Why does work cause fatigue? A real-time investigation of fatigue, and determinants of fatigue in nurses working 12 hour shifts.

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Abstract

Background.

One of the striking regularities of human behaviour is that a prolonged physical, cognitive or emotional activity leads to feelings of fatigue. Fatigue could be due to: (1) depletion of a finite resource of physical and/or psychological energy or (2) changes in motivation, attention, and goal-directed effort (e.g. motivational control theory).

Purpose. To contrast predictions from these two views in a real-time study of subjective fatigue in nurses while working.

Methods. 100 nurses provided 1453 assessments over two 12-hour shifts. Nurses rated fatigue, demand, control, and reward every 90 minutes. Physical energy expenditure was measured objectively using Actiheart. Hypotheses were tested using multilevel models to predict fatigue from a) the accumulated values of physical energy expended, demand, control and reward over the shift and b) from distributed lag models of the same variables over the previous 90 minutes.

Results Virtually all participants showed increasing fatigue over the work period. This increase was slightly greater when working overnight. Fatigue was not dependent on physical energy expended nor perceived work demands. However, it was related to perceived control over work and perceived reward associated with work.

Conclusions. Findings provide little support for a resource depletion model; however, the finding that control and reward both predicted fatigue is consistent with a motivational account of fatigue.

Key works: fatigue, ecological momentary assessment, control, reward, resource depletion, motivation

One of the striking regularities of human behaviour is that a prolonged period of demanding physical, cognitive or emotional activity leads to feelings of fatigue. This phenomenon is mundane, universally accepted, and central to some current models of fatigue (1, 2) but often unremarked. Indeed, Hockey (2), in the most comprehensive review of fatigue published for many decades, states that he will "not review the evidence on subjective fatigue since it all points in one direction, increasing with time on task"(p. 58). Fatigue (and time on task) reliably leads to diminished performance in laboratory studies ranging from the classic early studies of complex mental arithmetic (3, 4) to more recent studies using computerised tasks and simulated office work (5, 6, see 2 for a review) and to increases in the likelihood of accidents and errors at work (7, 8).

As Hockey (2) discusses at length, fatigue is challenging to define. Most agree that fatigue relates to a deterioration of some aspect of behaviour with some emphasising the performance decrements (Bartlett, 1953 quoted by Hockey, 2), and others the subjective or mental experience of fatigue (9). In this paper we focus on subjective fatigue which is typically characterised by 'subjective feelings of tiredness and disinclination towards activity' (9), although most studies of subjective fatigue, including this one, focus on tiredness-related moods. For example, Hockey and Earle (5) obtained self-ratings of "fatigued", "tired", (not) "alert" and (not) "energetic", and Hulsheger (10) used four fatigue items from the Profile of Mood States (11): "fatigued", "tired", "exhausted" and "spent". We are explicitly examining acute subjective fatigue that we anticipate will increase over the work period.

Fatigue occurs frequently in the workplace setting with between 23% and 40% of workers (12, 13) reporting high levels of fatigue in the previous 2 weeks. In the health care professions, fatigue is higher than in the general population and varies between the different occupational groups with nurses and doctors having higher levels of fatigue than health service managers and administrative staff (14). Nurses exhibit moderately high levels of both chronic and acute fatigue, and poor recovery between shifts (15, 16).

There are few real-time, rather than retrospective, studies of fatigue in the workplace. Hulsheger (10) examined subjective fatigue in a convenience sample over 5 working days. Fatigue decreased slightly during the morning then increased throughout the remainder of the day. When researchers have attempted to track fatigue in real time, the evidence for theoretical determinants of fatigue has been unclear. While workloads were related to fatigue in naval crews (17), work demands were not related to fatigue in a study of nurses (18).

There are essentially two types of explanation for normal (i.e. non-clinical) fatigue. One view emphasises the depletion of a finite resource of physical and/or psychological energy needed to maintain performance (19) while the other focuses on progressive reductions in motivation associated with emotion, goals, rewards and effort (2). The present paper contrasts predictions from these opposing theoretical views in real time in a sample of 100 nurses as they become fatigued over the course of two 12-hour shifts. This is not simply of theoretical importance. It also has practical significance as fatigue within healthcare staff is associated with errors and accidents which may threaten patient and staff safety (8).

The view that resources become depleted over time is represented in the current psychological literature by Baumeister's ego depletion theory of self-control (19). Numerous studies (20) appear to demonstrate that expending cognitive effort on tasks involving self-control, such as choosing to consume a less-preferred but healthier food option (21) leads to poorer performance on subsequent tasks, such as endurance on a hand grip task or persistence on an impossible problem-solving task. The ego depletion hypothesis is attractive but the actual evidence base for depletion effects has been increasingly challenged, especially by a recent series of meta-analyses (22) and a substantial registered replication report (23) which failed to find depletion effects. However, in the context of fatigue, the explanatory models go beyond ego depletion effects on self-control and refer instead to the impact of a wider range of more general psychological and physical energy resources on subjective experience of fatigue.

