647$
	β_1	$r = -0.12$, $p = 0.601$	$r = -0.18$, $p = 0.460$	$r = -0.25$, $p = 0.286$	$r = -0.12$, $p = 0.620$
	β_2	$r = -0.05$, $p = 0.851$	$r = -0.27$, $p = 0.243$	$r = -0.23$, $p = 0.329$	$r = -0.09$, $p = 0.704$
	β_3	$r = -0.13$, $p = 0.582$	$r = -0.23$, $p = 0.327$	$r = -0.21$, $p = 0.386$	$r = -0.12$, $p = 0.613$
s9	δ	$r = -0.20$, $p = 0.400$	$r = -0.12$, $p = 0.621$	$r = -0.14$, $p = 0.555$	$r = -0.12$, $p = 0.625$
	θ	$r = -0.09$, $p = 0.716$	$r = 0.09$, $p = 0.711$	$r = 0.09$, $p = 0.697$	$r = 0.12$, $p = 0.626$
	α_1	$r = 0.08$, $p = 0.747$	$r = 0.05$, $p = 0.823$	$r = 0.14$, $p = 0.571$	$r = 0.23$, $p = 0.325$
	α_2	$r = -0.03$, $p = 0.896$	$r = -0.04$, $p = 0.877$	$r = 0.28$, $p = 0.238$	$r = 0.31$, $p = 0.184$
	β_1	$r = 0.03$, $p = 0.918$	$r = 0.01$, $p = 0.976$	$r = 0.29$, $p = 0.215$	$r = 0.26$, $p = 0.267$
	β_2	$r = -0.08$, $p = 0.737$	$r = -0.02$, $p = 0.925$	$r = 0.25$, $p = 0.291$	$r = 0.23$, $p = 0.320$
	β_3	$r = -0.05$, $p = 0.824$	$r = 0.02$, $p = 0.935$	$r = 0.20$, $p = 0.403$	$r = 0.12$, $p = 0.630$
s10	δ	$r = 0.47$, $p = 0.036$	$r = 0.20$, $p = 0.406$	$r = 0.44$, $p = 0.055$	$r = 0.39$, $p = 0.090$
	θ	$r = 0.16$, $p = 0.515$	$r = 0.12$, $p = 0.601$	$r = 0.01$, $p = 0.954$	$r = 0.02$, $p = 0.928$
	α_1	$r = 0.16$, $p = 0.511$	$r = -0.004$, $p = 0.988$	$r = -0.16$, $p = 0.512$	$r = -0.13$, $p = 0.589$
	α_2	$r = 0.29$, $p = 0.223$	$r = 0.16$, $p = 0.494$	$r = -0.18$, $p = 0.454$	$r = -0.13$, $p = 0.581$
	β_1	$r = 0.24$, $p = 0.315$	$r = 0.24$, $p = 0.312$	$r = -0.21$, $p = 0.380$	$r = -0.19$, $p = 0.419$
	β_2	$r = 0.32$, $p = 0.164$	$r = 0.25$, $p = 0.295$	$r = -0.15$, $p = 0.533$	$r = -0.16$, $p = 0.501$
	β_3	$r = 0.23$, $p = 0.326$	$r = 0.27$, $p = 0.245$	$r = -0.16$, $p = 0.508$	$r = -0.17$, $p = 0.463$

** adjusted significant p level at $p < 0.002$

Correlations Between Error Rate and Mental Effort (0.1 Hz HRV × -1)

Table 13.13. *Correlations between error rate in the last 10-minute session and the mental effort (0.1 Hz HRV × -1) of the* ***LM schedule***

		0.1 Hz HRV × -1
Morning	S1	$r = 0.26$, $p = 0.261$
	S2	$r = -0.64$, $p = 0.002$**
	S3	$r = 0.16$, $p = 0.496$
Afternoon	S4	$r = -0.16$, $p = 0.503$
	S5	$r = 0.18$, $p = 0.446$
	S6	$r = 0.09$, $p = 0.705$

** adjusted significant p level at $p < 0.0056$

Table 13.14. *Correlations between error rate in the last 10-minute session and the mental effort (0.1 Hz HRV × -1) of the* ***SM schedule***

		0.1 Hz HRV × -1
Morning	s1	$r = 0.34$, $p = 0.145$
	s2	$r = -0.04$, $p = 0.868$
	s3	$r = 0.12$, $p = 0.608$
	s4	$r = 0.21$, $p = 0.387$
	s5	$r = -0.01$, $p = 0.982$
Afternoon	s6	$r = -0.05$, $p = 0.850$
	s7	$r = -0.05$, $p = 0.827$
	s8	$r = 0.22$, $p = 0.360$
	s9	$r = -0.03$, $p = 0.887$
	s10	$r = -0.04$, $p = 0.867$

** adjusted significant p level at $p < 0.002$

Correlations Between Eye Blink Rate and EEG Spectral Power

Table 13.15. *Correlations between eye blink rate in the last 10-minute session and the EEG spectral power of the* ***LM schedule***

