Title: Separating the effects of task load and task motivation on the effort-fatigue relationship

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Key Words: AFTER-EFFECTS, EFFORT, FATIGUE, TASK LOAD, TASK MOTIVATION

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Abstract

A study is reported on the effects of task load and task motivation on the relationship between effort and fatigue in a demanding life-support simulation, aimed to test the hypothesis that effort, rather than demands, was the direct cause of fatigue in task performance. This was done by independently manipulating two factors that affect effort: task load and task motivation. A total of 28 participants were tested in a mixed 3 x 2 factorial design; task load (within-Ss) was varied in terms of the number of manual control systems (1, 3 or 5) that needed to be managed during a 100 min session, while task motivation (between-Ss) was defined by instructions (standard vs. enhanced) designed to influence the level of voluntary commitment to task goals. Effort and fatigue were measured by self report, as were perceived demands and anxiety (included as manipulation checks). While both task load and task motivation led to an increase in effort, there was a stronger fatigue response to task load under enhanced task motivation. As predicted, while both perceived demands and anxiety increased with task load, they were not affected by task motivation. An independent assessment of after-effects of fatigue on a fault finding task showed an increased use of low effort strategies under enhanced task motivation. The findings support the hypothesized effort→fatigue linkage. During task performance, fatigue is a consequence not of task demands *per se,* but of the level of commitment of effort in meeting demands.

Key Words: AFTER-EFFECTS, EFFORT, FATIGUE, TASK LOAD, TASK MOTIVATION

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Introduction

The requirement to perform a task may be considered a stressful encounter, particularly when it is carried out under time pressure or high information load, or when failures are costly. Under such conditions performance can attract many of the same costs of coping as environmental stressors (Frankenhaueser, 1986; Gaillard, 1993; Hockey, 2013; Matthews, 2011; Ursin & Eriksen, 2004). We may therefore ask how objective task load (the stressor) is appraised or perceived by the performer. Under typical task stress demands may be perceived as a threat and give rise to anxiety. The natural coping response requires the use of active coping (Carver, Scheier & Weintraub, 1989; Henry & Stephens, 1977; Obrist, 1976) or problem-focused coping (Lazarus & Folkman, 1984): engaging with task demands through effort motivated by the need to overcome obstacles and satisfy goals. Under different circumstances, demands may instead act as a challenge, when resources are evaluated as being adequate for meeting demands (Blascovich, 2008) or when opportunities for control are high (Frankenhaeuser, 1986; Hockey, 2013; Hockey & Earle, 2006).

The focus of this paper is on the relationship between effort and fatigue in task performance under low control (threat) conditions. Effort is recognized as a central feature of active coping and purposeful goal-related activity (Carver & Scheier, 1990; Frankenhaeuser, 1986; Hockey, 1997; Kahneman, 1973; Locke & Latham, 1990). However, the function of effort and the mechanism through which it affects performance remains unclear. Mainstream motivational theories have generally considered it to have a drive or intensity function, rather than influence behavioural direction: for example, research influenced by Brehm's motivation intensity theory (e.g., Brehm & Self, 1989; Gendolla &

Richter, 2010; Wright, 2008). Brehm’s approach makes an important distinction between two criteria for effort expenditure: potential motivation and motivation intensity. Potential motivation refers to a hypothetical upper limit of how much effort individuals would be prepared to commit in order to achieve a goal, assumed to depend on such factors as goal value and importance. Motivation intensity, on the other hand, refers to the actual level of effort applied on a moment to moment basis, as determined by varying demands and perceived constraints of the task. The same distinction has been made by Kalsbeek (1968) and Schmidtke (1976), in terms of a 'willing to spend' capacity, with a reserve available for meeting unexpected demands.

