Factors contributing to officers' fatigue in high-speed maritime craft operations

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Abstract

The purpose of this study was to investigate the difference in the level of fatigue induced by high-speed maritime craft operation between the day-shift and night-shift officers. The demographic and work-related factors that contribute to fatigue were also explored. A total of 93 high-speed maritime craft officers participated in the survey, of whom 35 worked a day-shift (Mean age = 48.3 years) and 58 worked a night-shift (Mean age = 45.8 years). Fatigue experience was measured with the Chinese version of the Swedish Occupational Fatigue Inventory (SOFI-C) at the beginning, in the middle and at the end of the work shift. Information on age, work experience, perceived voyage difficulty and duty schedule was obtained. The study found that the night-shift officers seemed to manifest an overall higher level of perceived fatigue than the day-shift officers, while the day-shift officers demonstrated a fatigue carry-over effect across the two workdays. Besides the shift pattern, age, experience in operating high-speed maritime craft and perceived voyage difficulty were the significant factors contributing to the officers' fatigue experience. The finding that the fatigue experience associated with high-speed maritime craft operation has a rapid and accumulative nature suggests that different occupational safety and health guidelines should be devised for these two groups of officers.

1. Introduction

Fatigue manifests itself as a decrement of performance as a result of having worked for a considerable length of time (Okogbaa et al., 1994). In high-speed maritime craft operation, a decline in performance can endanger the passengers, the ship and the crew. The International Maritime Organization (2001) points out that high-speed maritime craft plying demands a high mental workload. Mental workload refers to people's experiences of cognitive task performance as effortful and resource demanding (Mulder, 1986). High-speed maritime craft operation is characterized by a high manoeuvring speed, about 33 to 45 knots, that requires intense concentration and rapid response from navigating officers. The officers have to continuously communicate with their crew and monitor the operating system on the bridge (Sauer et al., 2002). Prolonged mental workload of such kind has been found to exacerbate fatigue, which may influence various information-processing functions (Matthews et al., 2000). Previous studies have further indicated that operations carried out on a ship's bridge place heavy demands on the cognitive resources of officers (Wickens, 2000). The study on driving (Lal and Craig, 2001) found that long-haul drivers' fatigue was modulated by the time of day of the work shift. It is intuitive that, as with long-haul drivers, high-speed maritime craft officers' intensity of fatigue at work would be modulated by their shift schedule. Nevertheless, the extent to which the fatigue experienced by high-speed maritime craft officers differs according to different work schedules has not been previously examined.

Fatigue refers to feelings of tiredness and bodily discomfort associated with prolonged activity (Matthews et al., 2000). In occupational work, fatigue is work-task specific and can be aggravated when the exposure to the task is prolonged (Ahsberg, 2000). Fatigue can be divided into physical and mental fatigue (Leung, Chan and He, 2004). Physical fatigue is accompanied by a reduction of performance in the muscular system, whereas mental fatigue is accompanied by a sense of weariness, reduced alertness and reduced mental performance. Long working hours are one of the main work overload factors that contribute to fatigue (Iwasaki et al., 1998; Spurgeon and Harrington, 1989). Prolonged concentration, loss of sleep and working at night have been found to result in subjective tiredness (Matthews et al., 2000). People who carry out shift work often show a high level of fatigue. Disruptions in both sleep pattern and circadian rhythms have been found to account for feelings of fatigue (Akerstedt et al., 1987; Bonnet, 1985; Rosekind et al., 1994). Circadian rhythms refer to time-of-day changes in physiological or psychological functioning (Gundel et al., 1995; Kecklund and Akerstedt, 1993; Matthews et al., 2000; Samel et al., 1997). Previous studies have revealed that cognitive function, semantic memory and perceptual processing are less efficient at evening-time, especially from 18:00 to 22:00 (Folkard and Monk, 1980; Folkard, 1983; Oakhill, 1986; Tilley and Warren, 1983). Grandjean (1988) also found that the readiness for action was generally low at night. Horne and Reyner (1995) revealed that night-time driving was associated with a higher accident rate than daytime driving. The risk factors identified to account for the high accident rate were poor visual conditions, fatigue and impaired performance (Haworth et al., 1989; Kecklund and Akerstedt, 1993; Mackie and Miller, 1978; Torsvall and Akerstedt, 1987; Vanakoski et al., 2000). Fatigue can also be exacerbated by psychological factors such as anxiety, and task factors such as task difficulty (Matthews et al., 2000) and monotonous conditions (Hamelin, 1987; Horne and Reyner, 1995; McDonald, 1984; Samel et al., 1997).

Fatigue is commonly assessed by means of self-reported rating scales and questionnaires (Wierwille and Eggemeier, 1993). The Swedish Occupational Fatigue Inventory, developed by Ahsberg et al. (1997), is used to quantify the fatigue profile of workers such as firemen, cashiers, teachers and drivers. A Chinese version (SOFI-C) has been psychometrically tested for use in Chinese populations (Leung, Chan and He, 2004).

The present study aimed to examine the fatigue experienced by a group of Chinese high-speed maritime craft officers who worked either a day shift or a night shift. Officers on the day shift navigated six to seven one-hour voyages in 11 hours, whilst the night-shift officers navigated three to four voyages in seven hours. Though the night-shift officers went on fewer voyages due to the difficulties of navigating in the dark, they were expected to experience fatigue in a more rapid and intense manner than were their day-shift counterparts. The contributions of other personal and work-related factors to officers' fatigue were also tested. They included demographic characteristics, anxiety, perceived voyage difficulty and the psychosocial status of the officers. The findings of this study would provide a basis for reviewing the existing work design and schedule for high-speed maritime craft officers. They also shed light on the needs for revising the occupational safety and health guidelines for this group of officers.