		Normalized EEG spectral power			
		Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
S1	δ	$r = -0.21, p = 0.374$	$r = -0.50, p = 0.025$	$r = -0.20, p = 0.409$	$r = -0.18, p = 0.449$
	θ	$r = -0.12, p = 0.627$	$r = -0.03, p = 0.915$	$r = -0.20, p = 0.397$	$r = -0.09, p = 0.697$
	α_1	$r = -0.24, p = 0.314$	$r = 0.05, p = 0.826$	$r = -0.22, p = 0.351$	$r = -0.19, p = 0.433$
	α_2	$r = -0.13, p = 0.577$	$r = -0.08, p = 0.751$	$r = -0.04, p = 0.875$	$r = 0.13, p = 0.576$
	β_1	$r = -0.12, p = 0.610$	$r = 0.13, p = 0.585$	$r = -0.03, p = 0.917$	$r = 0.01, p = 0.978$
	β_2	$r = 0.10, p = 0.683$	$r = 0.20, p = 0.395$	$r = -0.05, p = 0.832$	$r = 0.01, p = 0.958$
	β_3	$r = 0.04, p = 0.873$	$r = 0.28, p = 0.240$	$r = 0.01, p = 0.955$	$r = 0.16, p = 0.493$
S2	δ	$r = -007, p = 0.799$	$r = -0.42, p = 0.066$	$r = 0.22, p = 0.359$	$r = 0.37, p = 0.109$
	θ	$r = 0.28, p = 0.234$	$r = -0.08, p = 0.736$	$r = 0.11, p = 0.642$	$r = 0.13, p = 0.585$
	α_1	$r = 0.04, p = 0.866$	$r = -0.50, p = 0.026$	$r = -0.34, p = 0.144$	$r = -0.28, p = 0.233$
	α_2	$r = 0.37, p = 0.112$	$r = -0.37, p = 0.113$	$r = -0.32, p = 0.170$	$r = -0.33, p = 0.158$
	β_1	$r = 0.37, p = 0.110$	$r = 0.08, p = 0.073$	$r = -0.24, p = 0.303$	$r = -0.16, p = 0.491$
	β_2	$r = 0.24, p = 0.312$	$r = 0.12, p = 0.626$	$r = -0.19, p = 0.432$	$r = -0.04, p = 0.877$
	β_3	$r = 0.29, p = 0.221$	$r = -0.07, p = 0.777$	$r = -0.12, p = 0.604$	$r = -0.03, p = 0.894$
S3	δ	$r = -0.31, p = 0.191$	$r = -0.40, p = 0.082$	$r = 0.03, p = 0.907$	$r = 0.08, p = 0.749$
	θ	$r = -0.15, p = 0.540$	$r = -0.30, p = 0.202$	$r = -0.03, p = 0.906$	$r = -0.06, p = 0.792$
	α_1	$r = -0.14, p = 0.563$	$r = -0.42, p = 0.066$	$r = -0.10, p = 0.685$	$r = -0.18, p = 0.459$
	α_2	$r = -0.13, p = 0.584$	$r = -0.44, p = 0.050$	$r = -0.34, p = 0.139$	$r = -0.36, p = 0.116$
	β_1	$r = -0.05, p = 0.835$	$r = -0.32, p = 0.171$	$r = -0.33, p = 0.159$	$r = -0.34, p = 0.147$
	β_2	$r = -0.09, p = 0.699$	$r = -0.29, p = 0.218$	$r = -0.15, p = 0.539$	$r = -0.16, p = 0.496$
	β_3	$r = -0.06, p = 0.789$	$r = -0.28, p = 0.239$	$r = -0.25, p = 0.282$	$r = -0.22, p = 0.358$
S4	δ	$r = -0.33, p = 0.152$	$r = -0.28, p = 0.226$	$r = -0.17, p = 0.478$	$r = -0.22, p = 0.353$
	θ	$r = -0.51, p = 0.023$	$r = -0.36, p = 0.121$	$r = -0.41, p = 0.075$	$r = -0.37, p = 0.110$
	α_1	$r = -0.14, p = 0.547$	$r = -0.36, p = 0.116$	$r = -0.51, p = 0.023$	$r = -0.40, p = 0.078$
	α_2	$r = -0.52, p = 0.018$	$r = -0.52, p = 0.018$	$r = -0.50, p = 0.026$	$r = -0.45, p = 0.046$
	β_1	$r = -0.47, p = 0.035$	$r = -0.72, p < 0.001$**	$r = -0.45, p = 0.045$	$r = -0.27, p = 0.251$
	β_2	$r = -0.45, p = 0.047$	$r = -0.65, p = 0.002$**	$r = -0.47, p = 0.036$	$r = -0.29, p = 0.210$
	β_3	$r = -0.35, p = 0.127$	$r = -0.39, p = 0.093$	$r = -0.47, p = 0.037$	$r = -0.21, p = 0.365$
S5	δ	$r = -0.17, p = 0.468$	$r = -0.06, p = 0.816$	$r = -0.13, p = 0.590$	$r = -0.18, p = 0.442$
	θ	$r = -0.35, p = 0.131$	$r = -0.37, p = 0.104$	$r = -0.39, p = 0.092$	$r = -0.33, p = 0.156$
	α_1	$r = -0.13, p = 0.582$	$r = -0.28, p = 0.226$	$r = -0.19, p = 0.226$	$r = -0.31, p = 0.184$
	α_2	$r = -0.31, p = 0.188$	$r = -0.34, p = 0.144$	$r = -0.25, p = 0.287$	$r = -0.29, p = 0.220$
	β_1	$r = -0.26, p = 0.268$	$r = 0.09, p = 0.710$	$r = -0.04, p = 0.855$	$r = -0.03, p = 0.902$
	β_2	$r = -0.14, p = 0.544$	$r = 0.14, p = 0.546$	$r = 0.07, p = 0.758$	$r = 0.09, p = 0.709$
	β_3	$r = -0.04, p = 0.858$	$r = 0.36, p = 0.114$	$r = 0.09, p = 0.720$	$r = 0.20, p = 0.407$
S6	δ	$r = -0.01, p = 0.970$	$r = -0.11, p = 0.647$	$r = -0.21, p = 0.387$	$r = -0.04, p = 0.879$
	θ	$r = -0.02, p = 0.919$	$r = -0.17, p = 0.487$	$r = -0.35, p = 0.136$	$r = -0.28, p = 0.238$
	α_1	$r = -0.12, p = 0.629$	$r = -0.14, p = 0.560$	$r = -0.42, p = 0.066$	$r = -0.54, p = 0.015$
	α_2	$r = -0.23, p = 0.331$	$r = -0.35, p = 0.132$	$r = -0.44, p = 0.050$	$r = -0.37, p = 0.113$
	β_1	$r = -0.42, p = 0.063$	$r = -0.21, p = 0.381$	$r = -0.16, p = 0.509$	$r = -0.04, p = 0.857$
	β_2	$r = -0.37, p = 0.104$	$r = -0.10, p = 0.666$	$r = -0.24, p = 0.312$	$r = -0.12, p = 0.605$
	β_3	$r = -0.30, p = 0.193$	$r = -0.04, p = 0.863$	$r = -0.25, p = 0.285$	$r = -0.10, p = 0.683$

