Grech, Michelle R. and Neal, Andrew and Yeo, Gillian B. and Humphreys, Michael and Smith, Simon (2009) *An examination of the relationship between workload and fatigue within and across consecutive days of work: Is the relationshiop static or dynamic?* Journal of Occupational Health Psychology, 14(3). pp. 231-242.

Workload and Fatigue:

An Examination of the Relationship within and Across Consecutive Days of Work

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Abstract

Cognitive-energetical theories of information processing were used to generate predictions regarding the relationship between workload and fatigue within and across consecutive days of work. Repeated measures were taken on board a naval vessel during a non-routine and a routine patrol. Data were analyzed using growth curve modeling. Fatigue demonstrated a non-monotonic relationship within days in both patrols – fatigue was high at midnight, started decreasing until noontime and then increased again. Fatigue increased across days towards the end of the non-routine patrol, but remained stable across days in the routine patrol. The relationship between workload and fatigue changed over consecutive days in the non-routine patrol. At the beginning of the patrol, low workload was associated with fatigue. At the end of the patrol, high workload was associated with fatigue. This relationship could not be tested in the routine patrol, however it demonstrated a non-monotonic relationship between workload and fatigue – low and high workloads were associated with the highest fatigue. These results suggest that the optimal level of workload can change over time and thus have implications for the management of fatigue.

Keywords: fatigue, workload, energetical resources, growth curve modeling

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Fatigue is a common problem in industries which entail 24-hour operations, long work periods and/or shift-work, such as in the areas of aviation, maritime, health and defence. Fatigue is a psychophysiological state that is characterized by feelings of tiredness and the loss of energy (Hockey, 1997; Matthews et al. 2002). Consequences of this state include impairments in motivation, performance, health, well-being and safety (e.g., Sonnentag & Zijlstra 2006; VanYperen & Janssen, 2002; Zohar, Tzischinski & Epstein, 2003). Whilst a great deal is known about the effects of sleep schedules, work patterns, and time of day on fatigue (Colquhoun, 1971; Dawson & Reid 1997; Dinges et al., 1997; Lal & Craig, 2002), less is known about the impact of workload (Craig, Tran, Wijesuriya & Boord, 2005; Hockey & Earle, 2006). As will be seen below, the relationship between workload and fatigue is complex, because both underload and overload have been identified as potential causes of fatigue (Hancock & Verwey, 1997). To complicate matters further, the optimal level of workload may change over time. Thus, in some circumstances having too little to do may be fatiguing, while in other circumstances, having too much to do may be fatiguing. We examine whether or not this is the case, by assessing whether the relationship between perceived workload and fatigue changes within individuals, over time.

The reason we examine the relationship between perceived workload and fatigue at the within-person level is because the underlying process that generates fatigue is dynamic. For example, cognitive-energetical theories (Gopher & Donchin, 1986; Kahneman, 1973) explain fatigue in terms of the rate of energy expenditure in relation to the rate of recovery, and the ability of the cognitive system to adapt to any imbalance between the two (e.g., Hockey, 1997; Meijman & Mulder, 1998). However, most research consists of cross-sectional correlational studies, or laboratory-based experimental studies using pre-post measures of fatigue. There is growing awareness that between-person designs and analyses cannot be used to answer questions about within-person processes (Kozlowski & Klein, 2000). If we are to develop an understanding of the dynamic processes that govern psychological states at work, we first need to develop theoretical models that specify relationships at the within-person level, then we need to use within-subjects designs to test the models (Vancouver, 2005). For this reason, there have been repeated calls for within-person analyses of the determinants of fatigue (Hockey, 1997).

The current paper responds to these calls by drawing on prior theory (Hockey, 1997; Humphreys & Revelle, 1984) to develop a model of the relationship between perceived workload and fatigue across consecutive days of work. We test our model using data collected in a context in which personnel were working rotating shifts with minimal opportunity for recovery, and performing activities that varied in the demands placed on the individual. The data are analyzed at the within-person level using growth curve modeling.

Perceived Workload

Subjective perceptions of workload reflect an assessment of the individual's capacity to meet task demands (Wickens, 1992). High levels of perceived workload occur when task demands exceed the capacity of the individual to meet those demands. Previous studies suggest that the relationship between workload and fatigue may be non-monotonic. Vigilance studies have demonstrated that periods of low workload can cause fatigue, if the individual is required to maintain attention on the task for a prolonged period (Matthews et al. 2002). Other studies have demonstrated that periods of high workload can cause fatigue (Matthews & Desmond, 2002).