2. Subjects and Method

2.1. Study sample

Ninety-three high-speed maritime craft officers were recruited by means of convenient sampling from two local companies. The selection criteria were: 1) masters, chief officers or night vision officers operating high-speed maritime craft between Hong Kong and Macau; 2) a minimum of one year's experience in the job; 3) no work-related injuries; and 4) no chronic illness such as renal failure or heart disease that might contribute to subjective fatigue. The reason for excluding other officers such as chief engineers was that their duties were not directly involved in navigation. The demographic data of the participating officers were obtained from the company. All of the officers were male, their mean age was 46.8 years (SD=6.5), and they had a mean of 10.5 years (SD=6.7) of experience of high-speed maritime craft operation. Thirty-five were working a day shift (daytime duty) and 58 were working a night shift (night-time duty) at the time of the study (Table 1).

Seventy-two of the officers operated a hydrofoil model and 21 (15 day-shift and six night-shift officers) operated a catamaran model. They travelled between Hong Kong and Macau, a voyage that took about one hour. They changed their shift once a month and the pattern of their work shift was two consecutive workdays followed by one rest day. At the time of the interviews, the officers had taken shift duty for 2 $\pm$ 0.2 weeks. Each officer was assessed either on the first or the second workday of their shift. During the day shift, they navigated six to seven voyages between 07:30 and 18:00. There was a 15-minute rest break scheduled between each voyage and a one-hour lunch break in the middle of the shift. During the night shift, the officers navigated three to four voyages between 18:00 and 23:30 with a 30-minute rest break between each voyage.

Insert Table 1 about here

2.2. Measurement of fatigue, anxiety and psychosocial work characteristics

2.2.1 Subjective fatigue

The fatigue experienced by the officers was measured by the Chinese version Swedish Occupational Fatigue Inventory (SOFI-C) (Leung et al., 2004). The SOFI is a multidimensional instrument consisting of 25 items divided into five subscales, namely Physical Exertion (PE), Physical Discomfort (PD), Lack of Energy (LE), Lack of Motivation (LM) and Sleepiness (S) (Ahsberg, 1998, 2000; Ahsberg et al., 2000). Physical Exertion and Physical Discomfort are physical factors. Lack of Motivation and Sleepiness are primarily mental factors. Lack of Energy is a more general and underlying dimension of fatigue. The internal consistency of each of the subscales ranges from 0.45 to 0.95 (Ahsberg et al., 2000). Each item is composed of a word or phrase which describes feelings and symptoms associated with fatigue. The participant is required to rate on an 11-point scale with ‘0’ indicating the least extent and ‘10’ the greatest extent. The SOFI has been found to be sensitive to different aspects of fatigue, such as a feeling of sleepiness during shift work (Ahsberg et al., 2000). The Chinese version has also been found to reflect the extent of fatigue of sedentary workers (Leung et al., 2004). In this study, the SOFI-C was administered at the beginning, in the middle and at the end of a work shift in order to capture the changes in the fatigue level of the officers during the work shift.

2.2.2. Anxiety

The anxiety level of the officers was measured using the Chinese version State-Trait Anxiety Inventory (STAI-C) (Shek, 1993). The STAI-C consists of 40 items (20 for the state subscale and 20 for the trait subscale), each of which describes an emotional state related to anxiety. The participant is required to rate on a five-point scale with ‘0’ indicating the least extent and ‘4’ the greatest extent. The psychometric properties of the STAI-C have been previously reported (Shek, 1988, 1991). In this study, only the 20 items of the state subscale were administered to the officers. The administration regimen was the same as that of the SOFI-C.

2.2.3 Socio-demographic measures and voyage difficulty

A custom-designed questionnaire covering work schedule, perceived voyage difficulty and psychosocial status was used to guide the in-take interview with the officers before the work shift began. A checklist was designed to guide the officers in assessing the different aspects of perceived difficulty of high-speed maritime craft operation on the day of the interview. There were a total of nine separate items, namely sea visibility, seas and swell, wind, water flow, traffic, route, voyage duration, work time and vessel manoeuvrability. The officers were asked to report the extent to which each of these separate items described their perceived difficulty of navigation in the workday. All the items were rated on an 11-point Likert scale with '0' indicating the least extent and '10' the greatest extent. The average score of these nine items indicated the overall perceived difficulty. A psychosocial status checklist was designed based on the physical health questionnaire developed by Siu (1999). It consisted of eight items with four relating to job stress (perceived overload, work duration, cognitive load and work autonomy) and four relating to psychosocial status (job satisfaction, job security, communication and support from co-workers). The items were rated on a five-point Likert scale with '1' indicating strongly disagree and '5' indicating strongly agree. Each of the subscale scores was calculated as the average of the ratings on the four items.

2.3 Interview procedure

All the officers who were screened were contacted via the participating companies prior to the day of the interview. They were requested to arrive at the meeting venue at the pier 45 minutes before the start of their shift. The officers of a work team were grouped together. They consisted of a master and a chief officer for a day shift, and a master, a chief officer and a night vision officer for a night shift. Trained interviewers conducted face-to-face interviews with each of the officers. They were explained the purpose of the study before signing a consent form. The interviewers collected demographic and work schedule information from them and they were required to complete the SOFI-C, the STAI-C and the perceived voyage difficulty questionnaire. Before they left for work, they were given two new sets of questionnaires (each consisting of the SOFI-C and the STAI-C), which they were instructed to fill out in the middle and at the end of their work shift. The middle of the work shift was determined arbitrarily between the officer team and the researcher. For a six- or seven-voyage day shift, the middle was usually set at the end of the third or fourth voyage. For a three- or four-voyage night shift, the middle was set at the end of the second or third voyage. The officers were reminded to follow the same process when completing the questionnaires. The completed questionnaires were collected at the pier by the researcher at the end of the work shift.