** adjusted significant p level at $p \leq 0.0056$

Table 13.16. *Correlations between eye blink rate in the last 10-minute session and the EEG spectral power of the* ***SM schedule***

		Normalized EEG spectral power			
		Left frontal (F_3)	Right frontal (F_4)	Left occipital (O_1)	Right occipital (O_2)
s1	δ	$r = -0.24, p = 0.309$	$r = -0.19, p = 0.418$	$r = 0.17, p = 0.482$	$r = 0.10, p = 0.684$
	θ	$r = 0.05, p = 0.828$	$r = 0.03, p = 0.902$	$r = 0.29, p = 0.218$	$r = 0.32, p = 0.170$
	α_1	$r = -0.42, p = 0.068$	$r = -0.31, p = 0.191$	$r = 0.03, p = 0.900$	$r = -0.02, p = 0.949$
	α_2	$r = -0.42, p = 0.065$	$r = -0.28, p = 0.226$	$r = -0.10, p = 0.679$	$r = -0.13, p = 0.589$
	β_1	$r = -0.43, p = 0.058$	$r = -0.32, p = 0.166$	$r = -0.17, p = 0.473$	$r = -0.15, p = 0.519$
	β_2	$r = -0.56, p = 0.011$	$r = -0.45, p = 0.049$	$r = -0.24, p = 0.305$	$r = -0.17, p = 0.477$
	β_3	$r = -0.51, p = 0.020$	$r = -0.44, p = 0.055$	$r = -0.15, p = 0.525$	$r = -0.06, p = 0.812$
s2	δ	$r = 0.02, p = 0.948$	$r = -0.11, p = 0.632$	$r = -0.17, p = 0.480$	$r = -0.14, p = 0.572$
	θ	$r = -0.06, p = 0.804$	$r = -0.22, p = 0.348$	$r = -0.21, p = 0.379$	$r = -0.24, p = 0.305$
	α_1	$r = -0.17, p = 0.481$	$r = -0.36, p = 0.120$	$r = 0.02, p = 0.031$	$r = -0.18, p = 0.439$
	α_2	$r = -0.10, p = 0.672$	$r = -0.27, p = 0.244$	$r = 0.06, p = 0.792$	$r = -0.11, p = 0.638$
	β_1	$r = -0.31, p = 0.179$	$r = -0.19, p = 0.424$	$r = 0.12, p = 0.618$	$r = -0.04, p = 0.880$
	β_2	$r = -0.42, p = 0.064$	$r = -0.29, p = 0.216$	$r = 0.12, p = 0.604$	$r = 0.01, p = 0.938$
	β_3	$r = -0.32, p = 0.164$	$r = -0.21, p = 0.378$	$r = 0.14, p = 0.542$	$r = 0.07, p = 0.787$
s3	δ	$r = -0.17, p = 0.472$	$r = -0.11, p = 0.632$	$r = -0.38, p = 0.099$	$r = -0.37, p = 0.113$
	θ	$r = -0.03, p = 0.912$	$r = 0.01, p = 0.983$	$r = -0.12, p = 0.623$	$r = -0.07, p = 0.774$
	α_1	$r = -0.38, p = 0.095$	$r = -0.43, p = 0.059$	$r = -0.30, p = 0.197$	$r = -0.29, p = 0.217$
	α_2	$r = -0.31, p = 0.183$	$r = -0.35, p = 0.131$	$r = -0.26, p = 0.264$	$r = -0.21, p = 0.369$
	β_1	$r = -0.32, p = 0.174$	$r = -0.18, p = 0.450$	$r = -0.10, p = 0.671$	$r = -0.01, p = 0.967$
	β_2	$r = -0.32, p = 0.177$	$r = -0.19, p = 0.423$	$r = -0.15, p = 0.533$	$r = -0.05, p = 0.829$
	β_3	$r = -0.33, p = 0.155$	$r = -0.18, p = 0.452$	$r = -0.05, p = 0.827$	$r = -0.03, p = 0.894$
s4	δ	$r = -0.27, p = 0.250$	$r = 0.09, p = 0.699$	$r = -0.84, p = 0.725$	$r = -0.08, p = 0.725$
	θ	$r = -0.01, p = 0.969$	$r = -0.19, p = 0.429$	$r = -0.21, p = 0.365$	$r = -0.24, p = 0.320$
	α_1	$r = -0.18, p = 0.462$	$r = -0.03, p = 0.902$	$r = 0.09, p = 0.711$	$r = 0.12, p = 0.620$