Motivational views of fatigue are widely held. Perhaps the most consistent modern proponent has been Hockey who, in a series of papers over two decades, proposes a complex model in which subjective fatigue is part of a control mechanism that monitors and controls the effort put into a task (2). In Hockey's motivational control theory of fatigue, as people expend effort on tasks they "have to" perform (e.g. paid work), increasing feelings of mental fatigue prompt a cost-benefit analysis where either (a) continued effort on the current task persists, as it is deemed worthwhile given expectations of appropriate reward or negative consequences of not continuing, or (b) effort and attention is diverted elsewhere (goals are altered) towards tasks with greater utility (more benefits, less costs). Related motivational models have been proposed by Inzlicht et al. (24) and Kurzban, Duckworth, Kable, & Myers (25). The main contrast between the two types of explanation of fatigue is that the resource models explain fatigue in terms of reduction in the availability of (psychological and physical) resources, while motivational models of fatigue posit that changes in motivation alter the deployment of available resources.

Distinguishing between the resource and motivational theories of fatigue is vital both scientifically and in terms of application as the two views have very different implications for intervention. For example, while a resource model might suggest that rest would restore resources and therefore reduce fatigue, a motivational model would suggest that increasing reward (to increase motivation) would likely be a more effective way to reduce the effects of fatigue; or increasing the worker's control over their work might allow them more flexibility to shift attention and effort to more rewarding aspects of the work when experiencing fatigue. Across both resource-depletion and motivational accounts of fatigue, theories of work and coping would propose that demand and effort may increase fatigue. For example, a depletion account would predict that as effort increases, fatigue will also increase as resources become depleted. Inzlicht et al.'s (24) motivational model would also propose that continuous effort increases fatigue but by reducing motivation for the current goal and directing attention and efforts toward a different goal. However in a work context, the worker often does not have the option of diverting effort to a different goal other than by withdrawing from work. One might expect, if the motivational account is correct, that perceived rewards or feelings of control would mitigate the effects of continuous effort and result in less fatigue. By contrast, neither control nor reward should affect resource availability directly, so, within a finite resource model, these cognitions should have little effect on fatigue.

In the present paper we test these opposing predictions in a real-time study of fatigue and its possible determinants in a dataset derived from 100 nurses delivering health care over the course of two 12 hour shifts. Nursing is an occupation where shifts are long, work is complex, psychologically and physically demanding and where optimal performance is important. Consequently it provides an ideal setting in which to empirically contrast different models of fatigue. The resource model is tested by examining the effects of objectively measured physical energy expenditure and perceived work demand on fatigue. Evidence that bears more clearly on the motivational model is obtained by examining the predictive effects of perceived reward and control on fatigue.

We examine the changes in fatigue over time to confirm that fatigue increases over the work period but additionally we examine whether that is true for all, or even most, individuals. We then examine the following research questions based on the dominant models of fatigue, a finite resource model and a motivational model.

To test the finite resource model, subjective fatigue in nurses over the work shift will be predicted from

1. Physical energy expended: a resource model would predict that fatigue should increase as the amount of physical effort expended increases
2. Perceived work demand: a resource model would predict that fatigue should increase as perceived demands increase.

To investigate the motivational model, subjective fatigue in nurses over the work shift will be predicted from;

3. Perceived reward: a motivational model would predict that fatigue should decrease as perceived rewards increase.
4. Perceived control over work: a motivational model would predict that fatigue should decrease as freedom to pursue alternative goals increases.

Method

A full protocol for the study methods has been published previously (26) and a test of models of occupational stress reported in a later paper (25). The study was approved by NHS North of Scotland Research Ethics Committee (10/S0801/87) in January 2011 and data collected between September 2011 and January 2013.

Study overview. Nurses from medical and surgical wards completed initial questionnaires and wore an activity and heart rate monitor to assess physical energy expenditure for the duration of their participation in the study. They completed real-time ecological momentary assessment (27) items assessing fatigue and hypothesised determinants using electronic diaries every 90 minutes over two 12-hour working shifts. While 28 of the nurses provided consecutive shifts, the time between shifts varied by up to 54 days. Eighty one of the nurses were assessed only on day shifts, 19 night shifts only, and 10 both day and night.

We examined the course of fatigue over the working day and the generality of these effects within and between people, as well as the determinants of fatigue. Individuals may be fatigued both because of the immediately preceding activities and because of the build-up of effects due to activity sustained over some time, perhaps the whole working day if there has been little opportunity for rest and recovery. However, as cumulative effects may be dissipated by rest, both immediate and cumulative approaches are required. It is therefore necessary to examine both effects: first by accumulating the putative determinants of fatigue (i.e., physical energy expended, demand, reward and control) over the work period and second by examining the effects of the immediately preceding period of assessment in what is called a distributed lags model (28). The distributed lagged models are dynamic and can allow for restorative processes but are limited in the time span they can deal with (approximately 90 minutes prior to the current assessment of fatigue in this study).

Participants and Recruitment

All qualified nurses on medical and surgical wards with at least 20 nurses at a large UK teaching hospital were eligible to participate and were recruited via advertisements posted on ward noticeboards. A maximum of 10 nurses per ward were recruited to ensure adequate coverage of wards. The total number of nurses on the recruiting wards was 425 of which we recruited 100, as required by a power analysis directed at our primary research questions concerning the stress associated with specific nursing tasks (see study protocol, (26)). Nurses who expressed an interest in participating received an information pack and those who chose to participate returned a signed consent form. Nurses received a £25 voucher for a major store on completion of the study.