2.4 Data analysis

A three-way repeated measure ANOVA (2 shifts × 2 workdays × 3 points in time) was used to test the effects of work shift, workday and time of high-speed maritime craft operation on the SOFI-C scores. This was followed by conducting two-way repeated measure ANOVAs to test the differences in SOFI-C scores between the day and night shift, and between the first and second workdays. Pair-wise comparisons adjusted with Bonferroni method were conducted to test the changes in fatigue across three different points in time under each of the work conditions. Differences in perceived difficulty between the two workdays and between the two work shifts were examined using independent t-tests. This provided supplementary information on whether there were differences in the environments under which the officers operated the crafts. An analysis of the anxiety states of the officers was carried out using the same statistical procedure as the SOFI-C. Linear regression analyses were run to identify the significant predicting factors of fatigue among the officers by the end of the second workday. The factors included in the regression analysis were age, experience, perceived difficulty, job stress, psychological stress and anxiety scores. All the analyses were performed using SPSS 11.0. The significance level of all the statistical tests was set at $p \leq 0.05$. The final sample size was estimated using NCSS and PASS 2002. Eighteen subjects in each group were deemed sufficient to yield an effect size of 0.4 and a power of 0.8.

3. Results

3.1 The effects of the work shift and the workday on perceived fatigue

The overall model of the three-way repeated measure ANOVA was statistically significant for all five SOFI-C subscales (Pillai's Trace: $F(2,88)=31.33$ to 106.75, $p<0.001$). The results revealed that both the work shift and the workday had significant main effects on the officers' scores on the SOFI-C (Table 2 and Figure 1). The interaction effects between the work shift and the workday on the officers' SOFI-C scores were also statistically significant. Regarding the work-shift effect, on three SOFI-C subscales, the night-shift officers' scores were found to be significantly higher than the scores of the day-shift officers. These subscales were Physical Exertion ($F(1,89)=6.61$, $p<0.05$), Physical Discomfort ($F(1,89)=4.65$, $p<0.05$) and Lack of Energy ($F(1,89)=4.339$, $p<0.05$) (Table 2). Regarding the workday effect, the officers' scores on four SOFI subscales obtained on the second day were significantly higher than those obtained on the first day. These subscales were Physical Exertion ($F(1,89)=4.45$, $p<0.05$), Physical Discomfort ($F(1,89)=4.77$, $p<0.05$), Lack of Energy ($F(1,89)=6.89$, $p<0.01$) and Sleepiness ($F(1,89)=5.00$, $p<0.05$).

Insert Table 2 and Figure 1 About Here

The significant work-shift and workday interaction effects showed that the night-shift officers tended to score higher on the SOFI-C subscales than their day-shift counterparts on the first workday. The opposite was true, however, on the second workday. This pattern was found across all five SOFI-C subscales: Sleepiness ($F(1,89)=12.71$, $p<0.005$), Lack of Motivation ($F(1,89)=8.85$, $p<0.005$), Lack of Energy ($F(1,89)=17.36$, $p<0.001$), Physical Discomfort ($F(1,89)=7.36$, $p<0.01$) and Physical Exertion ($F(1,89)=4.466$, $p<0.05$) (Table 2). The significant work-shift and time interaction effects suggested that the rates of change in the SOFI-C scores were different for the day-shift and night-shift officers. In general, the night-shift officers showed a faster rate of increase in the SOFI-C scores than the day-shift officers for Sleepiness ($F(2,88)=12.81$, $p<0.005$), Lack of Motivation ($F(2,88)=7.98$, $p<0.001$), Lack of Energy ($F(2,88)=6.85$, $p<0.005$), Physical Discomfort ($F(2,88)=6.75$, $p<0.005$) and Physical Exertion ($F(2,88)=7.19$, $p<0.005$).

Since significant interactions were found in the SOFI-C scores between the work-shift and workday effects, post hoc two-way ANOVAs with bonferroni correction were conducted to further investigate the effect of work-shift (shift × time) and workday (day × time) on SOFI-C scores. In the work-shift effect, the results revealed significant differences in SOFI-C scores between the day shift and the night shift on the first workday ($F(1,53)=12.03$-23.62, $p\leq 0.001$) but not on the second workday ($F(1,36)=0.08$-2.02, $p>0.05$). In the workday effect, however, significant differences in the SOFI-C scores between the first and second workdays were found on the day shift ($F(1,33)=5.95$-12.37, $p<0.05$) but not on the night shift ($F(1,56)=<0.01$-2.20, $p>0.05$). Independent t-tests were conducted to compare the SOFI-C subscale scores for the day shift with those for the night shift for each of the two workdays. Significant *p*-level was adjusted to $p\leq 0.025$. The results revealed that the five subscale scores for the night shift were significantly higher than those for the day shift both in the middle and at the end of the first workday ($p<0.02$). All the subscale scores except for Physical Exertion were significantly higher for the day shift than for the night shift at the start of the second workday ($p<0.01$). No significant differences were found in any of the SOFI-C scores between the day shift and the night shift at the start of the first workday, and in the middle and at the end of the second workday ($p>0.025$).

Table 3 shows the results of the one-way repeated measure ANOVA for each of the work-shift and workday conditions. For both the first and the second nights, all of the SOFI-C subscale scores increased significantly over the course of the work shift. The same pattern, however, was not observed for daytime work. Only a few subscales showed significant increases, namely the Lack of Energy and Sleepiness subscales on the first workday, and the Lack of Energy and Physical Discomfort subscales on the second workday. The majority of the increases found during the day shift were from the beginning to end of work. No significant differences were observed in the Physical Exertion subscale scores on the second workday.

Insert Table 3 About Here

3.2 Perceived difficulty and anxiety of the officers

Officers who worked a night shift generally reported higher perceived difficulty than those who worked a day shift except for the items ‘sea visibility’, ‘seas and swell’, ‘wind’, ‘water flow’ and ‘traffic’. T-tests revealed that officers who worked a night shift reported significantly higher scores than those who worked a day shift on ‘voyage duration’ (p<0.005), ‘work time’ (p<0.05) and ‘vessel manoeuvrability’ (p<0.05). The comparison between workdays revealed that the perceived difficulty appeared to be higher on the second workday than on the first. T-tests only revealed significantly higher scores for the item ‘route’ (p<0.05). The details of the results are shown in Table 4. There were no significant differences in the scores for the item ‘vessel manoeuvrability’ between the officers who operated a hydrofoil model and those who operated a catamaran model.