	α_2	$r = 0.02, p = 0.934$	$r = 0.05, p = 0.839$	$r = 0.05, p = 0.820$	$r = 0.04, p = 0.871$
	β_1	$r = 0.26, p = 0.263$	$r = 0.32, p = 0.174$	$r = 0.10, p = 0.662$	$r = 0.30, p = 0.201$
	β_2	$r = 0.32, p = 0.167$	$r = 0.30, p = 0.204$	$r = 0.15, p = 0.528$	$r = 0.35, p = 0.127$
	β_3	$r = 0.32, p = 0.165$	$r = 0.32, p = 0.164$	$r = 0.27, p = 0.251$	$r = 0.50, p = 0.026$
s5	δ	$r = -0.21, p = 0.370$	$r = -0.27, p = 0.253$	$r = -0.15, p = 0.526$	$r = -0.28, p = 0.230$
	θ	$r = -0.26, p = 0.276$	$r = -0.29, p = 0.219$	$r = -0.45, p = 0.049$	$r = -0.39, p = 0.086$
	α_1	$r = -0.22, p = 0.345$	$r = -0.36, p = 0.119$	$r = -0.23, p = 0.341$	$r = -0.29, p = 0.215$
	α_2	$r = -0.15, p = 0.528$	$r = -0.30, p = 0.196$	$r = -0.19, p = 0.425$	$r = -0.22, p = 0.360$
	β_1	$r = 0.05, p = 0.828$	$r = -0.16, p = 0.513$	$r = -0.13, p = 0.595$	$r = -0.13, p = 0.584$
	β_2	$r = 0.02, p = 0.938$	$r = -0.16, p = 0.507$	$r = -0.14, p = 0.543$	$r = -0.06, p = 0.790$
	β_3	$r = 0.05, p = 0.822$	$r = -0.12, p = 0.625$	$r = -0.10, p = 0.665$	$r = -0.02, p = 0.939$
s6	δ	$r = 0.05, p = 0.838$	$r = -0.14, p = 0.554$	$r = -0.24, p = 0.312$	$r = -0.27, p = 0.255$
	θ	$r = 0.17, p = 0.473$	$r = -0.11, p = 0.654$	$r = -0.05, p = 0.822$	$r = -0.04, p = 0.867$
	α_1	$r = -0.11, p = 0.660$	$r =0.004, p = 0.986$	$r = -0.09, p = 0.693$	$r = -0.11, p = 0.644$
	α_2	$r = 0.19, p = 0.433$	$r = 0.10, p = 0.679$	$r = 0.04, p = 0.863$	$r = 0.05, p = 0.850$
	β_1	$r = 0.14, p = 0.565$	$r = 0.12, p = 0.602$	$r = 0.03, p = 0.915$	$r = 0.01, p = 0.975$
	β_2	$r = 0.19, p = 0.427$	$r = 0.13, p = 0.598$	$r = -0.02, p = 0.937$	$r = -0.06, p = 0.811$
	β_3	$r = 0.16, p = 0.515$	$r = 0.24, p = 0.301$	$r = -0.05, p = 0.835$	$r = -0.05, p = 0.826$
s7	δ	$r = -0.20, p = 0.393$	$r = -0.65, p = 0.002$**	$r = -0.40, p = 0.082$	$r = -0.39, p = 0.087$
	θ	$r = 0.13, p = 0.591$	$r = -0.53, p = 0.016$	$r = -0.15, p = 0.540$	$r = -0.16, p = 0.510$
	α_1	$r = -0.03, p = 0.889$	$r = -0.53, p = 0.017$	$r = -0.12, p = 0.603$	$r = -0.19, p = 0.430$
	α_2	$r = 0.16, p = 0.500$	$r = -0.38, p = 0.102$	$r = -0.09, p = 0.692$	$r = -0.12, p = 0.620$
	β_1	$r = 0.21, p = 0.370$	$r = -0.22, p = 0.359$	$r = 0.03, p = 0.908$	$r = 0.05, p = 0.841$
	β_2	$r = 0.18, p = 0.454$	$r =0.004, p = 0.986$	$r = -0.03, p = 0.900$	$r = 0.06, p = 0.803$
	β_3	$r = 0.16, p = 0.502$	$r = 0.06, p = 0.797$	$r = 0.05, p = 0.851$	$r = 0.15, p = 0.540$
s8	δ	$r = -0.38, p = 0.102$	$r = -0.70, p = 0.001$**	$r = -0.71, p < 0.001$**	$r = -0.67, p = 0.001$**
	θ	$r = -0.03, p = 0.891$	$r = -0.62, p = 0.004$	$r = -0.30, p = 0.204$	$r = -0.30, p = 0.193$
	α_1	$r = -0.36, p = 0.116$	$r = -0.75, p < 0.001$**	$r = -0.25, p = 0.297$	$r = -0.44, p = 0.053$