Theoretical accounts of task-induced fatigue explain these effects in terms of arousal and compensatory effort (Humphreys & Revelle, 1984; Hockey, 1997; Meijman & Mulder, 1998). In the psychophysiology literature, the term “arousal” describes the level of activation in centrally organized appetitive or defensive motivational systems (Bradley, 2000). It is regarded as an energizing force, providing the metabolic requirements for cognition and action. Cognitive-energetical theories of information processing treat arousal as a hypothetical construct, and use it to describe the level of resource availability (Humphreys & Revelle, 1984). According to this explanation, arousal levels change in response to task demands. Chronically low levels of workload produce low arousal, making it difficult to maintain alertness and attention, thereby producing the subjective experience of fatigue. Increases in task demands produce an increase in arousal, which is energizing. If these increases are within capacity limits, they will produce an increase in alertness and a decrease in subjective fatigue. However, as task demands approach and then exceed the individual’s capacity limit, the individual needs to compensate by applying effort. For example, the individual may have to reallocate resources among tasks, change their strategies or goals, and/or regulate their emotional reactions. Compensatory effort imposes a cost on resource capacity, draining energy reserves, thereby producing fatigue. Whilst these theoretical arguments are well established, to our knowledge, no studies have examined the effects of overload and underload at the within-person level. Our first hypothesis is as follows:

Hypothesis 1: There is a non-monotonic relationship between workload and fatigue within individuals. Increases in workload from low to moderate levels are associated with reductions in fatigue. Increases in workload from moderate to high levels are associated with increases in fatigue.

Time

The preceding arguments provide a basis for generating predictions regarding the way in which the relationship between workload and fatigue may change over time, particularly for individuals with limited opportunities to recover from work. However, when modeling dynamic processes, it is important to differentiate among processes that operate at different time scales (Kozlowski & Klein, 2000; Nesselroade, 1991). We will first consider how the effect of perceived workload on fatigue may change over consecutive days of work, and then consider how it may change within days.

In the current study, participants were working on rapidly rotating shifts involving four hours of work and eight hours of rest. Shift work is known to disrupt sleep patterns (Pilcher, Lambert, & Huffcutt, 2000). The four hours on, eight hours off cycle is likely to be particularly disruptive, because the sleep and wake times change continuously, making adaptation to the shift pattern difficult. Of critical relevance is the effect of partial sleep deprivation on arousal. Studies suggest that partial sleep deprivation produces a flattening of arousal over consecutive days, and that as a result, individuals become less responsive to external stimulation (Dinges et al., 1997). If so, then according to the arguments presented above, the point at which individuals need to respond to increases in task demands with compensatory effort should change. This should produce a change in the relationship between perceived workload and fatigue. On the first day of the shift roster, workers are likely to be fresh and energized, and should respond to increases in task demands with increased arousal. As a result, they should be able to deal with high levels of perceived workload with minimal effort, because they have substantial resources available for the task. This should produce a negative relationship between perceived workload and fatigue. By the end of the work period, accumulated sleep debt should flatten arousal levels. As a result, workers will need to apply compensatory effort to deal with task demands that they previously had the resources to deal with. Put another way, increases in task demands will require more effort to handle after consecutive days of shift work. As a result, we should observe a positive relationship between perceived workload and fatigue towards the end of the work period.

Hypothesis 2: The within-person relationship between perceived workload on fatigue changes over consecutive days of shift work. The relationship is negative at the beginning of the work period, but becomes positive over the following days.

The second temporal process that may produce changes in the relationship between workload and fatigue is the circadian rhythm. Arousal levels are at their highest in the early afternoon and their lowest in the early morning around 03:00 (Carrier & Monk, 2000; Folkard & Monk, 1985). If so, then the effect of perceived workload may change cyclically over the 24 hour period. Individuals may need to apply more effort to deal with the same level of task demands in the early morning than in the early afternoon. A study of bus drivers in the Netherlands provides some evidence to suggest that the effect of workload may change over the course of the day. Meijman (1991, cited in Meijman & Mulder, 1998) reported a positive correlation between perceived effort and subjective fatigue at the end of a morning shift (9:00-12:30) and a non-significant correlation at the end of an afternoon shift (13:00-17:00), however this relationship was tested at the between-person level of analysis. Within-person effects may well be different to between-person effects. Our model suggests that the within-person relationship between perceived workload and fatigue could be negative at the circadian peak (during the afternoon), and positive at the circadian nadir (around 03:00).

Hypothesis 3: The within-person relationship between perceived workload on fatigue changes throughout the day. The relationship is negative during the afternoon, but becomes positive during the early hours of the morning.

The Current Context

The current hypotheses were tested on a sample of Navy crewmembers within an industrialized country. We collected data from each crewmember while they performed their watchkeeping duties on a Navy patrol vessel. Watchkeeping duties were performed in the engine room and on the bridge. Crewmembers operated on a 4-hours on, 8-hours off watch schedule.

Each crewmember participated in two types of patrols. First, they performed a *non-routine patrol*, which refers to a training period. This training involved a number of simulated scenarios, which were based on events that crewmembers may be exposed to during their routine operations. Examples include boardings and contact with illegal fishing vessels. In addition, training drills were conducted, which included responding to emergency situations such as man-overboard, fires and collision. Crewmembers were continuously active during the training period because drills were presented successively and sometimes concurrently. Further, some activities were conducted outside of the crewmembers' scheduled watches. Next, the crewmembers performed a *routine patrol*, which refers to a period in which the vessel was out at sea on a routine voyage. This patrol was less demanding than the non-routine patrol and was characterized by long periods of time on board with little activity. However, all crewmembers had to maintain vigilance whilst they were on watch, and could not fall asleep.