Measures

Physical Energy Expenditure (measured continuously). Participants wore ambulatory heart rate and activity monitors (Actiheart, Camntech Ltd, Cambridge, UK) throughout 2 shifts. Physical Energy expenditure was calculated from combined heart rate and activity data from a chest mounted uniaxial accelerometer using published equations (29). This provides a valid and widely used measure of physical energy expenditure which several studies have successfully validated against indirect calorimetry in laboratory (30) and field (31) settings. Actiheart software operates on 15-second epochs with artefacts detected in a standard multi-stage process (32) as follows. First individual heart beats of exactly 2000ms (the longest inter-beat interval stored and indicating a missed beat) are rejected, as are beats that differ from the preceding beat by more than 20 times the average difference in the epoch. The last 16 good inter-beat intervals are then averaged and any that are outside +/- 25% of this average are removed and the remaining inter-beat intervals re-averaged and converted to beats per minute. In addition, all 1-minute means below 40 bpm or above 170bpm were excluded. The data were of high quality and only 0.01% of 1-minute means were rejected.

Fatigue and Perceptions of Work (EMA measures taken repeatedly in real time). Measures of fatigue and perceptions of work (demand, control and reward) were completed on an electronic diary using PDAs (Dell Axim 51, Round Rock, TX, USA) every 90 minutes, on average, over 2 shifts. [Full details of the measures with screen grabs of the diary are available in the online supplementary material.] The diary measures were developed and delivered using Pocket Interview software (33). Data entry was prompted by an audible alarm that sounded for 8 seconds approximately every 90 minutes during the shift (with a window of +/- 15 minutes determined randomly). If a participant did not respond within 2 minutes the alarm sounded again and this continued for a maximum of 10 cycles. If the participant did not respond then the device closed down until the next scheduled alarm occurred. The participant could postpone ("snooze") an alarm for up to 60 minutes if it occurred at a time when it was not possible to make a diary entry.

Fatigue. Four high loading items from the energetic arousal scale of the UWIST mood scale (34) were summed to assess fatigue (alert, energetic (both reverse scored), tired, sluggish). These factor analytically derived items (34) are similar to those used in other measures of subjective fatigue (5, 10) that have been shown to have convergent and divergent validity. Participants rated fatigue items "now" on visual analogue scales labelled 'no' to 'yes' scored from 0 to 100. High scores indicate high fatigue. The between and within person reliabilities were calculated using established procedures (35). The between person reliability was calculated as the average over the 2 shifts. The reliabilities in this study were: between 0.98, within 0.65 which are considered satisfactory for this type of measurement (36).

Perceptions of work: demand, control and reward were each assessed using analogue scales (no – yes) scored in the same way as the fatigue items and, for demand and control, binary items based on standard questionnaire measures (37). The different type of scales were used to reduce common method variance. The five binary items assessing demand asked participants to rate the extent to which; they had to "work fast", "work hard", "do too much", "were interrupted" and "had enough time available to complete tasks". The three control items asked whether "work required a high level of skill", whether "they were allowed a lot of say in what they did", and were "allowed to make the main decisions about what they did". Reward was assessed by one analogue scale (work has been rewarding, no-yes) and three binary ones – reflecting the extent to which work was perceived to be "valued", "appreciated" and "respected". In all cases higher scores indicated greater demand, control etc. The analogue items were rescored from 0 to 1 to give them comparable weight to the binary items. Items were summed within categories. The reliabilities were: demand: between 0.96, within 0.77; control: between 0.88, within 0.45 and reward, between 0.94, within

0.85. Control, within person, was less reliable than the other measures. Examination of the inter-item correlations indicated that the item “work required a high level of skill” was negatively correlated with the other control items between people and uncorrelated with the other control items within people. The skill item was removed, and the within-person reliability was slightly improved to 0.50.

Procedure

A member of the research team met the participating nurse on the ward before the start of each shift (i.e., at either 7 am or 7 pm) and equipped them with the Actiheart device using Ambu Blue Sensor-R electrodes, following the procedures recommended by the manufacturers (32). In advance the nurses were given a training booklet explaining how they were to categorise nursing tasks (these data are not reported here) and trained immediately before the first session on completion of the electronic diary. They were then given a pre-programmed electronic diary, completed the rest of their shift as usual (making diary entries when prompted to do so) and were met by the researcher at the shift end for equipment retrieval.

Statistical Analyses

Data scoring. Before integrating the physical energy data over time to achieve a score of accumulated physical energy expended, all missing values were replaced by the average value for that shift. This simple procedure was used as missing values were rare (only 1309 of the over 1.2 million measures of physical energy expended) and physical energy expended did not vary systematically over the shift. The physical energy expended was accumulated on a minute by minute basis. The minute values were accumulated up to that moment to give accumulated physical energy expenditure. The current value of physical energy expended was taken as the average since the last diary entry. Perceptions of work (demand, control, reward) were also scored to give current response and accumulated predictors. Missing values were rare (1.5%) and are dealt with by the maximum likelihood methods used in multilevel modelling.

Fatigue over time. All analyses were based on a 2 level model nesting observations over time within participants. The changes in fatigue over time were tested in a model with intercept, shift (first or second), day versus night shift, time into shift and the interaction of time with day versus night shift. The intercept was allowed to vary at all levels, shift was fixed and the model allowed the time effect, day versus night and the interaction to vary at the person level.