	α_2	$r = -0.09, p = 0.722$	$r = -0.72, p < 0.001$**	$r = -0.14, p = 0.557$	$r = -0.27, p = 0.244$
	β_1	$r = -0.17, p = 0.471$	$r = -0.65, p = 0.002$**	$r = -0.08, p = 0.750$	$r = -0.24, p = 0.314$
	β_2	$r = -0.26, p = 0.266$	$r = -0.50, p = 0.027$	$r = -0.19, p = 0.424$	$r = -0.33, p = 0.161$
	β_3	$r = -0.26, p = 0.271$	$r = -0.42, p = 0.065$	$r = -0.15, p = 0.518$	$r = -0.27, p = 0.251$
s9	δ	$r = -0.27, p = 0.253$	$r = -0.30, p = 0.193$	$r = -0.47, p = 0.038$	$r = -0.48, p = 0.033$
	θ	$r = -0.05, p = 0.826$	$r = 0.11, p = 0.636$	$r = 0.01, p = 0.984$	$r = 0.04, p = 0.870$
	α_1	$r = -0.03, p = 0.885$	$r = 0.08, p = 0.735$	$r = -0.05, p = 0.846$	$r = 0.01, p = 0.954$
	α_2	$r = -0.02, p = 0.949$	$r = 0.10, p = 0.675$	$r = -0.71, p = 0.766$	$r = 0.01, p = 0.978$
	β_1	$r = -0.07, p = 0.761$	$r = 0.07, p = 0.784$	$r = -0.15, p = 0.530$	$r = -0.16, p = 0.514$
	β_2	$r = -0.16, p = 0.497$	$r = -0.01, p = 0.981$	$r = -0.16, p = 0.496$	$r = -0.18, p = 0.436$
	β_3	$r = -0.21, p = 0.377$	$r = -0.05, p = 0.840$	$r = -0.23, p = 0.323$	$r = -0.28, p = 0.236$
s10	δ	$r = -0.03, p = 0.902$	$r = -0.21, p = 0.385$	$r = -0.21, p = 0.373$	$r = -0.20, p = 0.391$
	θ	$r = -0.35, p = 0.130$	$r = -0.30, p = 0.200$	$r = -0.47, p = 0.035$	$r = -0.30, p = 0.195$
	α_1	$r = -0.25, p = 0.294$	$r = -0.32, p = 0.164$	$r = -0.05, p = 0.822$	$r = 0.11, p = 0.643$
	α_2	$r = -0.19, p = 0.427$	$r = -0.21, p = 0.371$	$r = -0.04, p = 0.882$	$r = 0.13, p = 0.578$
	β_1	$r = 0.01, p = 0.978$	$r = -0.11, p = 0.633$	$r = -0.03, p = 0.900$	$r = 0.22, p = 0.362$
	β_2	$r = 0.02, p = 0.944$	$r = -0.10, p = 0.670$	$r = -0.15, p = 0.512$	$r = 0.08, p = 0.734$
	β_3	$r = 0.07, p = 0.778$	$r = -0.16, p = 0.503$	$r = -0.19, p = 0.436$	$r = 0.04, p = 0.871$

** adjusted significant p level at $p \leq 0.002$

Correlations Between Eye Blink Rate and Mental Effort (0.1 Hz HRV × -1)

Table 13.17. *Correlations between eye blink rate in the last 10-minute session and the mental effort (0.1 Hz HRV × -1) of the* ***LM schedule***

		0.1 Hz HRV × -1
Morning	S1	$r = 0.10, p = 0.662$
	S2	$r = -0.09, p = 0.712$
	S3	$r = -0.06, p = 0.796$
Afternoon	S4	$r = 0.03, p = 0.893$
	S5	$r = 0.02, p = 0.934$
	S6	$r = -0.25, p = 0.296$

** adjusted significant p level at $p < 0.0056$

Table 13.18. *Correlations between eye blink rate in the last 10-minute session and the mental effort (0.1 Hz HRV × -1) of the* ***SM schedule***

		0.1 Hz HRV × -1
Morning	s1	$r = 0.31, p = 0.183$
	s2	$r = 0.23, p = 0.327$
	s3	$r = 0.11, p = 0.646$
	s4	$r = -0.15, p = 0.525$
	s5	$r = 0.39, p = 0.092$
Afternoon	s6	$r = -0.39, p = 0.086$
	s7	$r = -0.33, p = 0.157$
	s8	$r = -0.40, p = 0.089$
	s9	$r = -0.49, p = 0.027$
	s10	$r = -0.07, p = 0.774$