Given the differences in task demands across days for the two patrol types, it is possible that the results will differ across patrols. For example, fluctuations in fatigue across days may be most evident in the non-routine patrol, because the demands were more variable than in the routine patrol. Similarly, the interaction between perceived workload and consecutive days of work may be more pronounced in the non-routine patrol because there was less opportunity to recover in this patrol due to the high demands. However, it is difficult, on an a priori basis, to predict the exact number or nature of events that will occur in the routine patrol, nor how much variability in task demands would be required to generate different results across patrols. Therefore, we did not make specific predictions regarding potential differences across patrols.

Method

Participants and Procedure

The sample consisted of 20 Navy patrol vessel crewmembers. The patrol vessels included in this research operate with 24 crewmembers, however, three personnel were excluded because they did not undertake shift work (the commanding officer, chief engineer and cook) and one crewmember did not wish to participate. Two participants were female, and the mean age was 28.5 (*SD* = 5.23).

Participants performed the non-routine patrol over five days, followed by a ten-day break, and then performed the routine patrol over four days. There were six four-hour watches during each 24-hour period. Each crewmember completed two to three of these watches per day. Participants were provided with a paper based questionnaire booklet and carried these booklets with them at all times. Participants completed the fatigue and perceived workload measures 30-minutes into their watch, and each successive 30-minute interval, until the end of their watch. Hence, seven fatigue and perceived workload scores were collected from each participant for each 4-hour watch schedule they were assigned to. These data were collected by the first author who was present on board the vessel during the data collection periods. Prior to sailing, participants were briefed on the method and frequency for completing the questionnaires. Announcements were made periodically while at sea as a reminder to fill out the questionnaires.

Measures

Fatigue. Fatigue was measured using a scale from the Crew Status Survey (CSS) originally developed by Pearson and Byars (1956), and later modified by the Air Force School of

Aerospace Medicine. The CSS was developed for the purpose of assessing dynamic levels of fatigue and workload throughout an operator's shift (Gawron, 2000). This measure has been employed successfully in the aviation, command and control, and driving domains and is considered to be reliable (Charlton, 2002; Charlton & Baas, 2001; Gawron, 2000). It has also been shown to have good convergent validity with the Epsworth Sleepiness Scale (ESS) (Charlton & Baas, 2001). This measure requires minimal time to complete, making it appropriate for an operational setting because repeated measurements can be collected within short timeframes. The CSS measures fatigue with one item on a 7-point scale ranked from 1 *(fully alert, wide awake, extremely peppy)* to 7 *(completely exhausted; unable to function effectively, ready to drop).* The seven measurements within each watch were averaged to create a fatigue score for each watch. The average inter-occasion correlations between these measurements can be used as an indicator of reliability (Matthews, Jones & Chamberlain, 1990[1]). In the non-routine patrol, the average inter-occasion correlations for these seven fatigue scores ranged from α = .59 (day 3) to α = .80 (day 1) (X= .69; SD =.09). In the routine patrol, these correlations ranged from α = .82 (day 2) to α = .90 (day 3) (X = .86; SD = .03).

Perceived workload. Perceived workload was measured using the average workload dimension from the CSS. This scale demonstrates adequate convergent validity with other workload scales, such as the Subjective Workload Assessment Technique (SWAT) and the NASA Task Load Index (TLX), which supports its use in field settings (Charlton, 2002). The CSS measures average workload with one item on a 7-point scale ranging from 1 *(nothing to do; no system demands)* to 7 *(unmanageable; potentially dangerous; unacceptable).* The seven measurements within each watch were averaged to create a workload score for each watch. For

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[1] Note that only a small number of crewmembers performed each watch, so there was not enough data to compute these statistics for each watch.

the non-routine patrol, the average inter-occasion correlations for the seven workload scores ranged from α = .78 (day 3) to α = .88 (day 4) (X = .83; SD = .04). In the routine patrol, these inter-occasion correlations ranged from α = .82 (day 3) to α = .94 (day 4) (X = .90; SD = .03).

Results

Data Structure and Descriptive Statistics

The hypotheses were tested via growth curve modeling, conducted using Hierarchical Linear Modeling (HLM) (Raudenbush & Bryk, 2002). Data were analyzed separately for the non-routine and routine patrols[2]. Each data set had three levels of analysis. At Level 1 (within-day level), perceived workload and fatigue were measured during six watch periods over each 24-hour period. Each person only conducted two or three watches each day[3]. The watch measurements were nested within each of five days (for the non-routine patrol) or four days (for the routine patrol) in this second level (within-patrol level). Each of these measurements was nested within the 20 crewmembers at the third level (between-person level). All predictors were standardized around their grand mean. The means, standard deviations and intercorrelations among the variables for the non-routine and routine patrols are displayed in Tables 1 (within-day level) and 2 (within-patrol level).