Predicting fatigue from accumulated determinants. The effects of the accumulated determinants were tested in a 2-level model nesting observations over time within participants. The model consisted of fatigue as the dependent variable and the predictors being the intercept, shift, time (into the shift), and the accumulated value of the predictor at that time. Time was included in the model since fatigue increases over time and the accumulated values of the predictors will inevitably be highly correlated with time. This confound must be allowed for to obtain realistic estimates of the extent to which the accumulated predictor relates to fatigue. Since the increase in fatigue is slightly greater at night (see results section) this was also allowed for in the model. The intercept was allowed to vary at all levels. Shift was treated as fixed. Time varied at the person-level as did the theoretical predictors. Day versus night and the interaction were fixed. If there were convergence problems then time was always allowed to vary randomly at the person level, as were as many of the theoretical predictors as possible for maximal random effects (38). This is the most conservative way of testing the predictors.

Predicting fatigue dynamically from lagged values of determinants. The effects of the current or immediately preceding theoretical determinants of fatigue were tested with what are termed distributed lag models in econometrics (28) in which the value of the predictor at lag1 (90 minutes previously) was included in the model. These models included the intercept, shift and time into the shift, day versus night shift and the interaction all treated as described above. The additional predictors were fatigue at lag1 (i.e. at the previous diary entry), the current value of the predictor and the predictor at lag1. Fatigue at lag1 was included in the model to ensure that relationship between the predictor at lag1 and fatigue was independent of the relationship of fatigue and predictor 90 minutes previously (a likely problem with an autocorrelated dependent variable). As many of the theoretical predictors as possible were allowed to vary randomly at the person level. All analyses were carried out using MLwiN v2.36 (39). The alpha level was set at p<.01.Variance explained was used to indicate size of effects using recently developed methods (40, 41).

Results

Diary entries plus Actiheart data were obtained from all 100 nurses, over 193 shifts. The sample was comparable to the total workforce on the wards sampled in terms of age and years since qualifying but contained slightly more men (7 out of 100) compared to the 3.5% of the population sample, see Table 1 for details. Seventy five percent of participation shifts (147) were day shifts and 4% (8) were at the weekend.

Diary completion rate was excellent: Overall 1453 (98.5%) out of a possible 1476 diary entries were completed. The diary was opened with a median delay of 30 seconds and completion of a complete diary entry (including items not reported in this paper) took a median time of 148 seconds with an inter quartile range of 86 seconds. Three hundred and fifty nine (25%) entries were snoozed and the modal snooze time was 10 minutes.

The average values of fatigue and the predictor variables are shown in Table 2. It is clear that there is substantial variation in the measures, indicating that range restrictions are unlikely to reduce the opportunity to demonstrate predictive relationships if they exist.

Does fatigue increase over the working day? In Table 3, nested multilevel models are shown: a fixed linear model, a fixed quadratic model and, finally, a model in which the effects of time were allowed to vary randomly at the level of the participant. The differences in fatigue on day and night shifts are examined as well as the interaction of day versus night with time. Only the interaction with the linear effects of time are presented. Allowing for a quadratic effect of time in interaction with day versus night shifts did not improve model fit. It is clear from Table 3 that fatigue increases over the shift and that the best fitting model is quadratic. The quadratic model had a significantly better fit (X^2= 38.22, *df* 1, p <.001,) than the linear and this was markedly improved when the slopes were allowed to vary randomly between participants

(X^2= 141.19 df= 14, p <.001). The total variance explained by the final model was 70.22% with time and the differences between day and nightshifts accounting for 24.3%. The full model shows that there is an interaction between day versus night shift and time into the shift. As shown in Figure 1a, after a very slight decrease there is little increase in fatigue for the first 4 hours of the shift then a considerable increase for the remaining time. The day and night shifts start with comparable fatigue but the night shift shows a greater increase in fatigue over the work period. The spaghetti plots in Figure 1b and 1c show the results for the individuals. The differences in the effect of time are marked between people (with significant random slopes and a substantially better model fit) so some people become much more fatigued than others over the work period, indeed some show diminishing fatigue initially but almost everyone displays an increase by the end of the shift, even those who start the shift with high levels of fatigue. In Figure 1c the intercept (time into shift=0) is fixed to show the differences over time within individuals more clearly. The regularity of the predicted values is striking. It is difficult to estimate the number who display increasing fatigue when the quadratic model is fitted. However if the simpler linear model is fitted to enable estimation, 90% of this population would be expected to show an increasing trend.

Is fatigue predicted by physical energy expended? It is clear from Table 4 (first column) that fatigue was not consistently related to accumulated physical energy expended (fixed effect). The random slopes effect was significant indicating that individuals differed in their relationship between physical energy expended and fatigue. This effect is shown in Fig2a, with the intercept fixed to ease visualisation. Some individuals showed increasing fatigue as physical energy expenditure increases while others show the opposite. The full model explained 80.35% of the variance with the random slopes explaining 10.1%. Table 4 also shows results for the distributed lag model, i.e. the effect of physical energy expended over the preceding ~90 mins, allowing for fatigue scores on the previous diary recording. It proved difficult to get stable models if the quadratic effect of time was included in the distributed lag models so the results are based on only the linear effects of time in all the distributed lag models. Neither current physical energy expended nor physical energy expended at lag 1 related to fatigue.

Is fatigue predicted by subjective ratings of demand? It can be seen in Table 4 (second column) that fatigue was unrelated to current demand, accumulated demand or demand at lag1 (fixed effect). The effects of accumulated demand and current demand varied randomly at the person level suggesting that in some people demand was associated with more fatigue, in others less. The accumulated demand results for individuals are shown in the spaghetti plot in Figure 2b which shows both positive and negative relationships occurring, i.e., demand can be fatiguing or energising. This effect explained 2.2% of the variance in fatigue.