** adjusted significant p level at $p < 0.002$

Correlations Between Eye Blink Rate and SOFI-C

Table 13.19. *Correlations between the SOFI-C measured at the end of morning and afternoon and the eye blink rate in the last 10-minute of S2 and S3 for the morning block, and S5 and S6 for the afternoon block of the* ***LM schedule***

		Morning			Afternoon
		Eye blink rate			Eye blink rate
S2	SL	$r = 0.14, p = 0.559$	S5	SL	$r = -0.26, p = 0.265$
	PD	$r = 0.16, p = 0.497$		PD	$r = -0.13, p = 0.592$
	LM	$r = 0.11, p = 0.650$		LM	$r = -0.20, p = 0.398$
	LE	$r = 0.19, p = 0.435$		LE	$r = 0.17, p = 0.474$
	PE	$r = 0.46, p = 0.042$		PE	$r = 0.13, p = 0.590$
S3	SL	$r = 0.46, p = 0.042$	S6	SL	$r = -0.03, p = 0.898$
	PD	$r = 0.34, p = 0.140$		PD	$r = -0.14, p = 0.555$
	LM	$r = 0.51, p = 0.021$		LM	$r = -0.07, p = 0.781$
	LE	$r = 0.22, p = 0.344$		LE	$r = 0.10, p = 0.677$
	PE	$r = -0.10, p = 0.663$		PE	$r = 0.21, p = 0.379$

SL = sleepiness; PD = Physical Discomfort; LM = Lack of Motivation; LE = Lack of Energy; PE = Physical Exertion

** adjusted significant p level at $p < 0.017$

Table 13.20. *Correlations between the SOFI-C measured at the end of morning and afternoon and the eye blink rate in the last 10-minute of s3, s4, and s5 for the morning block, and s8, s9, and s10 for the afternoon block of the* ***SM schedule***

		Morning			Afternoon
		Eye blink rate			Eye blink rate
s3	SL	$r = 0.14, p = 0.564$	s8	SL	$r = 0.05, p = 0.821$
	PD	$r = -0.28, p = 0.226$		PD	$r = 0.24, p = 0.309$
	LM	$r = -0.16, p = 0.510$		LM	$r = 0.17, p = 0.477$
	LE	$r = -0.14, p = 0.553$		LE	$r = 0.10, p = 0.671$
	PE	$r = -0.21, p = 0.364$		PE	$r = 0.24, p = 0.308$
s4	SL	$r = 0.11, p = 0.656$	s9	SL	$r = -0.22, p = 0.364$
	PD	$r = -0.12, p = 0.615$		PD	$r = -0.03, p = 0.903$
	LM	$r = -0.19, p = 0.427$		LM	$r = -0.11, p = 0.655$
	LE	$r = -0.11, p = 0.635$		LE	$r = -0.27, p = 0.252$
	PE	$r = -0.15, p = 0.523$		PE	$r = -0.12, p = 0.611$
s5	SL	$r = 0.11, p = 0.636$	s10	SL	$r = 0.30, p = 0.195$
	PD	$r = -0.19, p = 0.427$		PD	$r = 0.57, p = 0.008$**
	LM	$r = -0.20, p = 0.400$		LM	$r = 0.46, p = 0.044$
	LE	$r = -0.17, p = 0.470$		LE	$r = 0.45, p = 0.048$
	PE	$r = -0.17, p = 0.470$		PE	$r = 0.76, p < 0.001$**

SL = sleepiness; PD = Physical Discomfort; LM = Lack of Motivation; LE = Lack of Energy; PE = Physical Exertion

** adjusted significant p level at $p \leq 0.010$

Correlations Between Eye Blink Rate and Task Performance

Table 13.21. *Correlations between eye blink rate in the last 10-minute session and the task performance (error rate & speed of data entry) of the* ***LM schedule***

		Error rate	Speed of entering data
Morning	S1	$r = 0.29, p = 0.211$	$r = -0.17, p = 0.465$
	S2	$r = -0.10, p = 0.687$	$r = 0.09, p = 0.704$
	S3	$r = 0.10, p = 0.691$	$r = -0.07, p = 0.780$
Afternoon	S4	$r = -0.23, p = 0.329$	$r = -0.28, p = 0.237$
	S5	$r = -0.18, p = 0.446$	$r = -0.26, p = 0.272$
	S6	$r = 0.30, p = 0.195$	$r = -0.11, p = 0.635$

** adjusted significant p level at $p < 0.0056$

Table 13.22. *Correlations between eye blink rate in the last 10-minute session and the task performance (error rate & speed of data entry) of the* ***SM schedule***

		Error rate	Speed of entering data
Morning	s1	$r = -0.40, p = 0.090$	$r = -0.04, p = 0.855$
	s2	$r = -0.03, p = 0.886$	$r = 0.44, p = 0.051$
	s3	$r = 0.001, p = 0.996$	$r = -0.22, p = 0.348$
	s4	$r = -0.31, p = 0.183$	$r = 0.18, p = 0.455$
	s5	$r = 0.05, p = 0.828$	$r = -0.21, p = 0.376$
Afternoon	s6	$r = -0.11, p = 0.640$	$r = -0.22, p = 0.350$
	s7	$r = -0.14, p = 0.549$	$r = 0.15, p = 0.528$
	s8	$r = -0.28, p = 0.241$	$r = 0.02, p = 0.938$
	s9	$r = 0.20, p = 0.390$	$r = 0.16, p = 0.495$
	s10	$r = -0.02, p = 0.930$	$r = -0.04, p = 0.860$