The Empty Models

The first model that was run for each patrol was an empty model, which allows examination of the variance in fatigue scores prior to including any predictor variables. These models were

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[2]Our data structure actually represents a three-level cross classified model (time of day at level 1, time across days and patrol type crossed at level 2, and persons at level 3). That is, type of patrol and day of patrol are crossed, as the measurements are not uniquely nested within a day of a certain type of patrol because each person participated in both patrols. However, the sample size of two for patrol type is not sufficient for running such a model. The reason for this is that the ratio between persons and type of patrol is 1:2, which limits this model's ability in terms of what can be estimated. As a result, there are not enough degrees of freedom to estimate the necessary variance components.

[3] Note that the resulting missing data are considered to be missing completely at random (MCAR), such that the missingness is independent of both observed and unobserved data (Raudenbush & Bryk 2002; Litlle & Rubin, 2002). As a result, the estimation of parameters is not biased by this type of missing data. Also, HLM allows missing data at Level 1.

tested by specifying fatigue as the dependent variable and specifying its intercept as a random effect at the within-patrol and between-person levels of analysis.

The intra-class correlation coefficient (ICC1) indicates the proportion of variability in fatigue that exists at each of the three levels of analysis. The ICC1 for the non-routine patrol indicated that 64.50% of the variance in fatigue scores occurred within days, 7.83% occurred across days and 27.34% occurred between individuals. The ICC1 for the routine patrol indicated that 34.62% of the variance in fatigue scores occurred within days, 0.10% of variance occurred across days and 65.29% occurred between individuals.

Chi-square tests of the intercept variance components at the within-patrol and between-person levels were used to test whether the variance in fatigue scores at those levels was statistically significant. The second intra-class correlation coefficient (ICC2) indicates how much of the variance component is parameter variance, rather than error. If the chi-square test is significant and the ICC2 is greater than .05, it is deemed appropriate to specify variables as predictors of those variance components (Snijders & Bosker, 1999).

For the non-routine patrol, the random effect for the intercept at the within-patrol level was significant, $\chi^2(65) = 96.95$, $p < .01$ and the ICC2 (.17) was adequate. The random effect for the intercept at the between-person level was also significant $\chi^2(18) = 71.04$, $p < .001$ with an adequate ICC2 (.72). For the routine patrol, the random effect was not significant, $\chi^2(49) = 48.88$, $p > .50$ at the within-patrol level and the ICC2 was inadequate (.003). Nevertheless, the random effect for the intercept at the between-person level was significant, $\chi^2(18) = 184.52$, $p < .001$ with an adequate ICC2 (.89).

These results indicate that it was appropriate to specify the within-patrol variables as potential predictors of both within-patrol and between-person variance in fatigue scores for both patrols. However, due to the low variance in fatigue scores obtained at the within-patrol level for the routine patrol, the within-patrol variables for this analysis would only be able to explain variance in fatigue scores at the between-person level. Similarly, the within-day variables would only be able to explain variance in fatigue scores at the within-day and between-person levels.

The Growth Models

The next models assessed the change in fatigue within and across days. This change was assessed by introducing linear and quadratic time of day variables as Level 1 predictors, and linear and quadratic time into patrol variables as Level 2 predictors. The results from these models are displayed in Step 1 of Tables 3 (non-routine patrol) and 4 (routine patrol).

First we will report the results relating to change in fatigue scores within days. The quadratic trend for time of day was significant in both the non-routine, b = .45, $t(116) = 6.41$, $p < .001$ and the routine, b = .15, $t(83) = 2.33$, $p < .05$, patrols. Consistent with theory and past research (Blake, 1967; Colquhoun, 1971), fatigue was high at midnight, started decreasing until noontime and then increased again (see Figure 1). Now we will report the results relating to change in fatigue scores across days. For the non-routine patrol, the linear trend for time into patrol was not significant, b = .09, $t(81) = .84$, $p = 0.40$, however the quadratic trend was significant, b = .12, $t(81) = 2.06$, $p < .05$. As seen in Figure 2, fatigue remained relatively constant across days 1-3, but increased across days 4 and 5. For the routine patrol, neither the linear, b = -.01, $t(65) = -.15$ $p = .86$, nor quadratic, b = -.15, $t(65) = -1.26$ $p = .21$, trends for time into patrol were significant. This suggests that fatigue did not change substantively across days in the routine patrol, which is consistent with the finding that there was little variance at the within-patrol level in this patrol.

The linear and quadratic trends for time into day and time into patrol accounted for an additional 46.90% and 12.11% of the within-day variability in fatigue scores for the non-routine and routine patrols respectively. These effects also accounted for 24.30% and 2.53% of the between-person variability in fatigue scores for the non-routine and routine patrols respectively[4].