Within this paradigm, the variability in effort observed in different goal contexts has been assumed to be determined largely by the ‘attention pull’ of extrinsic task demands (Brehm & Self, 1989; Kahneman, 1973; Kruglanski et al., 2012), a view generally supported by research findings, though typically only when success is both valued and seen as achievable (Wright, 2008). This is consistent with the idea of an adaptive motivational system in which aversive effortful states serve to limit investment in unrewarding activities (Kool, McGuire, Rosen & Botvinick, 2010; Kurzban, Duckworth, Kable & Myers, 2013); no more effort than necessary is expended in order to meet task goals. However, effort is unlikely to be driven purely by external factors. The level of effort committed by the individual (Brehm's motivation intensity) must be based on their estimate of the level of demands made by the task, as informed by judgements of the difficulty of attaining task goals, environmental constraints (such as opportunities for control), and their experience of other (similar) situations. This suggests a significant contribution of voluntary control to the management of effort, particularly in the willingness to commit either more or less effort when goals become increasingly difficult to attain (though demands remain essentially unchanged).

Potential motivation clearly has a strong voluntary component, since it is driven partly by personal interests and values, though it is usually considered to influence effort expenditure only when task demands are unclear or goals very general (Gendolla & Richter, 2010). In these circumstances effort committed to the task would be influenced by individual differences in factors such as level of interest.

In contrast to the view of effort as a mechanism to increase the intensity of general task motivation, there is an alternative approach exemplified by recent developments in cognitive neuroscience. This approach has treated effort as having a guiding (or control) function, as well as an intensive function, through its role in the executive control system based on anterior cortical mechanisms (e.g., Hockey, 2013; Kane & Engle, 2002; MacDonald, 2008; Mulert, Menzinger, Leicht, Pogarell & Hegerl, 2005; Sarter, Gehring & Kozak, 2006). The control function of effort is argued to take the form of maintaining focussed attention on task goals, thus helping to prevent distraction and displacement by other competing goals and threats from external stressors (Hockey, 1997; Mulder, 1986; Wickens & Hollands, 2000). In Hockey's model (1997, 2013) effort is assumed to be a function of both responsive and voluntary factors, through the operation of a compensatory control feedback loop. As in Brehm's approach, the setting of an effort budget allows committed effort (motivation intensity) to be determined largely by experienced demands, up to the point where the set limit is reached. In that case, the performer may opt to increase the effort budget (if task values remain high) or leave it unchanged (or even lowered), as may occur if goals are no longer highly valued or as a response to increasing feelings of fatigue.

Fatigue has generally been assumed to be a direct consequence of doing work *per se*, and is widely understood to have a central causal role in decrements in task performance (Hancock & Desmond, 2001; Hockey, 2013). In fact, such effects do not always occur, depending on the extent to which tasks make demands on executive control functions, rather than routine procedures. In a comprehensive review of the literature, Hockey (2013) concluded that fatigue is best viewed not as a depletion of energy or resources, but as an adaptive motivational control mechanism. This prevents fixation on unrewarding activities by influencing strategic withdrawal from current goals, allowing alternative goals to become active. However, in contexts where current goals are important, such constraints may be overcome by increased effort, allowing goals to be maintained. Within the context of task performance, the growth of fatigue with sustained work is attributable to the deployment of the increased high effort response. This effect is similar to findings on ego depletion (Baumeister, Vohs & Trice, 2007), which show a fatigue-like state resulting from the application of self-control, an executive activity closely related to the use of effort (Inzlicht, Schmeichel & Macrae, 2013). In both paradigms, the exercise of executive control/effort leads to fatigue and a state of resistance to further effort, as measured in post-work probe tasks sensitive to effort variations (Broadbent, 1979; Cohen, 1980; Hockey & Earle, 2006; van der Linden, Frese & Meijman, 2003).

The present study

The primary aim of the study is to examine the hypothesized effort→ fatigue linkage more closely. While the idea that effort leads to fatigue is intuitively appealing, there have, to date, been no direct formal tests of this relationship. The responsive view of effort as being driven by external demands would lead us to expect that fatigue would also be a direct function of demands. Such a result is found in typical task situations (Hockey, 2013), though only under low control conditions, where demands and effort are strongly related (Hockey & Earle, 2006). However, if, as we have argued, effort has a voluntary component independent of demands (an increase in motivation to maintain commitment to task goals), then we should be able to separate their effects on fatigue, allowing us to test the hypothesis that effort, rather than demands, is the direct cause of fatigue.