** adjusted significant p level at $p \leq 0.002$

Correlations Between SOFI-C and Task Performance

Table 13.23. *Correlations between he SOFI-C measured at the end of morning and afternoon and task performance (error rate & speed of data entry) in the entire session of S2 and S3 for the morning block, and S5 and S6 for the afternoon block of the* ***LM schedule***

			Error rate	Speed of entering data
Morning	S2	SL	$r = 0.08, p = 0.746$	$r = 0.35, p = 0.134$
		PD	$r = 0.09, p = 0.696$	$r = 0.19, p = 0.414$
		LM	$r = 0.10, p = 0.679$	$r = -0.21, p = 0.372$
		LE	$r = 0.13, p = 0.585$	$r = 0.01, p = 0.970$
		PE	$r = -0.23, p = 0.324$	$r = 0.10, p = 0.691$
	S3	SL	$r = 0.18, p = 0.450$	$r = 0.30, p = 0.206$
		PD	$r = 0.18, p = 0.448$	$r = 0.16, p = 0.491$
		LM	$r = 0.29, p = 0.220$	$r = -0.27, p = 0.254$
		LE	$r = 0.15, p = 0.525$	$r = -0.26, p = 0.271$
		PE	$r = -0.35, p = 0.132$	$r = -0.18, p = 0.455$
Afternoon	S5	SL	$r = 0.07, p = 0.780$	$r = 0.47, p = 0.037$
		PD	$r = 0.09, p = 0.694$	$r = 0.18, p = 0.460$

	LM	$r = -0.16$, $p = 0.502$	$r = 0.09$, $p = 0.711$
	LE	$r = 0.10$, $p = 0.678$	$r = 0.06$, $p = 0.790$
	PE	$r = -0.41$, $p = 0.076$	$r = -0.01$, $p = 0.961$
S6	SL	$r = 0.14$, $p = 0.550$	$r = 0.21$, $p = 0.370$
	PD	$r = 0.07$, $p = 0.770$	$r = -0.22$, $p = 0.350$
	LM	$r = -0.10$, $p = 0.687$	$r = -0.27$, $p = 0.246$
	LE	$r = 0.002$, $p = 0.994$	$r = -0.14$, $p = 0.565$
	PE	$r = -0.18$, $p = 0.458$	$r = -0.25$, $p = 0.279$

** adjusted significant p level at $p \leq 0.017$

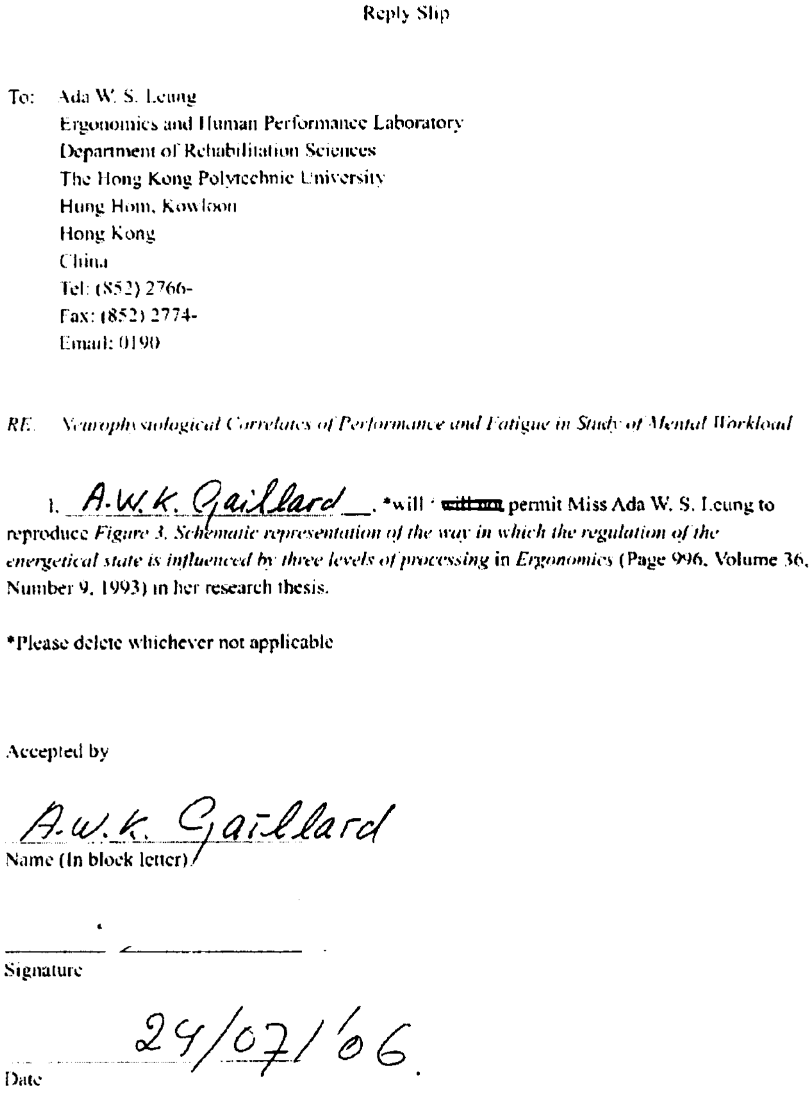
Table 13.24. *Correlations between he SOFI-C measured at the end of morning and afternoon and task performance (error rate & speed of data entry) in the entire session of s3, s4, and s5 for the morning block, and s8, s9, and s10 for the afternoon block of the* ***SM schedule***