The Final Models

The final models tested Hypotheses 1-3. The results from these models are displayed in Step 2 of Tables 3 (non-routine patrol) and 4 (routine patrol). Hypothesis 1 predicts that workload has a non-monotonic relationship with fatigue at the within-day level. This hypothesis was tested by specifying the linear and quadratic perceived workload variables as Level 1 predictors. In the non-routine patrol, the quadratic perceived workload variable was not significant b = 02, $t(113) = .74$, $p = .46$. However, this variable was significant in the routine patrol, b = .18, $t(81) = 2.83$, $p < .01$. As expected, low and high levels of perceived workload were associated with the highest fatigue, and moderate perceived workload was associated with the lowest fatigue (see Figure 3). Thus, Hypothesis 1 was supported for the routine patrol. Beyond the time of day variables, the perceived workload variables in the non-routine patrol accounted for 2.68% of the within-day variance in fatigue scores and 22.03% of the within-patrol variance. In the routine patrol, the perceived workload variables accounted for an additional 1.31% of the within-day, 20.15% of the within-patrol and 17.62% of the between-person variance in fatigue scores.

Hypothesis 2 predicts that the within-day relationship between workload and fatigue is negative during the afternoon but positive during the early hours of the morning. This hypothesis was tested by specifying time into patrol as a predictor of the perceived workload slope. A previous model indicated that this was appropriate for the non-routine patrol, because the random

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[4] It is fairly common for dummy-coded time variables to account for variance at a higher level. There are two potential explanations for these results. First, the reduction in variance at the between-person level can be a reflection of the fact that the strength of the effect of the time variables on fatigue is different for different people. Second, higher level variability in trajectory variables is often different to that assumed by the sampling model which can lead to mis-estimation of the intercept variance. However, in these cases the intercept variance is usually over-estimated (i.e., introduction of the trajectory variables usually increases rather than decreases the intercept variance; Hox, 2002), suggesting that the first explanation is the most likely in this case.

effect for perceived workload was significant at the within-patrol level, $\chi^2(11) = 21.33$, $p < .05$, and it had an adequate ICC2 (.08). However, this hypothesis could not be tested in the routine patrol because the model would not converge when the random effect of perceived workload was included. This is consistent with the finding that there was little variance at the within-patrol level in the routine patrol. In support of Hypothesis 2, there was a significant cross-level interaction between perceived workload and time into patrol, b = .19, $t(82) = 3.66$, $p < .01$ in the non-routine patrol. As predicted, there was a negative association between perceived workload and fatigue at the beginning of the patrol, whereas this relationship was positive at the end of the patrol (see Figure 4). Time into patrol accounted for 12.41% of the parameter variance around the perceived workload effect.

Hypothesis 3 predicts that the within-day relationship between workload and fatigue is negative during the afternoon, but becomes positive during the early hours of the morning. This hypothesis was tested by specifying the cross-product of workload and linear time of day as a level 1 predictor. The interaction between time of day and perceived workload was not significant for either patrol. Thus, Hypothesis 3 was not supported. The substantive results for hypotheses 1 and 2 remained the same when the time of day interactions were excluded, therefore, Tables 3 and 4 present the results relating to these more parsimonious models.

Discussion

This research assessed the within-person relationship between perceived workload and fatigue over time. There are two key findings from this research. The first relates to the non-monotonic relationship between workload and fatigue. The second relates to the within-person relationship between workload and fatigue across consecutive days of work. The implications of these results, in addition to study limitations will be discussed in the following sections.

The Non-monotonic Relationship between Workload and Fatigue

In the routine patrol, increases in perceived workload from low to moderate levels were associated with reductions in fatigue, whereas increases in perceived workload from moderate to high levels were associated with increases in fatigue. This finding demonstrates that the effects of overload and underload can be observed within the same individual over time. Previous studies have tended to focus either on overload or on underload, but not both (e.g., Galinsky, Rosa, Warm & Dember, 1993; Matthews et al., 2002). This finding supports theoretical arguments suggesting that there is an optimal level of workload (Hancock & Verwey, 1997; Hockey, 1997; Humphreys & Revelle, 1984). These theories assume that increases in workload from low to moderate levels produce increases in arousal, which are energizing. As workload approaches the individual's capacity limit, the individual needs to compensate by consciously applying effort. This may involve reallocating resources across tasks or changing strategy. These self-regulatory activities are assumed to deplete energy levels, and produce fatigue.