We examine this question by independently manipulating task load and task motivation, and measuring their separate influence on both effort and fatigue, using the Cabin Air Management Simulation (CAMS: Hockey, Wastell & Sauer, 1998). CAMS is a complex task, making considerable demands on executive control and, under its normal configuration, offering few opportunities for control, while allowing task load to vary from low to very high. Manipulation checks demand the use of two further measures, perceived demands and state anxiety. The effectiveness of task load is assessed by changes in perceived demands, and also anxiety as an indicator of task threat (Eysenck, 1992; Oatley & Johnson-Laird, 1987; Öhman, Flykt & Esteves, 2001). However, since effort may be driven by perceived demands under standard task conditions, it may also show increases with load, while increases in fatigue may occur because of the hypothesized mediating effect of the effortful response to demands. Task motivation, on the other hand, is predicted to specifically affect effort (and so fatigue), but have no direct consequences for perceived demands and threat (anxiety). As a further test of the selective effects of task load and task motivation on effort and fatigue, we also measure their after-effects on a fault finding task administered after the main session, which are predicted to show an increased use of low effort strategies following enhanced motivation.

Method

Design and participants

A mixed design was employed, with two independent variables of *task load* and *task motivation*. Task load was manipulated within subjects over three levels (*low*, *medium* and *high*) in separate experimental sessions, with 3-7 days between each of the sessions. Task motivation was manipulated as a between-subjects factor, with two levels, *normal* and *high*. Following approval of protocol from an independent ethics committee, participants were recruited from within the University of Hull. A campus-wide advertisement outlined the study, and requested good computer literacy, a science background and good English-language skills. The high demands of the study meant that an initial sample of only 39 students agreed to take part. Of these, six had to be rejected on the basis of the selection criteria, and a further five because of a failure to meet the criterion set by the training standard (see below). In all, a total of 28 participants (18 male, 10 female; mean age 23.8, SD = 3.3) were tested. Participants were paid £5 per hour for their participation.

Performance tasks

The study made use of two performance tasks; the *Cabin Air Management System (CAMS)* developed by Hockey and his colleagues (Hockey, Wastell & Sauer, 1998) and the *Fault finding task (FFT)*.

Cabin Air Management System (CAMS). This is a simulation of a semi-automatic process control system designed to maintain a suitable life support environment within a closed vessel, such as a space capsule or submarine. It makes major executive demands on the performer by requiring them to interact with a dynamic visual display that provides data on the current state of system variables and functions via a range of controls and automation tools (see Figure 1). The main task of the operator is to monitor the state of the display and to intervene if a malfunction is suspected, in order to maintain an appropriate quantity and quality of breathable air within the vessel. The environment is normally managed by automatic controllers for each of five key system parameters: oxygen (O_2), carbon dioxide

(CO_2), and cabin air pressure, temperature and humidity. These normally maintain system variables within predefined safe limits, but may be programmed to fail at predefined times. A failure of any of the automatic controllers means that the operator has to use manual control procedures to maintain the parameters within their respective normal operating ranges. By reading the gauges on the sensors, the operator is trained to pinpoint the source of a system disturbance and implement appropriate corrective procedures. Figure 1 shows a screen display in which the operator has assumed manual responsibility for three of the five system parameters, and a temperature alarm which has to be responded to.