Is fatigue predicted by reward? Accumulated and lagged reward both relate reliably and negatively to fatigue, i.e. reward is associated with reduced fatigue (Table 4, third column, fixed effects and Figure 2c). Accumulated reward explained 2.0% of the variance while reward at lag1 (while significant) explained only 0.8%

Does greater control over work predict less fatigue? Table 4 (fourth column, fixed effects) shows that greater control accumulated over the work period was associated with less fatigue (see also Figure 2d), however the effects at lag1, while in the expected direction, were not statistically significant (p =.08). Accumulated control explained 5.9% of the variance.

Discussion

In this real-time study of nursing work as it unfolds across the day, subjective fatigue increased over a 12-hour shift in virtually all of 100 nurses studied while they cared for patients. The energy expended over the shift (i.e. physical effort exerted) did not relate consistently to fatigue nor did the perceived demands the nurse had experienced. However both perceptions of reward accumulated over the whole shift and 90 minutes earlier predicted fatigue. Accumulated control was also associated with reduced fatigue. Taken together, these results support a motivational, as opposed to a resource depletion account of fatigue.

On average there was little increase in fatigue over the first 4 hours of the shift, then it increased markedly, approximately doubling by the end of the shift. Previous studies of fatigue have also shown an increase in fatigue over time (4, 42) but these have mainly, but not exclusively (e.g. 43) involved laboratory tasks or simulations of real life tasks such as driving or flying. In addition they have not reported the results for individuals. A most striking feature of the present data is its regularity. Fatigue increased systematically in virtually everyone and while it did not necessarily increase monotonically, as expected most people were more fatigued at the end of the shift than the start. In addition fatigue increased to a slightly greater extent when nurses were working a night shift. Individual regression lines, shown in the spaghetti plots (Figures 1b and c) confirm this. Hulsheger (10) recently also found a quadratic trend for fatigue in a study with only four measures during the day and including both time at home and at work. Hulsheger does not comment on the pattern for individuals but did find the quadratic trend was primarily present in participants who started the day fatigued after a poor night's sleep. These findings may not be surprising since most authorities assert that fatigue increases with time on task (2, 44) but the transfer of a phenomena from controlled laboratory conditions to real life is noteworthy, especially as ecological momentary assessment studies show that nursing is a varied and engaging activity (45): both factors that are believed to counteract fatigue (2, 44).

Nurses spend a lot of time standing and performing activities that require physical effort. The literature suggests that physical effort is not a major contributor to subjective fatigue (2) and that even physical fatigue has a large psychological component, as the early ergometer studies showed (see 46). Nevertheless, resource depletion models would predict that nurses who have more active days will experience more fatigue either because of the direct effects of physical activity or because such activity reflects a more demanding and effortful day, leading to large depletions in available resource. This was not the case in the present study. The energy expended over the shift, as assessed by a measure of accumulated physical energy expenditure, did not relate to fatigue nor did physical energy expenditure immediately preceding the fatigue assessment (i.e. the distributed lag model). This null result is unlikely to be due to problems with the measurement of physical energy expenditure as the measure used is a reliable and validated method using both heart rate and activity, the data obtained were of high quality and related meaningfully to what the nurses were doing (47). Further, it was not due to restricted variance in the measures, as nurses differed markedly in their accumulated physical energy expenditure across the shift. Energy expended during a shift might still be replenished by breaks and consumption of food and drink and this is examined in the dynamic distributed lag model. In neither case did physical energy expended earlier in the shift reliably predict future fatigue. Instead, participants differed in the relationship between physical energy expended and fatigue with some apparently energised and some fatigued by expending energy.

Perceived demands were also unrelated to fatigue in either accumulated or distributed lag analysis even though participants differed greatly in their perception of demand across the working day. The absence of an effect of demand is surprising since theorists suggest that high persistent demand should lead to fatigue, probably because of the effort involved in meeting demand (2). In other studies (18, 48) we have argued that demand can have a positive or negative effect, perhaps because it can be both energising and tiring in different people or in different situations or times. This was also seen in this study since allowing accumulated demand to vary randomly between people added to the predictive power of the model and as, with energy expended, while many showed no relationship some showed increasing fatigue with increasing demand and some showed the opposite. The relationship between current level of demand and fatigue also differ between people in a similar way. These findings provide little or no support for a resource depletion model of fatigue: most nurses did not show increased fatigue as physical energy was used or demand increased and some even showed diminished fatigue.

Reward had a straightforward relationship to fatigue and was associated with reduced fatigue, a finding compatible with a motivational but not a resource model and thus more in line with Inzlicht, et al., (24) or Hockey's (2) motivational control model than a resource depletion model (19).

Perceptions of control related to fatigue with control accumulated over time being associated with less fatigue. This supports a motivational model. This may be because control allows nurses to choose how to direct their attention as Hockey suggests and to choose rest times or to select when to do each task within the limits of flexibility of the role, thus mitigating effects of fatigue. Current and accumulated control were both beneficial but control at lag1 was not reliably related to subsequent fatigue. It would appear that sustained or current control is beneficial but past, possibly brief, episodes may not be. However, the latter result may also be because control was a less reliable measure than the others used in this study.