The Relationship between Workload and Fatigue within and Across Consecutive Days of Work

The non-monotonic effect of workload was not significant in the non-routine patrol; however it was qualified by an interaction between perceived workload and day of the patrol. Fatigue was associated with low workload at the beginning of the patrol, but high workload by the end of the patrol. Inspection of activity logs suggest that the low workload periods primarily involved vigilance tasks such as look-out duties on the bridge, monitoring of equipment in the engine-room and navigation tasks such as plotting updated vessel positions on charts. During high workload periods, crewmembers conducted demanding drills and exercises, such as responding to simulated power failures, emergencies (such as floods and fire), man-overboard and boardings. We expected that, at the beginning of the patrol, crewmembers would experience less fatigue when conducting these types of demanding tasks than when conducting the less demanding vigilance tasks, because crewmembers should have responded to increases in work demands with increases in arousal. This increased arousal should have given them the energy to cope with these periods of high workload without feeling drained. We expected the opposite pattern to emerge at the end of the patrol because arousal levels are assumed to flatten over time in response to partial sleep deprivation, making crew members less responsive to external stimulation (Dinges et al., 1997). The crewmembers were working on rapidly rotating shifts, which were disrupted by exercises and drills. As a result, it is likely that they had accumulated a sleep debt by the end of the patrol. Indeed, fatigue increased across days 4 and 5 in this patrol. If the arousal response is flattened, then the same amount of work will need to be completed with fewer resources, making it necessary to apply compensatory effort. Thus, work that was energizing at the beginning of the patrol may become fatiguing at the end.

The interaction between perceived workload and day of the patrol could not be tested in the routine patrol because the model would not converge. A likely statistical explanation for this finding is that fatigue did not increase over days in the routine patrol. Indeed, there was practically no variance at the within-patrol level in this patrol (.10%). In comparison with the non-routine patrol, activity logs from the routine patrol reflected a relatively uneventful cruising patrol. Crew spent most of their watch keeping duties on routine activities such as the vigilance and monitoring tasks mentioned above. Drills and exercises were only presented occasionally when compared to the non-routine patrol. In line with our earlier speculations, the finding that the interaction between workload and consecutive days of work was only evident in the non-routine patrol may reflect the different nature of the two patrols. That is, although there was some variability in task demands throughout the day in the routine patrol, it makes theoretical sense that fatigue was relatively stable across days in this patrol because the demands were less variable across days. It also makes theoretical sense that the interaction effect was observed in the non-routine patrol, but not in the routine patrol, because the demands were higher in the non-routine patrol and there was less opportunity for recovery.

It is interesting that the relationship between perceived workload and fatigue changed over consecutive days rather than within days. In principle, either effect could have been observed. Fatigue levels did vary cyclically over the 24-hour period in line with the circadian rhythm, showing that the fatigue measure was sensitive to time of day effects. The most parsimonious explanation is that time of day and workload have an additive rather than an interactive effect on arousal. If so, then the point at which the individual has to compensate for increases in workload by applying effort should remain constant across the 24-hour cycle, and the relationship between workload and fatigue would not change within days. Over consecutive days, however, it appears that the individual's threshold for applying effort lowers, making the individual increasingly more sensitive to work overload.

Practical Implications

These findings may have practical implications. In general, the results suggest that individuals should be assigned tasks that they perceive as moderately demanding, because both overload and underload can be fatiguing. However, there may be times when high or low workload is optimal, particularly if the individual has been working a number of days with limited opportunity for recovery, as often occurs when working on a shift roster. At the beginning of a work session, when energetic resource capacity is presumably high, employees should be able to deal with highly demanding tasks. As energetic resources become depleted over consecutive days, employees may benefit from being assigned less demanding tasks.

Limitations

There are a number of potential limitations of the current study. First, the sample size at the between-person level (N = 20) may appear small. However, the focus of this study was on processes that operate within individuals over time. The sample size at the within-day and within-patrol levels was large enough to detect moderate effect sizes (Cohen, 1992). Related to this point, the use of growth curve modeling increased analysis sensitivity, as this technique enables studies of time variant phenomena to be conducted reliably with a relatively small sample size (Goldstein, 2003).

Second, we do not know whether the results will generalize beyond the navy patrol vessel context. The results may generalize to other domains in which work-rest patterns provide for inadequate recovery across consecutive shifts or days such as other defence force operations, or operations within the maritime, mining, aviation, manufacturing and health industries.

Third, the current study relied on self-report measures of workload and fatigue, which may have introduced the problem of common method variance. Response bias may have produced individual differences in the average level of self-reports, resulting in a spurious correlation between these two variables at the between-person level of analysis. However, common method variance is considered to be less of a concern at the within-person level (Beal, Weiss, Barros & MacDermid, 2005; Zohar, et al., 2003) because the multilevel structure controls for individual differences in response bias. Further, complex patterns of the type demonstrated in the current study are unlikely to be caused by common method variance (Evans, 1985). Another issue to consider is that self-reports are subjective perceptions, and as such may not be an accurate reflection of the actual states. Thus, for example, we do not know whether changes in objective workload would produce the same effects as changes in perceived workload.

Finally, the current analyses do not allow us to draw strong inferences regarding the direction of causation. We are a step closer to drawing causal inferences, by comparison to studies that have analyzed data at the between-person level at a single point in time. However, establishing the direction of causation is difficult, because theory suggests that the relationships among workload and fatigue are reciprocal (Hockey, 1997). It is possible that changes in fatigue produce changes in perceived workload. Disentangling the operation of reciprocally interdependent processes over time is a complex endeavor, and is something that may be easier to achieve in a controlled laboratory setting than in the field.