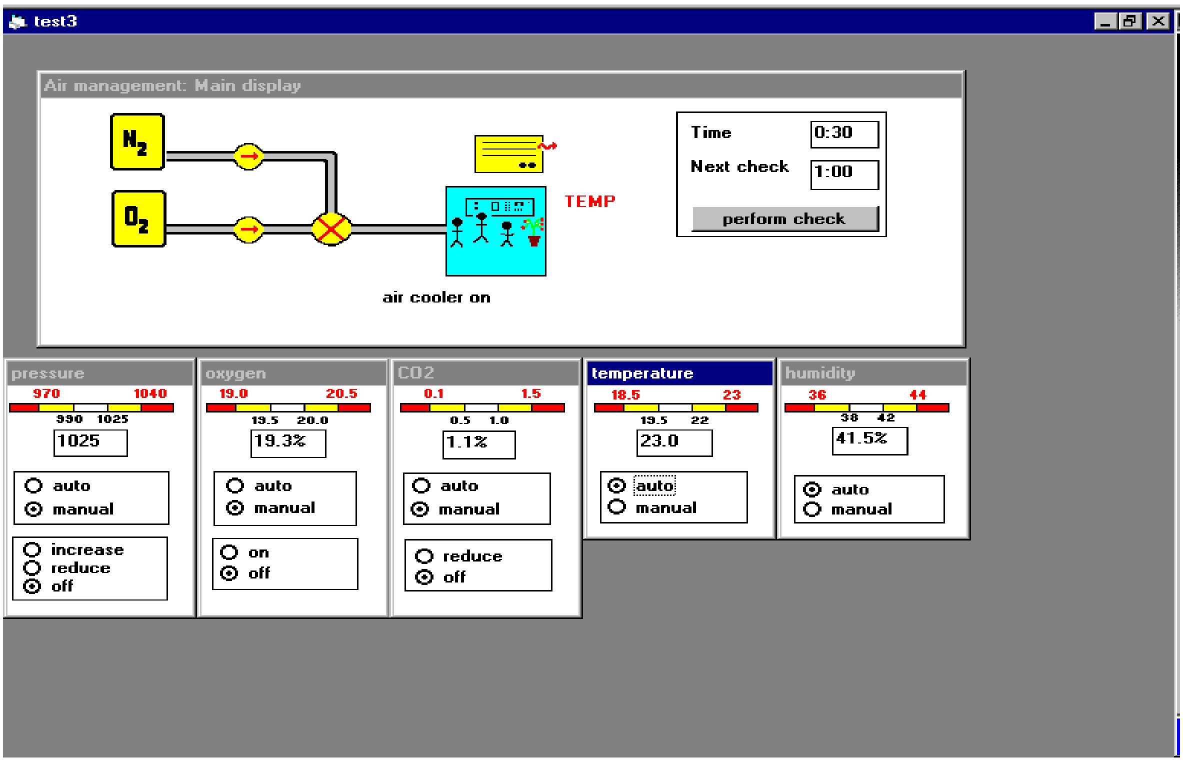


Fig. 1. Example of a screen display in the Cabin Air Management System (CAMS)

Fault finding task (FFT). This was designed to act as a probe test for the carry over of fatigue from the CAMS loading task, and provide an independent assessment of the hypothesized effects of increased task motivation (via effort) on fatigue. Participants were presented with a screen consisting of a single network made up of 30 nodes linked by a random series of interconnections (see Figure 2). Each network contained one 'faulty' node, which the operator was required to identify. Networks had clearly specified rules: (1) There is one faulty node per network; (2) This fault contaminates the nodes that follow it, specifically only those nodes connected to it and situated to its right; (3) Contaminated nodes will display a red cross when selected and uncontaminated nodes a green check mark (as in Figure 2). The initial presentation of the network included five columns of blank nodes and a single (far right) column which presents a series of ‘outputs’ (either a red cross to signify contamination or a green check mark). The task was to survey the outputs and the nature of the interconnections and make decisions as to which nodes they should sample (click on) to locate the fault. They were instructed to find the fault as efficiently as possible (i.e., in the minimum time, and with the minimum number of nodes checked). Figure 2 shows an example of a screen display in which four nodes have been sampled, two of which are contaminated and two uncontaminated. Given the current configuration of outputs and sampled nodes, the faulty node must lie on the bottom row in either the first column or the second column.

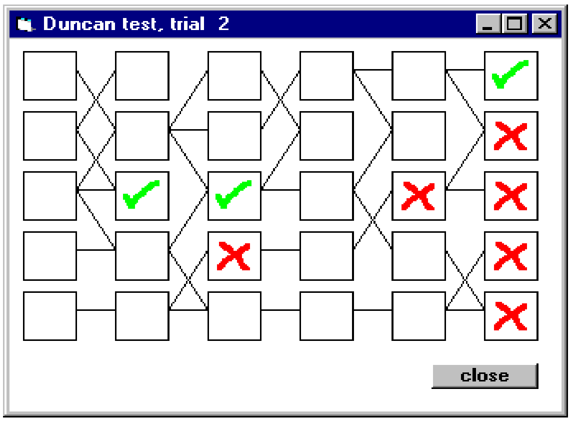


Fig. 2. Example of a screen display in the fault finding task (FFT)