The overall model of the three-way repeated measure ANOVA was statistically significant for the anxiety scores (Pillai’s Trace: $F(2,88)=35.45$, p<0.05). The interaction effects between the work shift and the workday on the officers’ anxiety scores were also statistically significant (p<0.01). This indicated that the night-shift officers showed a consistently higher anxiety level than the day-shift officers on the first workday (Table 5). On the second workday, however, the night-shift officers showed a lower anxiety level at the beginning of the workday but a higher anxiety level at the end. The details of the one-way repeated measure ANOVA and the pair-wise comparison are shown in Table 5.

Insert Table 4 and 5 About Here

3.3 Factors contributing to perceived fatigue

Significant regression models were obtained for predicting the Physical Exertion ($p<0.05$) and Physical Discomfort subscale scores ($p<0.005$) at the end of the night shift on the second workday, and the Sleepiness subscale ($p<0.05$) in the middle of the same night shift (Tables 6A and 6B). Experience and perceived voyage difficulty explained 69.8% of the Physical Exertion subscale scores (Tables 6A and 6B). Age, experience and perceived voyage difficulty explained 75.8% of the Physical Discomfort subscale scores (Tables 6A and 6B). Age, psychological stress and perceived difficulty explained 62.6% of the Sleepiness subscale scores (Tables 7A and 7B). In all of the models, perceived voyage difficulty had a positive effect on the SOFI-C scores. However, the age of the officers had a negative effect on the Physical Discomfort and Sleepiness subscale scores. Also, experienced officers tended to achieve a high score on the Physical Exertion and Physical Discomfort subscales. The predictors entered into the regression model for predicting Lack of Energy and Lack of Motivation subscale scores were all statistically not significant.

In contrast, there was only one significant regression equation established for predicting officers' perceived fatigue level among those who worked day shift. It was for the prediction of the Lack of Energy subscale scores ($p<0.05$) by the end of work on the second workday. Job stress alone explained 62.9% of the scores (Tables 6A and 6B).

Insert Tables 6A, 6B, 7A and 7B About Here

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4. Discussion

This study compared the extent of fatigue experienced by high-speed maritime craft officers working day and night shifts in Hong Kong. The results indicate that the officers experienced fatigue as they worked through a shift. The extent to which they felt fatigue appears to depend on the work shift and the workday. Officers on a night shift showed a more rapid rate of increase in fatigue during the workday. The officers seemed to recuperate from the fatigue after taking an overnight rest. In contrast, officers on a day shift showed a more gradual increase in fatigue during the workday. Nevertheless, the fatigue appeared to carry over to the next workday even if they took a half-day rest. Age, work experience and perceived voyage difficulty were found to be the important factors for predicting the officers' fatigue level.

4.1 Night-shift high-speed maritime craft operation is more fatiguing

The SOFI-C subscale scores reflect the extent to which the officers felt both physical and mental fatigue. The results suggest that, in general, the officers experienced fatigue as they progressed through a work shift. The number of voyages and total work hours involved in a day shift were higher than those involved in a night shift. Nevertheless, the officers who were on a night shift at the time of data collection had a significantly higher level of fatigue than those who were on a day shift. The rate of increase in fatigue was also found to be faster for the night-shift officers. The SOFI-C subscales on which the night-shift officers scored higher were the Physical Exertion, Physical Discomfort and Lack of Energy subscales. Our findings are consistent with studies of long-haul drivers (Hartley, 1998; Okogbaa et al., 1994;

Reyner, 1998).

The findings demonstrate that operating high-speed maritime craft during the night-time, from 18:00 to 23:30, is more fatiguing. Ahsberg et al. (2000) reported that increased subscale scores on the Lack of Energy, Physical Exertion and Physical Discomfort subscales were highly correlated with increased levels of perceived workload. It might be inferred from this that night-shift craft operation imposes greater mental workload on officers than does day-shift operation. Of the three SOFI-C dimensions, the Lack of Energy subscale is regarded as a general fatigue factor. The increase in the Physical Exertion subscale scores for the night-shift officers seems to suggest that operating high-speed maritime craft in a dark environment demands greater physical and mental effort. Ahsberg and Gamberale (1998), and Gamberale (1985) found that heightened physical exertion is usually associated with increased levels of physical work, which manifests in the form of palpitations and sweating. In high-speed night-time craft operation, officers cannot rely on direct surveillance at sea because of the dark environment. Instead, they are required to rely on the information and feedback provided by the navigation system which includes a radar. Detecting abnormal signals and warning signs requires a very high level of vigilance (Matthews et al., 2000). Maintaining such a highly alert state requires an intensive level of energy output from officers, and consequently leads to exhaustion.

Another reason for explaining the fatigue among the night-shift officers is the effects of circadian rhythm. Previous studies have associated circadian rhythms with psychological disturbances such as sleep disruption and sleepiness when one tries to adapt to a rapid shift-rotation pattern (Akerstedt, 1988; Matthews et al., 2000; Reinberg et al., 1984). The shift schedule of the high-speed maritime craft officers in the current study was two weeks or longer. During the night-shift work week, the officers were required to take alternate work-day (nocturnal) and rest-day (diurnal) routines. The consequence is that the officers would experience misalignment between circadian timing and the sleep/wake schedule which inhibits a full circadian adaptation (Monk and Folkard, 1983). In addition, the high fatigue level the officers experienced might be due to the inefficient cognitive functioning associated with night-time work (Folkard, 1983; Folkard and Monk, 1980; Oakhill, 1986; Tilley and Warren, 1983). The findings of the current study are consistent with those reported in studies of night shift pilots and drivers.