While these results on reward and control in general support a motivational model (2, 24, 25) the variance explained by reward and control is small in comparison to the substantial effect of time. Time at work remains a substantial predictor of increasing fatigue but it is challenging to find an adequate explanation. Why does time in work have such a dominating effect on fatigue when fatigue is unrelated to the effort expended over the course of time? Is it the inevitable result of time awake? The time effect allows prediction of when one might be fatigued but not why one is fatigued. It may be that the consistency of the effects of fatigue over time reflects expectancy effects, i.e. that nurses expect to be tired after several hours at work. However the individual results do not support this account: although the data is systematic it does not show a monotonic increase in fatigue over the shift and there is considerable between-person variation in the rate of increase of fatigue. Similarly, an early study of fatigue over different lengths of nursing shift indicated that fatigue reported was similar at the end of 8-hour and 12-hour shifts, counteracting the possibility of a fatigue-expectancy effect (49).

These results also suggest that in practical situations such as nursing it may be possible to mitigate fatigue and the effects of fatigue without reducing the demands and physical energy required to complete the tasks. Interventions might be directed at the worker's motivation rather than altering the actual work. Since fatigue is greatest late in the work period it might be valuable (although logistically challenging) to re-order tasks where possible so that workers have more control or do more rewarding work later in the working day which might serve to sustain motivation, reduce fatigue and as a result increase safety and reduce errors.

Strengths and limitations.

To the best of our knowledge this is the most comprehensive examination of subjective fatigue at work in real time. It is a substantial study with frequent measurement of fatigue throughout the work period in a homogeneous sample of nurses with very little missing data. The measure of fatigue was comparable to that used in other studies of fatigue, (5, and 10). The study combines direct physical measurement of energy expended with frequent measures of a range of the putative determinants of fatigue. We did not measure mental or psychological effort which may also be important in resource models. In addition we did not assess work related motivation nor changes in motivational processes and goals over time, important components of the motivational models. The study is limited to the work period and as result we cannot comment on fatigue outside the working day, or on contextual factors that may influence fatigue, such as work/home balance or the quality of participants' sleep before they come on duty (a factor that Hulsheger (10) has shown to be important). In future work it would be desirable to include explicit measures of work related motivation and include measurement outside the work period, although this could be a burdensome addition to an already demanding protocol. It would also be valuable to include objective measures of performance and conduct the studies in a range of hospitals.

Conclusion

This real-time study using valid and intensive measurement offers little support for the dominant resource depletion model of fatigue as neither directly measured physical energy expenditure nor perceived demands of the work predicted fatigue in nurses over the course of a 12-hour shift. By contrast, the finding that perceived reward and perceived control both predicted fatigue over time, supports a motivational account of fatigue. In addition, the study confirmed previous (but predominantly laboratory based or simulated work) findings of increasing fatigue with time during the working day and has shown that this is true in most nurses.

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Table 1

Participants: Demographic, professional and participation information.

	Medical	Surgical	Population[1]
N	47	53	425
Gender (% female)	93.6%	92.5%	96.5%
Age in years (mean, SD)	35.9 (9.5)	36.9 (10.2)	36.9 (10.3)
Body Mass Index (mean, SD)	27.8 (6.1)	25.9 (5.1)	
Qualifications (% graduate level)	47.9%	34.0%	
Percentage in lower pay bands	69.6%	76.9%	
Years registered as a nurse (mean, SD)	9.4 (8.7)	11.5 (9.9)	11.0 (9.5)
Years working on ward (mean, SD)	5.0 (4.9)	5.4 (5.0)	
Number of wards included	7	7	14
Number of shifts included	92	101	

[1] All nurses employed on participating wards

Table 2
Means and standard deviations for subjective fatigue and the predictor variables, separately for medical and surgical nurses.

	Medical		**Surgical**	
Measure	Mean	SD	Mean	SD
Fatigue (0-100)	29.39	18.98	32.66	22.10
Energy expended per minute (mets)	1.55	0.61	1.51	0.64
Energy expended accumulated	623.81	396.27	621.39	389.44
Demand (0-6)	2.56	1.88	2.74	1.93
Demand accumulated	10.89	8.13	11.38	8.79
Control (0-3)	2.20	0.95	2.23	0.92
Control accumulated	9.38	5.98	9.92	5.91
Reward (0-4)	2.84	1.41	2.87	1.33
Reward accumulated	12.26	8.15	12.71	8.00

Table 3
Changes in fatigue over the work period: estimate beta weights (standard error) for fixed effects and variances (standard errors) for random effects.

	Linear- fixed	Quadratic-fixed	Quadratic-random
Fixed effects			
Intercept	20.30 (1.64)***	24.43 (1.77) ***	23.57 (2.11)***
Shift (1 or 2)	0.40 (0.70)	0.36 (0.70)	0.65 (0.62)
Day v night shift#	-5.87 (2.21)**	-5.48 (2.18)*	0.33 (2.93)
Time (linear)	1.72 (0.12)***	-0.51 (0.38)	-0.53 (0.46)
Time (quadratic)	-	0.20 (0.03)***	0.21 (0.04)***
Day/night x time (linear)	1.31 (0.22)***	1.21 (0.22) ***	0.77 (0.36)*
Random Effects			
Level 2:person			
Intercept	188.25 (28.61)***	189.37 (28.47)***	321.59 (60.47)***
Day v night shift	-	-	60.07 (72.88)
Time (linear)	-	-	9.14(3.02)***
Time (quadratic)	-	-	0.05 (0.02)**
Day/night x time (linear)	-	-	0.93 (1.42)
Level 1: Observations over time			
Intercept	169.85 (6.53)***	165.07 (6.35)***	128.78 (5.38)***
Loglikelihood (of model)	11866.11	11827.89	11686.70

*p<.05 ** p<.01 *** p<.001 # Day/night binary coded, 1=night.