A number of fault-finding strategies are available in the task, with associated variations in effort and probability of success. Two of these were identified by Morrison and Duncan (1988) in an investigation of fault diagnosis strategies and tactics. The *hypothesis-test* strategy is the most cognitively demanding, making extensive use of effort; it requires the participant to observe the total output of the network and node interconnections and deduce a 'feasible fault set' (Rouse, 1978) of possibly defective nodes. This places a high demand on working memory and takes more time, but is likely to result in a correct diagnosis with few actions. The *tracing back* strategy involves participants working back from a single contaminated output until they find the faulty node. This may be considered a moderate effort strategy, making fewer demands on working memory than hypothesis testing, but likely to result in a greater number of checking actions. In addition to these identifiable strategies, the participant may also select nodes in a quasi-random (R) manner, a highly inefficient yet low effort strategy in terms of the probability of making incorrect choices. Preliminary tests revealed that participants consistently over-used low effort strategies, as there was, in practice, little difference in terms of solution time (Earle, 2004). Therefore, to maximise the sensitivity of the probe task to anticipated differences in effort-based strategies, a 3s time-out was introduced following each incorrect node choice. This reduced the attractiveness of random guessing strategies, making it more likely that they would be used only when high effort options could not be tolerated. Participants were required to complete two series of 25 networks, one series prior to the CAMS task and one post CAMS, in order to permit an analysis of the effects of the *task load* and *motivation* interventions. This yielded a series of dependent variables of *time to first choice*, *solution time*, and *number of choices to solution*.

Manipulation of task load and task motivation

Task load was defined in terms of three levels (low, medium and high) defined by failures of automatic controllers (1, 3 & 5). The three experimental sessions were randomly ordered for each participant. All system failures were scheduled to occur between three and 50 min. *Task motivation* was manipulated through modifying the instructions about how to manage task goals. The *standard* instructions were consistent with those routinely adopted for operating the CAMS task. This includes a general cover story of a simulated space mission, in which participants were responsible for the management of the life support system of a spacecraft. In order to carry out this task effectively, they should try to maintain all five cabin indicators within their allowable limits at all times. In the *enhanced* task motivation condition, while the instructions were essentially the same, an even greater emphasis was placed on the need to ensure the success of mission goals. This was done by explaining the value placed on carrying out scientific studies under zero gravity, and telling participants that the payload for this mission included a number of critical biological, chemical and medical experiments. Whereas humans could tolerate mild departures from optimal values of the environmental variables, particularly variations in temperature, pressure and humidity, the success of these experiments depended on the maintenance of highly stable conditions in the cabin. This meant that it was really important to make every effort to keep the cabin variables as close as possible to their optimum values. It was emphasised that they should be prepared to maintain a high level of effort to do this when conditions were difficult, and that the success of the mission depended on their ability and willingness to take on this responsibility. Thus, while the task load was constant across the two motivation conditions, the researcher appealed to those in the enhanced group to invest maximum effort to ensure mission success. In essence, in terms of the compensatory control theory, this means that these participants were required to increase their effort budget for the task (or, in Brehm's framework, to increase their level of potential motivation).

Training on CAMS and FFT

Prior to the study participants attended two 2-hr training sessions and one session of 1-hr, in groups of between three and five. The first training session provided them with a verbal explanation of the essential features of the CAMS task environment and the way in which the system worked, as well as a cover story explaining the nature of their task. The CAMS environment was presented as a generic simulation of the life support system of a spacecraft. Participants were encouraged to consider themselves as operators of the system which normally worked automatically but had to be maintained during periods in which automatic controllers were malfunctioning. To develop the high level of expertise required, they practiced taking manual control of each of the five system variables and monitoring the effects of their actions on the system. At the end of the first training session they received automatic feedback on their control performance, relating to the amount of time each of the key variables deviated from acceptable limits. The second training session occurred within one week of the first. Following a brief recap on the main features of the system, participants took part in a mock 35-min experimental session, during which they were required to identify and manually control each of the five automatic control failures.