			Error rate	Speed of entering data
Morning	s3	SL	$r = 0.18$, $p = 0.444$	$r = -0.13$, $p = 0.576$
		PD	$r = 0.33$, $p = 0.160$	$r = 0.03$, $p = 0.892$
		LM	$r = 0.27$, $p = 0.251$	$r = -0.15$, $p = 0.520$
		LE	$r = 0.41$, $p = 0.071$	$r = -0.32$, $p = 0.168$
		PE	$r = 0.24$, $p = 0.314$	$r = -0.25$, $p = 0.289$
	s4	SL	$r = 0.13$, $p = 0.601$	$r = -0.29$, $p = 0.218$
		PD	$r = 0.29$, $p = 0.210$	$r = -0.27$, $p = 0.249$
		LM	$r = 0.10$, $p = 0.679$	$r = -0.41$, $p = 0.074$
		LE	$r = 0.22$, $p = 0.343$	$r = -0.35$, $p = 0.128$
		PE	$r = 0.65$, $p = 0.002$**	$r = 0.05$, $p = 0.839$
	s5	SL	$r = 0.06$, $p = 0.812$	$r = -0.13$, $p = 0.597$
		PD	$r = 0.03$, $p = 0.890$	$r = -0.12$, $p = 0.614$
		LM	$r = 0.08$, $p = 0.754$	$r = -0.19$, $p = 0.413$
		LE	$r = -0.04$, $p = 0.863$	$r = -0.40$, $p = 0.082$
		PE	$r = -0.19$, $p = 0.413$	$r = -0.40$, $p = 0.080$
Afternoon	s8	SL	$r = 0.18$, p = 0.448	$r = 0.12$, p = 0.621
		PD	$r = 0.44$, p = 0.054	$r = -0.13$, p = 0.580
		LM	$r = 0.30$, p = 0.206	$r = 0.04$, p = 0.871
		LE	$r = 0.22$, p = 0.364	$r = -0.07$, p = 0.786
		PE	$r = 0.52$, p = 0.020	$r = -0.02$, p = 0.941
	s9	SL	$r = 0.00$, p = 0.999	$r = -0.41$, p = 0.070
		PD	$r = 0.37$, p = 0.113	$r = -0.38$, p = 0.103
		LM	$r = 0.26$, p = 0.278	$r = -0.49$, p = 0.027
		LE	$r = 0.24$, p = 0.304	$r = -0.28$, p = 0.233
		PE	$r = 0.07$, p = 0.774	$r = -0.08$, p = 0.748
	s10	SL	$r = -0.19$, p = 0.415	$r = 0.06$, $p = 0.791$
		PD	$r = 0.07$, p = 0.764	$r = -0.19$, $p = 0.432$
		LM	$r = -0.12$, p = 0.610	$r = -0.10$, $p = 0.674$
		LE	$r = -0.16$, p = 0.515	$r = -0.17$, $p = 0.463$
		PE	$r = 0.14$, p = 0.551	$r = -0.18$, $p = 0.455$

** adjusted significant p level at $p < 0.010$

Appendix XIII : Reply Slips of Permission to Reproduce Figures

Reply from Professor Gaillard



Reply Slip

To: Ada W. S. Leung
Ergonomics and Human Performance Laboratory
Department of Rehabilitation Sciences
The Hong Kong Polytechnic University
Hung Hom, Kowloon
Hong Kong
China
Tel: (852) 2766-
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Email: 0190

RE. Neurophysiological Correlates of Performance and Fatigue in Study of Mental Workload

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*Please delete whichever not applicable

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A.W.K. Gaillard
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Signature

24/07/06
Date

Reply from Professor Hockey

Date: Wed, 2 Aug 2006 12:05:48 +0100
From: "Bob Hockey" <g.r.j.hockey@ > Add To Address Book |

Subject: Re: Request for your Biological Psychology
To: "Ada Leung" <0190 >

Ada
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Good luck with the work
Bob

G R J Hockey
Professor of Human Factors and Cognitive Engineering
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----- Original Message -----
From: "Ada Leung" <0190 >
To: <G.R.J.Hockey@ >
Sent: Monday, July 17, 2006 11:49 AM
Subject: Request for your Biological Psychology

> Dear Prof. Hockey,
> I am a Ph.D. student at The Hong Kong Polytechnic University
> in Hong Kong. I am doing a research project on mental
> workload and fatigue. I would like to reproduce your
> information processing model, published in Biological
> Psychology in 1997, in my research thesis.
> Attached please find my letter for your reference. Please
> kindly grant the permission to me. Attached please find a
> reply slip. Would you please kindly sign and return by email
> attachment, fax (852) 2774- , or mail.
> Thank you very much.
> Ada
>

Reply from editorial of Oxford University Press

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