The officers on a night shift also reported more musculoskeletal discomfort than their day-shift counterparts. It is probable that the discomfort was due to the extra effort applied to compensate for the high level of fatigue experienced during night-time navigation (Matthews et al., 2000). Wersted et al. (1991, 1994) and Cohen et al. (1992) reported that attention-demanding tasks were associated with shoulder muscle tension and increased muscle activity in the corrugator supercilii. Edwards (1988), Svebak (1988), and Wallace and Buckle (1987) also found that mental stress contributes to the development of musculoskeletal pain or discomfort. In view of the fact that night-shift navigation does not require officers to maintain a prolonged and unusual posture, nor to perform physically demanding tasks, a mental origin of the discomfort seems to be more likely. The night-shift officers achieved a higher score on the Lack of Motivation subscale than the day-shift officers. Nevertheless, the difference was not statistically significant.

4.2 The day-shift officers experienced a greater fatigue carry-over effect

The officers on a night shift were found to experience more fatigue (higher SOFI-C subscale scores) on the first workday than on the second workday. The fatigue of these officers tended to intensify at a much faster rate (within seven hours). The extent to which the fatigue accumulated from the first to the second day was not great. The officers on a night shift appeared to recuperate from the fatigue, while the day-shift officers reported significantly more fatigue on the second workday (on all SOFI-C subscales). These officers generally showed a more gradual but steady increase in the intensity of fatigue from the beginning of the first workday to the end of the second workday (see the different baselines in Figure 1). The differences in changes in the level of fatigue between the night-shift and day-shift officers could partly be attributable to the negative effect of circadian rhythms on night-time work. But as what the findings of this study show, the differences could partly due to the difference in the length of the shift and the associated work demand between the two work shifts.

During sea navigation, officers have to continuously process the information displayed on the radar and make observations of the sea conditions (Sauer et al., 2002). In the daytime, when the weather is clear, officers use both radar and direct observation for navigation. At night, officers have to rely solely on the information conveyed by radar. Thus, there are clear differences between the demands placed on officers during daytime navigation and those placed on officers during a night shift. Daytime navigation requires officers to utilize various sources of information, namely the sea conditions and radar. Since sea conditions are busier during the daytime, it is likely that the officers would maintain a high level of alertness throughout the day shift. In contrast, night-time navigation requires officers to capture information from fewer sources, namely just radar. Nevertheless, both the vigilance and stress associated with navigation are high (Galinsky et al., 1993). Vigilance is required for capturing the monotonous signals displayed by the radar; whilst stress is associated with the uncertainties of navigating in the dark and the anticipation of unsafe conditions (Hodson, 2001). The consequence of the differences between daytime and night-time navigation is that night-shift officers feel more fatigue and have higher levels of stress than day-shift officers (Matthews and Desmond, 1998; Wickens, 2000). These differences in fatigue patterns could be the manifestation of task-specific versus generalized fatigue

(Holding, 1983). Our findings suggest that night-shift navigation leads to greater task-specific fatigue – that is, fatigue experienced as a consequence of performing a particular task – while day-shift navigation leads to a more generalized fatigue. According to Holding (1983), task-specific tiredness can be alleviated by rest breaks or by doing a different activity for 30 minutes or more, but that generalized fatigue cannot. This offers a plausible explanation of our observations that the night-shift officers had already recuperated from the fatigue they experienced during the first workday when they began their second workday, while the level of fatigue experienced by the day-shift officers had a carry-over effect from the first workday to the second workday.

4.3 Factors contributing to perceived fatigue

Of the five SOFI-C subscales, only the Physical Discomfort and Physical Exertion subscales were significantly predicted in the regression analyses. Age, experience and perceived difficulty were found to account for the level of physical discomfort, and experience and perceived difficulty for the level of physical exertion. Surprisingly, the age of the officers was found to be inversely related to their level of fatigue. Younger officers (aged between 23 and 47) who were on a night shift at the time of the data collection reported a higher level of physical fatigue. This finding is consistent with Kumashiro and Nagae's study (1984), in which sedentary workers under the age of 30 reported a higher level of fatigue than those who were above 30. Kumashiro and Nagae argued that this was because younger workers would be less favourably disposed towards their work and so would be more likely to experience boredom, loneliness and monotony. This can also explain our observations. The officers who worked a day shift tended to report a greater lack of energy on their second workday than their night shift counterpart. Since lack of energy reflects general fatigue

(Ahsberg, 2000), the prolonged working hours and intensive voyages during a day shift probably can account for this phenomenon.

4.4 Fatigue, work patterns and recommendations for occupational health

Physical fatigue was found to be especially high in the officers on a night shift. The day-shift officers reported a similar extent of physical fatigue during the second workday. Since physical discomfort can lead to musculoskeletal disorders (Wersted et al., 1991), it is desirable to build high-speed crafts with ergonomically designed bridges. As with other workers, a proper exercise program and health education are important for maintaining a healthy workforce of high-speed maritime craft officers. Appropriately scheduled rest periods appear to be crucial for alleviating fatigue and other health-related problems among these officers. In our study, although night-shift operation was found to be more fatiguing than day-shift operation, the relatively longer off-duty rest period seemed effective as a way of preventing the carrying over of fatigue into the second workday. It was apparent that the day-shift officers experienced fatigue on the second workday that had accumulated during the first. They oversaw a greater number of voyages during a workday and were allowed a shorter inter-voyage rest period (15 minutes for a day shift compared to 30 minutes for a night shift) than the night-shift officers. It can be inferred from this finding that if day-shift officers have to put up with lengthy working hours and a short inter-voyage rest period, they are likely to find it more difficult to recover from fatigue than night-shift officers who enjoy shorter working hours and a longer inter-voyage rest period, despite the greater mental demands of night-time navigation. It is therefore advisable that day-shift officers be given a longer inter-voyage rest period and/or fewer voyages to oversee. It is also important that officers get more rest after they finish their first day or night of work. It is recommended that officers take additional breaks on days and nights when voyages are anticipated to be more difficult.