A high level of system competence was considered essential for participants to continue to the main study, both for the development of intrinsic motivation (to instil the safety critical values of the task) and to reduce the impact of continued learning during performance testing. Expertise was assessed in two ways. First, operators were encouraged to keep all system variables within limits at all times, and were allowed no more than 1% control failures during the mock experimental session. Second, operators' understanding of CAMS operation was assessed via a system knowledge test, comprising thirteen questions relating to specific principles governing CAMS functioning. The third training session was 1 h duration and focused on the FFT, including familiarisation with the range of possible strategies and individual practice at solving a series of 25 networks.

Experimental sessions

Experimental sessions lasted approximately 2 h, during which participants were required to complete 25 Fault Finding networks before and after 100 min of CAMS operation. State fatigue and anxiety measures were obtained before and after CAMS operation, to measure the subjective impact of the loading task. Perceived demands and effort were assessed at the end of CAMS task via a subjective workload assessment questionnaire (see below). Following the completion of both experiments, participants were fully debriefed about the aims of the study, the manipulation of two conditions of task motivation and reminded about their right to withdraw.

Subjective measures

Strain measures. Anxiety and fatigue were assessed via a multidimensional state questionnaire (Earle, 2004) incorporating subscales of mental fatigue, (4 items: e.g., *I feel mentally tired* and *I feel unable to concentrate,* Cronbach's alpha =.86) and anxiety (3 items: e.g., *I feel uneasy* and *I feel tense and on edge,* Cronbach's alpha =.81). This scale was administered both pre- and post-CAMS to provide a measure of change in subjective strain following the task load/motivation manipulations.

Subjective work assessment (SWA). A further questionnaire assessed effort, perceived demands and control. *Effort* was assessed by a single item (How much effort did you put into the task?) *Perceived demands* was based on responses to six scales: *attentional demand*, *control demand*, *problem solving demand*, *process responsibility*, *time pressure* and *physical demand*. Because of the need for a sensitive index of within-task variation in mental load, the first four items were drawn from the descriptive items relating to mental demand developed by Jackson, Wall, Martin & Davids (1993), with the additional items of *time pressure* and *physical demand* retained from the NASA-TLX (Reid & Nygren, 1988). Responses were made on a 1-100 point scale with end points labelled 'very little' and 'a great deal' (Cronbach's alpha; perceived demands = .81, control = .83; Earle, 2004). Both measures were presented to participants in pencil and paper format.

Treatment of data

The data were analysed using a series of mixed design ANOVAs, using the Greenhouse-Geisser correction for violations of sphericity. For each analysis, *task load* was a within-Ss factor and *task motivation* a between-Ss factor. Performance on CAMS was assessed by an automatic facility, which logged all times when any of the variables was beyond its acceptable range. These data were expressed as a percentage of the total time, referred to here as the *DV* of CAMS control errors. Subjective data were reduced to subscale means for perceived demands, mental fatigue and anxiety. The FFT yielded three *DV*s, which were extracted from a data logging facility by a bespoke analysis programme and averaged across each series of 25 networks. This provided measures of *time to first choice*, *solution time*, and *number of choices to solution*. Effect sizes were estimated using Cohen's *f*: a value of 0.1 was taken to indicate a small effect, 0.25 a moderate effect and 0.40 a large effect (Cohen, 1988).

Results

The main goal of the study is to examine the effect of an independent manipulation of task motivation on affective state variables. We expect little change in CAMS performance, since it should be well protected under normal levels of motivation. However, the increased effort that we assume will be exerted under enhanced motivation, is predicted to selectively increase fatigue (rather than perceived demands or anxiety), and for the effect to increase over task load. The findings are reported in relation to performance on the CAMS task, measures of subjective demands, anxiety, effort and fatigue, and performance on the fault finding (after-effect) task.

Task performance

Performance on the control task was well protected. Fig. 3 shows that mean error was around 0.5 %, except for the high load/standard motivation condition, where it was 2.2 %. There was a significant effect of *task load* [F (2, 52) = 14.26, $p < .001$, $f = .73$], and also of *task motivation* [F (1, 26) = 5.09, $p <.05$, $f = .43$], though these are better explained in terms of the significant interaction [F (2, 52) = 5.38, $p < .01$, $f = .45$]; the advantage of enhanced motivation was primarily to reduce the error rate under high task load.