Conclusion

This research has contributed to understanding of the dynamic relationship among psychological states and fatigue. The documented effects of fatigue on impairments to health and wellbeing (Meijman & Mulder, 1998) underscore the importance of identifying when potential risk factors are likely to exert their effects. Drawing on cognitive-energetical theories, we developed a model of the temporal processes that may produce changes in the relationship between workload and fatigue over time. Our results suggest that the optimal level of workload can change over time. In a context where personnel were working rotating shifts, our findings suggested that underload can be fatiguing at the beginning of a work period, whereas overload can become fatiguing after a number of days. These results have implications for the management of fatigue in work settings, particularly where prolonged operations of work are involved.

Acknowledgements

The authors would like to express their gratitude to the Maritime Platforms Division of the Defence Science and Technology Organisation (DSTO) in Australia for funding this project.

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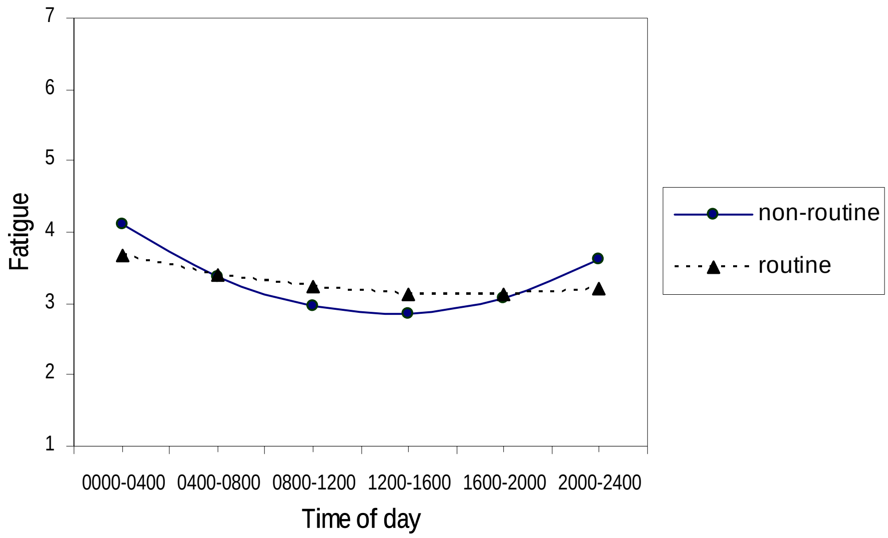
Figure Captions

Figure 1. Non-routine and routine patrols: Curvilinear relationship between time of day and fatigue.

Figure 2. Non-routine patrols: Curvilinear relationship between time into patrol and fatigue.

Figure 3. Routine patrol: Curvilinear relationship between workload and fatigue.

Figure 4. Non-routine patrol: The cross-level interaction between workload and time into patrol on fatigue.



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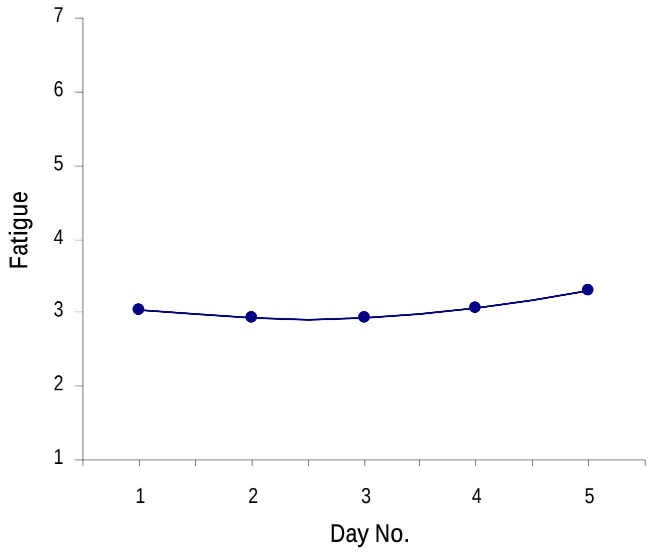
Time of day
non-routine
routine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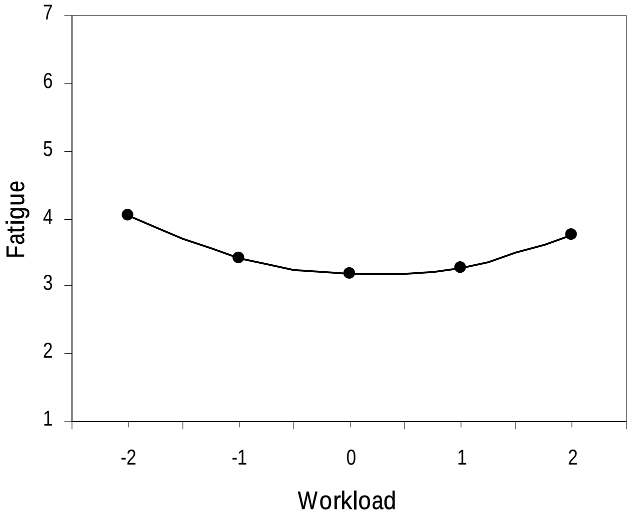
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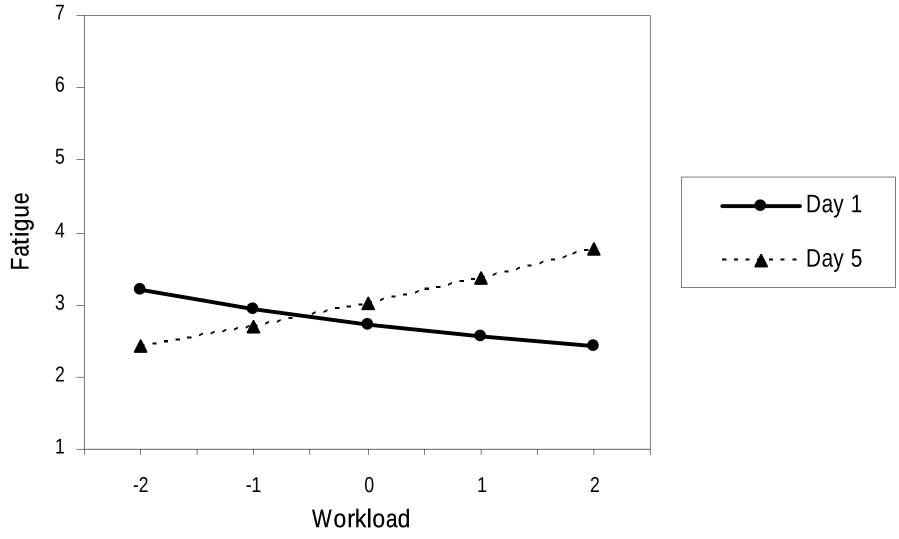
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Table 1.