The present study was limited by the lack of control over the variables within the selected work pattern. This included the number of voyages of the officers on the day of assessment, the quality and quantity of the intermittent rest period, and unexpected overtime duties. The type of vessel that the officers operated was also difficult to control in a real work situation. Nevertheless, it was observed that the manoeuvrability of the two types of vessels operated by these officers did not differ statistically. The results obtained from two consecutive workdays might not be applicable to those whose work pattern consisted of three or four consecutive workdays. Furthermore, since the study was carried out in January and February, seasonal characteristics might lower the generalizability of the results. Systematic studies on fatigue in navigation officers are rare. Kamada, Iwata and Kojima (Kamada et al., 1990) conducted a study to investigate the symptoms of fatigue in seamen during long voyages. They revealed that physical fatigue was more prominent among the crew than mental fatigue. In contrast, the results of our study indicate that high-speed maritime craft officers experience both physical and mental fatigue. The differences in the pattern of navigation and hence in the level of fatigue suggest that more work has to be conducted on how navigation during both day shifts and night shifts impacts the work and mental load of officers, and on the effectiveness of using different interventions to alleviate fatigue, such as longer rest breaks, improved shift schedules, and modifications of the work environment and the navigation system. This would require collaboration between the ship company, the officers and ergonomic experts.

5. Conclusion

This study found that the night-shift officers manifested an overall higher level of perceived fatigue than the day-shift officers. In contrast, the day-shift officers experienced a greater fatigue carry-over effect from one workday to the next. This could be due to the fact that the night-shift officers experienced problems with circadian adaptation and had a higher workload, while the day-shift officers were more fatigued by their lengthy working hours. The heightened physical discomfort and the substantial accumulation of fatigue highlight the importance of enhancing the occupational health of high-speed maritime craft officers. A sufficient rest period between voyages or after a workday is crucial for alleviating fatigue. However, owing to the limited control over the variables in the present study, further research is recommended. Future research could also use physiological methods such as electroencephalograms and electrocardiograms in order to gain a more comprehensive understanding of the fatigue and workload of high-speed maritime craft officers.

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Table 1.
Distribution of the high-speed maritime craft officers in terms of work shift, workday and job title

		Master (M)	Chief Officer (CO)	Night Vision Officer (NVO)	Total
Work shift	Night	20	20	18	58
	Day	18	17	---	35
	Total	38	37	18	93
Workday	1st	21	21	13	55
	2nd	17	16	5	38
	Total	38	37	18	93

Table 2.
Result of the three-way repeated measure ANOVA (2 shifts × 2 workdays × 3 points in time) on the SOFI-C subscale scores

SOFI-C[C]	Mean score of SOFI-C (±1S.E.)			
	Night shift	Day shift	1st workday	2nd workday
PE	3.23 (0.21)	2.38 (0.25)	2.46 (0.22)	3.16 (0.24)
PD	3.46 (0.21)	2.75 (0.25)	2.75 (0.22)	3.46 (0.24)
LE	4.16 (0.21)	3.54 (0.26)	3.41 (0.23)	4.29 (0.25)
LM	3.81 (0.24)	3.29 (0.30)	3.22 (0.26)	3.88 (0.28)
S	4.04 (0.24)	3.43 (0.29)	3.32 (0.25)	4.15 (0.27)

SOFI[C]	Shift[a]		Workday[a]		Shift × Workday[a]		Shift × Time[b]		Workday × Time[b]		Time[b]	
	F-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value
PE	6.61	0.012*	4.45	0.038*	4.47	0.037*	7.19	0.001**	0.88	0.418	31.33	<0.001**
PD	4.65	0.034*	4.77	0.032*	7.36	0.008**	6.75	0.002**	0.28	0.759	54.66	<0.001**
LE	4.34	0.044*	6.89	0.010*	17.36	<0.001**	6.85	0.002**	0.65	0.526	106.75	<0.001**
LM	1.90	0.172	2.93	0.090	8.85	0.004**	7.98	0.001**	0.15	0.863	52.97	<0.001**
S	2.69	0.104	5.00	0.028*	12.71	0.001**	12.81	<0.001**	0.12	0.887	68.00	<0.001**

* $p \leq 0.05$, ** $p \leq 0.005$
[a] Degree of freedom=1,89
[b] Degree of freedom=2,88

Table 3.
Results of the one-way repeated measure ANOVAs on the SOFI-C subscale scores for each work shift and workday

			Mean score of SOFI-C (±1S.E.)					
Day	Shift	SOFI[f]	Pre-work	Middle of work	End of work	*F*-value	*p*-value	Pair-wise[e]
1st	Night[a]	PE	1.81 (0.25)	3.06 (0.26)	4.83 (0.34)	44.19	<0.001**	1,2; 1,3; 2,3
	N=39	PD	1.48 (0.24)	3.68 (0.27)	5.48 (0.35)	67.88	<0.001**	1,2; 1,3; 2,3
		LE	1.73 (0.27)	4.55 (0.29)	6.97 (0.29)	122.76	<0.001**	1,2; 1,3; 2,3
		LM	2.11 (0.30)	3.88 (0.29)	6.17 (0.35)	72.99	<0.001**	1,2; 1,3; 2,3
		S	1.79 (0.33)	4.02 (0.33)	7.06 (0.31)	97.35	<0.001**	1,2; 1,3; 2,3
1st	Day[b]	PE	1.16 (0.32)	1.79 (0.44)	2.11 (0.44)	4.64	0.018*	1,3
	N=16	PD	0.90 (0.29)	2.29 (0.45)	2.66 (0.53)	9.60	0.001**	1,2; 1,3
		LE	0.99 (0.34)	2.58 (0.49)	3.64 (0.58)	17.90	<0.001**	1,2; 1,3; 2,3
		LM	1.50 (0.41)	2.39 (0.55)	3.29 (0.55)	9.98	<0.001**	1,2; 1,3
		S	1.44 (0.46)	2.29 (0.53)	3.34 (0.51)	15.44	<0.001**	1,2; 1,3; 2,3
2nd	Night[c]	PE	1.45 (0.36)	3.43 (0.39)	4.81 (0.53)	18.95	<0.001**	1,2; 1,3; 2,3
	N=19	PD	1.21 (0.31)	3.60 (0.35)	5.31 (0.52)	35.54	<0.001**	1,2; 1,3; 2,3
		LE	1,28 (0.32)	4.03 (0.33)	6.38 (0.54)	43.46	<0.001**	1,2; 1,3; 2,3
		LM	1.45 (0.31)	3.59 (0.38)	5.67 (0.52)	30.91	<0.001**	1,2; 1,3; 2,3
		S	1.18 (0.32)	3.90 (0.40)	6.32 (0.50)	42.89	<0.001**	1,2; 1,3; 2,3
2nd	Day[d]	PE	2.33 (0.48)	3.26 (0.57)	3.64 (0.58)	3.11	0.057	------
	N=19	PD	2.48 (0.46)	3.60 (0.53)	4.58 (0.61)	10.19	<0.001**	1,2; 1,3; 2,3
		LE	3.01 (0.60)	4.54 (0.53)	6.51 (0.53)	29.66	<0.001**	1,2; 1,3; 2,3
		LM	3.26 (0.59)	4.17 (0.65)	5.12 (0.68)	5.74	0.007*	1,3
		S	3.55 (0.66)	4.28 (0.68)	5.71 (0.59)	6.04	0.005**	1,3; 2,3