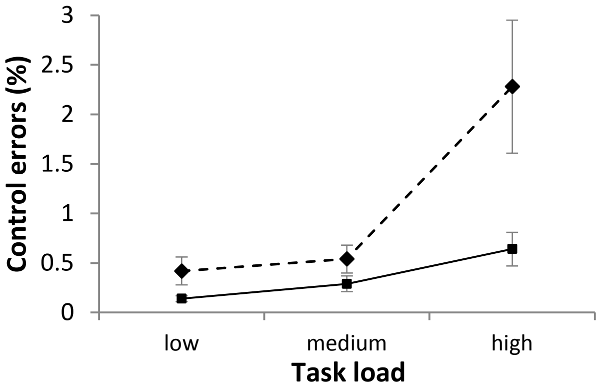


Fig. 3. Mean percentage of control errors as a function of *task load* and *task motivation*); dotted line = standard motivation, solid line = enhanced motivation (error bars signify +/- 1 SE of the mean)

Perceived demands and anxiety

Fig. 4 shows the mean changes in perceived demands and anxiety as a function of task load and motivation. As a manipulation check for task load, ratings of demand (Fig. 4a) were found to increase significantly with level of *load* [F (2, 52) = 34.65, p < .001, f = 1.15], with a strong linear trend [F (1, 52) = 48.58, p < .001, f = 1.34]. Also, as predicted, perceived demands were not affected by *task motivation* (F < 1), and there was no significant interaction [F (2, 52) < 1, p > 0.05, f = .17]. To adjust for pre-test differences in affective state, the data for both anxiety and fatigue were expressed as change scores (post-CAMS ratings – pre-CAMS ratings). For anxiety (Fig. 4b), the data show similar effects to those on perceived demands, with a significant effect of *task load* [F (2, 52) = 3.61, p < .05, f = .37], but no effects of *motivation* or interaction (both F < 1). The pattern of change in reported anxiety was closely related to that of perceived demands, and neither was affected by increases in task motivation.

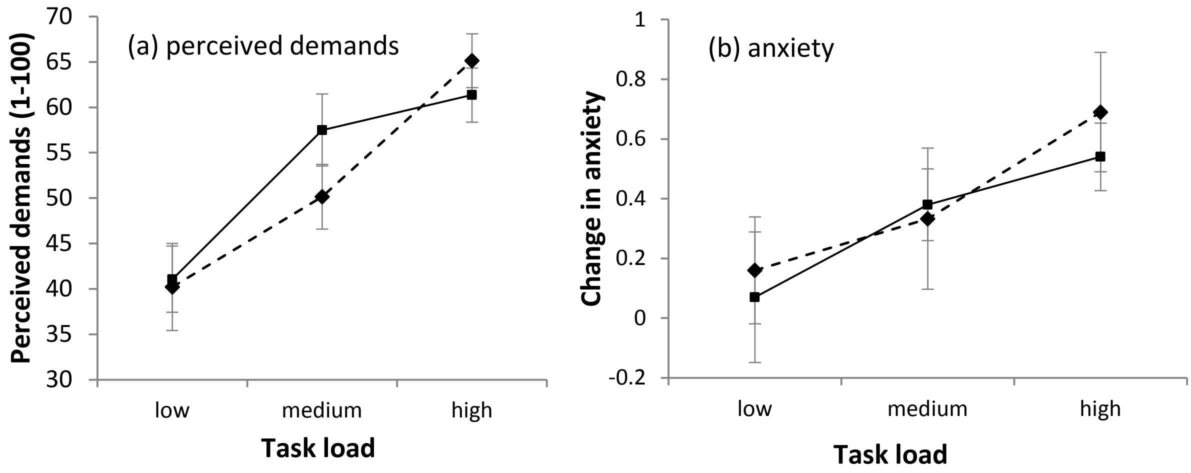


Fig. 4. The impact of *task load* and *task motivation* on ratings of perceived demands (a) and anxiety (b)*;* dotted line = standard motivation, solid line = enhanced motivation; higher anxiety change scores indicate an increase from pre- to post -task (error bars signify +/- 1 SE of the mean)

Subjective effort and fatigue

The data for reported effort and fatigue are shown in Fig. 5. Supporting the validity of the task motivation manipulation, Fig. 5 (a) shows that ratings of effort invested in the task were significantly higher in the *enhanced motivation* condition [F (1, 26) = 5.51, p < 0.05, f = .46]. Effort ratings also increased significantly with task load [F (2, 52) = 46.56, p < .001, f = 1.28], but there was no interaction between enhanced motivation and task load [F (2, 52) = 2.26, p > .05, f = .29]; the increase in effort under enhanced task motivation operated over the full range of task loads.