Table 4: Predicting fatigue from predictors (**P**) energy expenditure, demand, reward and control: accumulated and distributed lag models showing estimated beta weights (standard error) for fixed effects and variances (standard error) for random effects.

	P - Energy Expenditure		**P -** Demand		**P -** Reward		**P -** Control	
	Accumulated	Distributed lag	Accumulated	Distributed lag	Accumulated	Distributed lag	Accumulated	Distributed lag
Fixed effects								
Intercept	23.86(2.11)**	11.60(3.42)**	23.67(2.12)**	5.37(1.44)**	25.81(2.14)**	15.14(1.66)**	25.91(2.14)**	13.55(1.82)**
Shift	0.03(0.65)	-0.08(0.73)	0.17(0.69)	-0.22(0.66)	0.37(0.65)	-0.26(0.65)	-0.35(0.67)	-0.34(0.66)
Day/night#	-2.12 (2.52)	0.29 (2.61)	-2.05 (2.57)	-1.39(2.09)	-2.00 (2.53)	-0.37 (1.92)	-2.96(2.40)	-1.33(1.90_
Time(lin)	-0.16(1.31	1.66(0.21)**	-0.73(0.55)	1.50(0.15)**	1.23(0.64)	1.65(0.13)**	1.29(0.71)	1.55(0.15)**
Time(quad)	0.21(0.04)**	-	0.21(0.04)**	-	0.20(0.04)**	-	0.21(0.04)**	-
D/n x time	0.87 (0.35)	0.16 (0.36)	1.05 (0.36)**	0.58(0.28)	0.55(0.34)	0.32(0.26)	0.81 (0.32)	0.48(0.26)
P-accumul	**-0.01(0.01)**	**-**	**0.03(0.13)**	**-**	**-0.85(0.19)****	**-**	**-1.14(0.30)****	**-**
P-current	**-**	**-0.69(1.62)**	**-**	**0.48(0.25)**	**-**	**-1.83(0.33)****	**-**	**-1.96(0.50)****
P - lag1	**-**	**-2.24(1.66)**	**-**	**0.19(0.21)**	**-**	**-0.71(0.30)***	**-**	**-0.71(0.40)**
Fatigue lag1	-	0.49(0.03)**	-	0.48(0.03)**	-	0.45(0.03)**	-	0.47(0.03)**
Random effects								
Level 2: Person								
Intercept	331.62(56.67)**	17.80(20.23)	333.96(57.17)**	50.75(20.55)*	328.58(57.52)**	30.14(25.22)	335.78(58.37)**	50.41(28.54)
Time(lin)	78.48(22.01)**	0.99(0.46)	14.63(4.05)**	0.43(0.25)	20.24(5.66)**	0.23(0.22)	29.28(6.83)**	0.29(0.23)
Time(quad)	0.06(0.02)*	-	0.05(0.02)*	-	0.05(0.02)*	-	0.05(0.02)*	-
P- accumul	**0.01(0.00)****	**-**	**0.80(0.22)****	**-**	**1.26(0.42)***	**-**	**4.33(1.08)****	**-**
P - current	**-**	**NA**	**-**	**2.43(0.86)****	**-**	**1.61(1.24)**	**-**	**7.57(3.16)***
P - lag1	**-**	**NA**	**-**	**NA**	**-**	**NA**	**-**	**NA**
Fatigue lag1	-	0.03(0.01)*	-	0.02(0.01)*	-	0.03(0.01)*	-	0.03(0.01)*
Level 1: Observations over time								
Intercept	122.56(5.17)**	128.80(6.30)**	121.68(5.17)**	118.47(5.42)**	120.25(5.08)**	120.87(5.44)**	116.77(4.96)**	119.70(5.44)**

** *p<.01, ***p<.001*, NA random effect could not be estimated. # Day/night binary coded, 1=night.

Captions

Figure 1. Effects of time at work on fatigue. The top line shows fatigue on night shifts, lower line shows fatigue on day shifts. a) Quadratic model across participants, showing interaction between shift and time. b). Individual quadratic regression lines of effects of time on fatigue with Intercept allowed to vary between participants (group regression lines also shown) and c). Intercept fixed at mean intercept of sample (group regression lines also shown).

Figure 2. Effects of the accumulated predictor variables ((a) energy expended, (b) demand, (c) reward and (d) control on fatigue. Individual regression lines with intercepts fixed a mean intercept of the sample (group regression line also show)