* $p \leq 0.05$, ** $p \leq 0.005$
[a] Degree of freedom=2,76
[b] Degree of freedom=2,30
[c] Degree of freedom=2,36
[d] Degree of freedom=2,36
[e] Pair-wise comparison using Bonforreni procedure; $p<0.05$

Table 4.
Mean (SD) of different aspects of perceived difficulty and the results of the t-tests

Items	Day shift *n*=35	Night shift *n*=58	*p*-value[a]	1st workday *n*=55	2nd workday *n*=38	*p*-value[a]
Sea visibility	5.37 (3.43)	6.40 (3.13)	0.143	5.85 (3.29)	6.24 (3.27)	0.582
Seas and swell	5.40 (2.53)	5.36 (2.68)	0.946	5.13 (2.45)	5.74 (2.82)	0.270
Wind	5.46 (2.33)	6.84 (2.53)	0.248	4.76 (2.31)	5.53 (2.64)	0.143
Water flow	4.11 (1.89)	4.28 (2.21)	0.720	3.89 (2.18)	4.68 (1.88)	0.072
Traffic	7.17 (2.12)	7.67 (2.21)	0.285	7.25 (2.30)	7.82 (1.97)	0.224
Route	4.88 (2.42)	5.93 (2.26)	0.039*	5.05 (2.53)	6.27 (1.88)	0.015*
Voyage duration	5.82 (3.02)	7.84 (1.78)	0.001*	6.71 (2.67)	7.72 (2.07)	0.057
Work time	5.35 (2.73)	6.66 (2.47)	0.021*	5.71 (2.71)	6.86 (2.38)	0.038
Vessel manoeuvrability	4.12 (2.48)	5.36 (2.46)	0.024*	4.91 (2.33)	4.92 (2.84)	0.989

[a] Degree of freedom=91
* *p*-value at $p \leq 0.05$

Table 5.
Results of the one-way repeated measure ANOVAs on anxiety scores for each work shift and workday

			Mean anxiety score (±1S.E.)					
Shift	Day	*n*	Pre-work	Middle of work	End of work	*F*-value[a]	*p*-value	Pair-wise[b]
Day	1st	16	1.92 (0.12)	2.18 (0.08)	1.93 (0.07)	6.39	0.011*	1<2; 2>3
	2nd	19	2.24 (0.14)	2.52 (0.11)	2.10 (0.09)	5.42	0.009**	1<2; 2>3
Night	1st	39	2.15 (0.08)	2.46 (0.06)	2.37 (0.09)	13.51	<0.001**	1<2
	2nd	19	1.88 (0.10)	2.46 (0.07)	2.29 (0.12)	18.08	<0.001**	1<2; 1<3

[a] Degree of freedom=2,14 for first day; 2,36 for second day; 2,37 for first night; 2,17 for second night
[b] Pair-wise comparison using Bonforreni procedure; $p<0.05$
* $p \leq 0.05$, ** $p \leq 0.005$

Table 6.
Results of the linear regression models with age, experience, perceived voyage difficulty, job stress, psychosocial stress and anxiety as the independent variable in each SOFI-C subscale at the end of the second night and second day (A); and the coefficient (β) of the independent variables in each of the significant regression models (B)

A

			Residual	
	SOFI-C	R^2 (%)	*F*-value[a]	*p*-value
2nd Night	PE	69.8	4.618	0.012*
	PD	75.8	6.262	0.004**
	LE	53.4	2.287	0.105
	LM	44.2	1.584	0.234
	S	45.9	1.693	0.206
2nd Day	PE	28.0	0.714	0.646
	PD	30.2	0.793	0.594
	LE	62.9	3.104	0.050*
	LM	38.3	1.139	0.402
	S	43.6	1.418	0.291

B

	SOFI	Independent variable	β	S.E.	*t*-value	*p*-value
2nd Night	PE	Age	-1.103	0.053	-1.936	0.077
		Experience	0.226	0.077	2.950	0.012*
		Perceived difficulty	0.796	0.255	3.119	0.009**
		Job stress	-0.635	0.664	-0.956	0.358
		Psychosocial stress	-1.318	0.636	-2.071	0.061
		Anxiety	0.626	0.798	0.784	0.448
2nd Night	PD	Age	-0.157	0.046	-3.378	0.005**
		Experience	0.245	0.067	3.643	0.003**
		Perceived difficulty	0.770	0.223	3.451	0.005**
		Job stress	-1.109	0.581	-1.908	0.081
		Psychosocial stress	-0.242	0.557	-0.434	0.672
		Anxiety	0.929	0.698	1.330	0.208
2nd Day	LE	Age	-0.068	0.129	-0.525	0.610
		Experience	0.033	0.068	0.486	0.636
		Perceived difficulty	0.305	0.311	0.979	0.349
		Job stress	2.218	0.617	3.446	0.005**
		Psychosocial stress	0.498	0.649	0.766	0.460
		Anxiety	0.081	1.174	0.069	0.947