Descriptive statistics and inter-correlations among the variables at the within-day level for the non-routine (N=122) and routine (N=88) patrols.

Variable	Level 1 (within-day)							
	Non-Routine Patrol				Routine Patrol			
	M	*SD*	1	2	*M*	*SD*	1	2
1. Fatigue	3.48	.92			3.37	1.12		
2. Time of day	-	-	-.22*		-	-	-.16	
3. Workload	2.68	.73	.001	.03	2.45	.83	.21*	-.16

$^{*}p < .05$

Table 2.

Descriptive statistics and inter-correlations among the variables at the within-patrol level for the non-routine (N=100) and routine (N=80) patrols.

Variable	Level 2 (within-patrol)							
	Non-Routine Patrol				Routine Patrol			
	M	*SD*	1	2	*M*	*SD*	1	2
1. Fatigue	3.48	.79			3.27	1.00		
2. Workload	2.68	.62	.04		2.45	.73	.22*	
3. Time into patrol	-	-	.18	-.02	-	-	.10	.10

* p < .05

Table 3.

HLM Results for the Non-routine Patrol

Variable	Coefficient	*SE*	*t*	Coefficient	*SE*	*t*
	Step 1			Step 2		
Intercept, π_{0i}						
Intercept, β_{00}	2.93***	.15	20.21	2.87***	.15	18.54
Time into patrol, β_{01}	.09	.11	.84	.10	.08	1.25
Quadratic time into patrol, β_{02}	.12*	.06	2.06	.13	.07	1.97
Time into day, π_{1i}						
Intercept, β_{10}	-.15*	.07	-2.23	-.17**	.07	-2.64
Quadratic time into day, π_{2i}						
Intercept, β_{20}	.44***	.07	6.41	.47***	.07	6.86
Workload, π_{3i}						
Intercept, β_{30}				.07	.07	1.04
Time into patrol, β_{31}				.19**	.05	3.65
Quadratic workload, π_{4i}						
Intercept, β_{40}				.02	.03	.74

* $p < .05$ ** $p < .01$ *** $p < .001$

Table 4.

HLM Results for the Routine Patrol

Variable	Coefficient	*SE*	*t*	Coefficient	*SE*	*t*
	Step 1			Step 2		
Intercept, π_{0i}						
Intercept, β_{00}	3.31***	.24	13.60	3.17***	.22	14.21
Time into patrol, β_{01}	-.01	.07	-.15	-.02	.07	-.24
Quadratic time into patrol, β_{02}	-.15	.12	-1.26	-.17	.12	-1.44
Time into day, π_{1i}						
Intercept, β_{10}	-.17	.11	-1.60	-.16	.11	-1.47
Quadratic time into day, π_{2i}						
Intercept, β_{20}	.15*	.06	2.33	.13*	.06	2.03
Workload, π_{3i}						
Intercept, β_{30}				-.07	.12	-.60
Quadratic workload, π_{4i}						
Intercept, β_{40}				.18**	.06	2.83

* $p < .05$ ** $p < .01$ *** $p < .001$