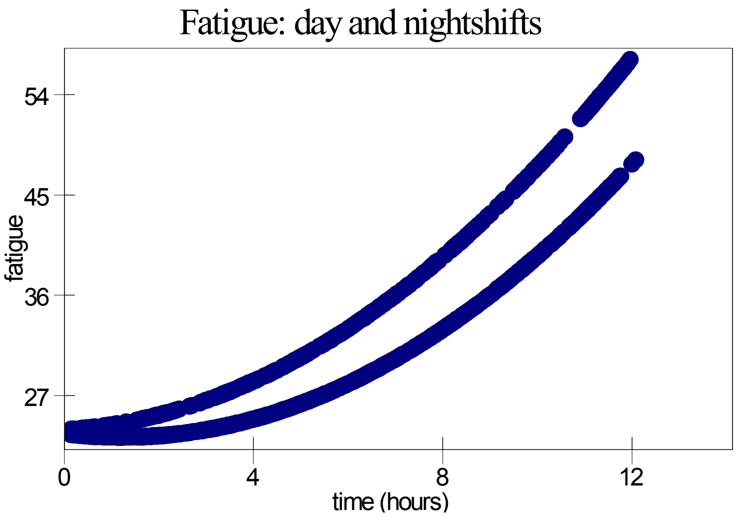

Figure 1a

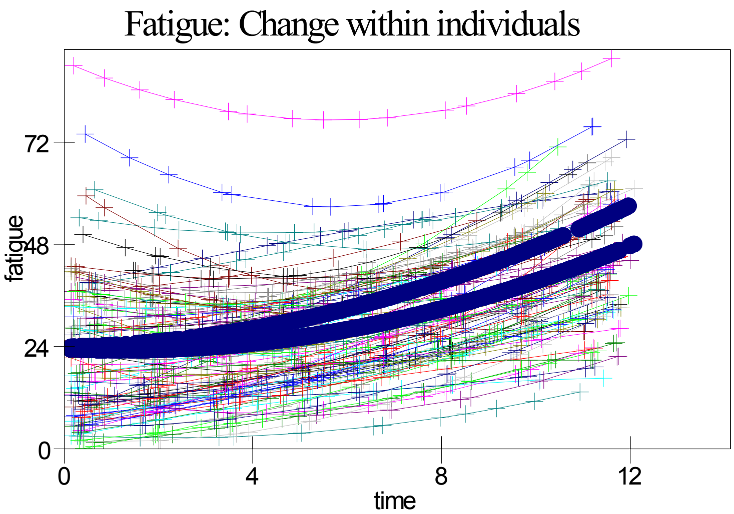

Figure 1b

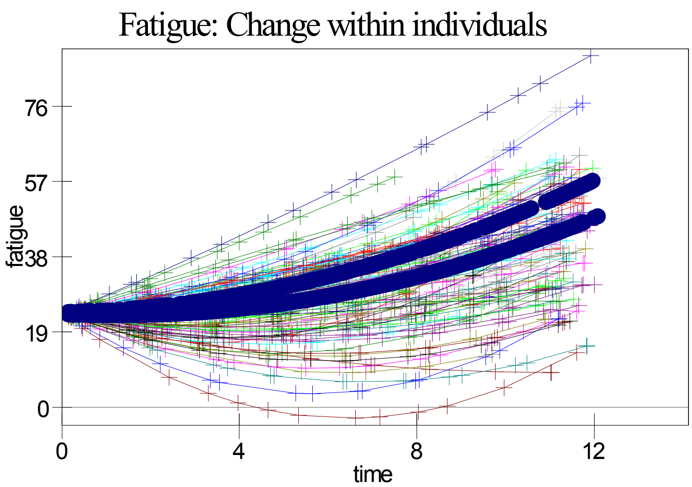

Figure 1c.

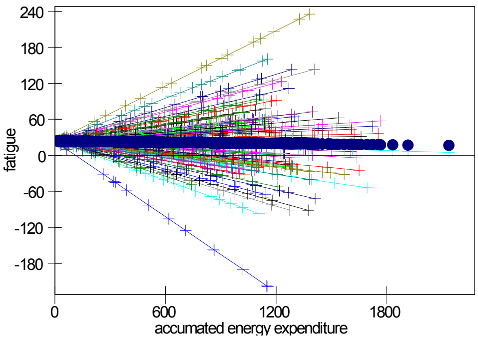

Figure 2a

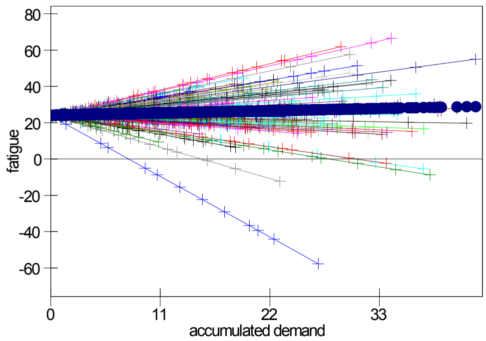

Figure 2b

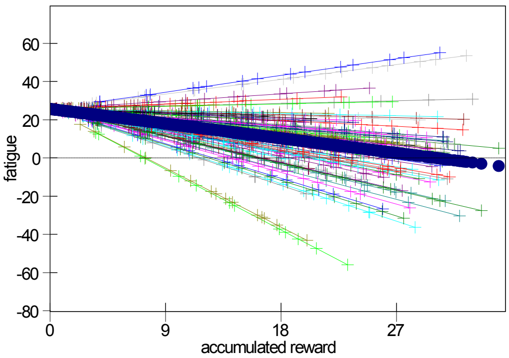

Figure 2c

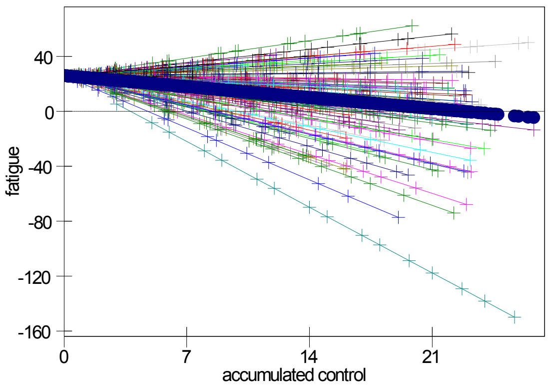

Figure 2d