* $p \leq 0.05$, ** $p \leq 0.005$

[a] Degree of freedom=6,18

Table 7.
Results of the linear regression model with age, experience, perceived voyage difficulty, job stress, psychosocial stress and anxiety as the independent variable in each SOFI-C subscale in the middle of the second night and the second day (A); and the coefficient (β) of the independent variables in each of the significant regression models (B)

A

	SOFI-C	R^2 (%)	Residual	
			F-value[a]	*p*-value
2nd Night	PE	22.2	0.572	0.746
	PD	43.6	1.544	0.246
	LE	36.9	1.169	0.384
	LM	36.7	1.158	0.389
	S	62.6	3.346	0.036*
2nd Day	PE	37.8	1.114	0.414
	PD	35.3	1.000	0.472
	LE	40.7	1.259	0.350
	LM	34.0	0.946	0.501
	S	30.4	0.801	0.589

B

	SOFI	Independent variable	β	S.E.	*t*-value	*p*-value
2nd Night	S	Age	-0.097	0.045	-2.162	0.052
		Experience	0.118	0.065	1.822	0.093
		Perceived difficulty	0.583	0.215	2.718	0.019*
		Job stress	-0.914	0.559	-1.637	0.128
		Psychosocial stress	1.153	0.535	2.718	0.052
		Anxiety	0.700	0.671	-1.044	0.317

* $p \leq 0.05$, ** $p \leq 0.005$
[a] Degree of freedom=6,18

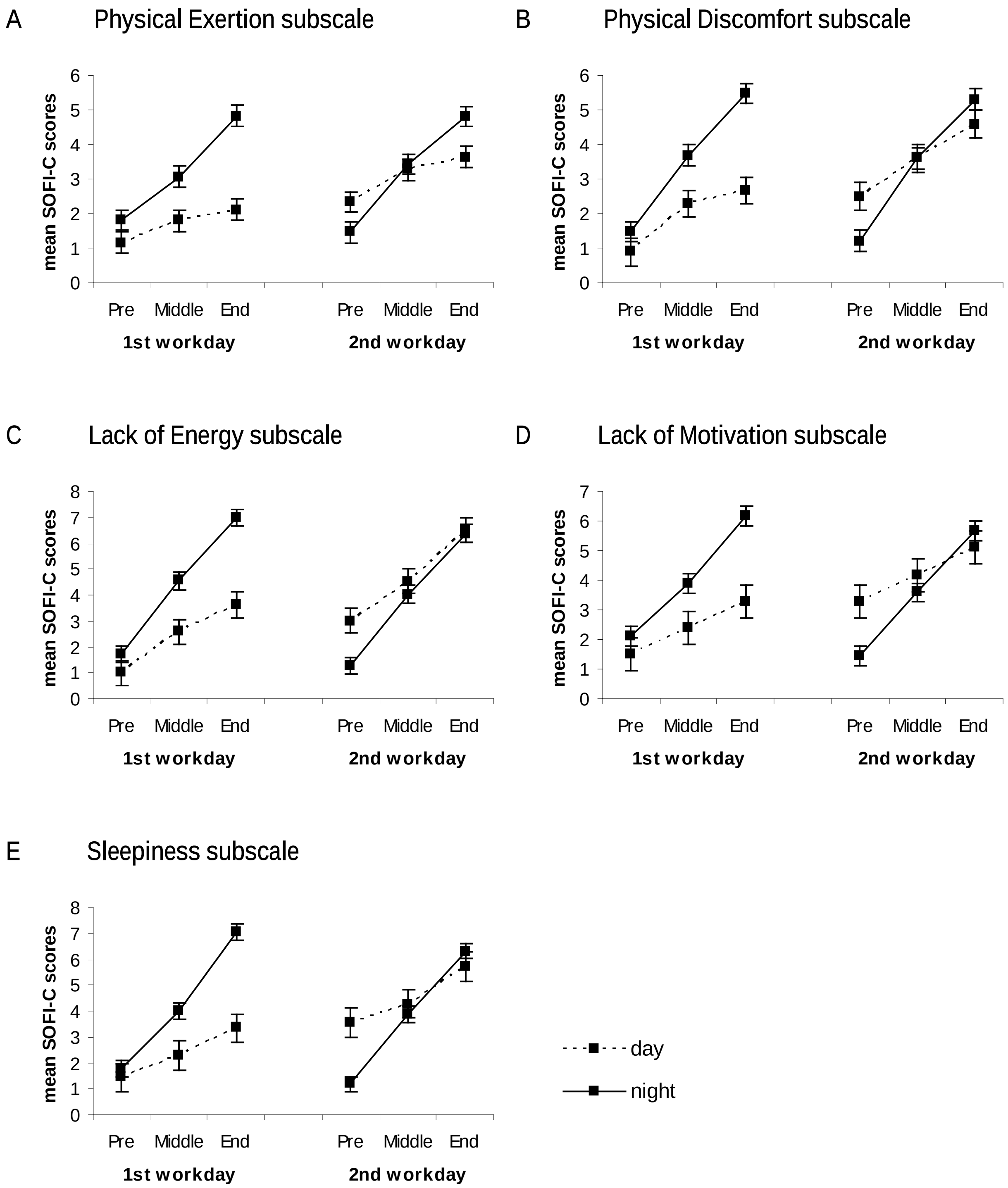

Figure 1.
Mean scores on the SOFI-C (±1S.E.) for the Physical Exertion subscale (A), the Physical Discomfort subscale (B), the Lack of Energy subscale (C), the Lack of Motivation subscale (D) and the Sleepiness subscale (S)