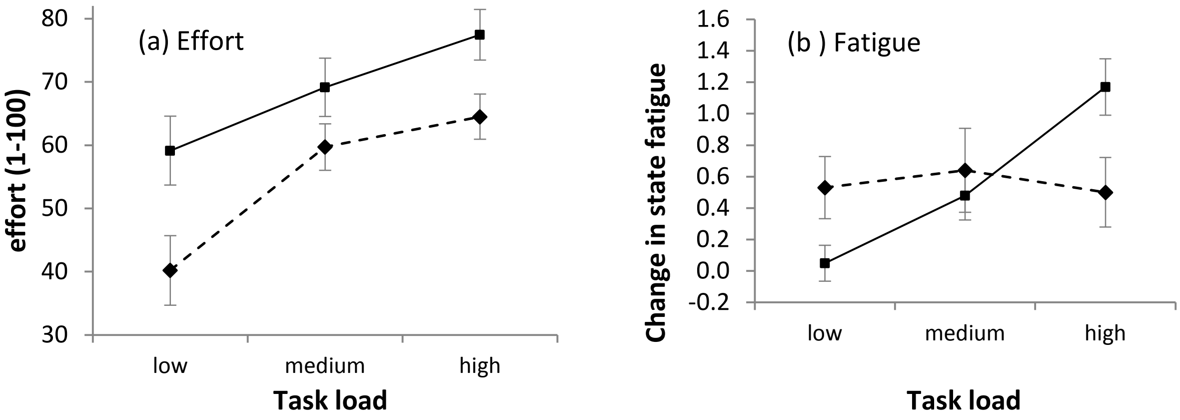
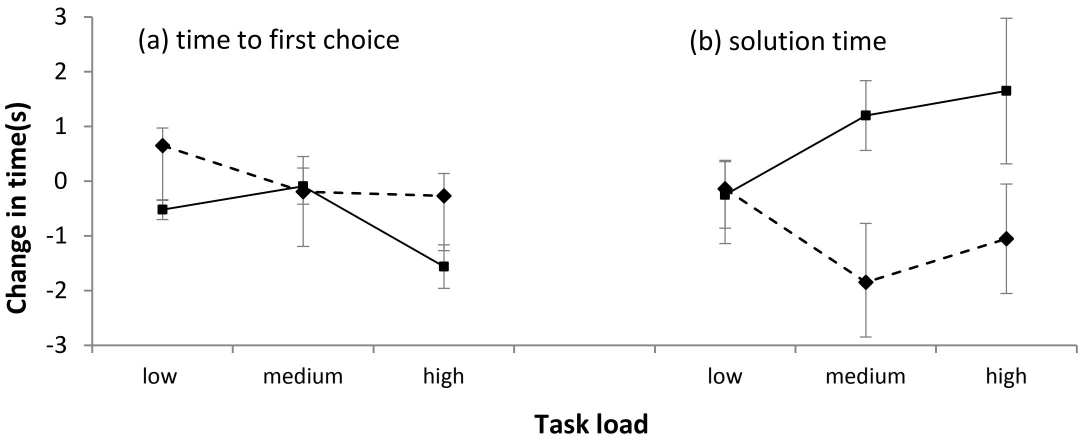


Fig. 5. The impact of task load and motivation manipulation on (a) effort and (b) change in state fatigue (b); dotted line = standard motivation, solid line = enhanced motivation; higher fatigue-change scores indicate an increase from pre- to post-task (error bars signify +/- 1 SE of the mean)

The corresponding data on reported fatigue are shown in Fig. 5 (b). As with anxiety, these are represented as change scores over the CAMS session (post-CAMS – pre-CAMS ratings). There was no main effect of task motivation on mental fatigue [$F(1, 26) < 1$, $p > .05$, $f = .00$], but there was a main effect of *task load* [$F(2, 52) = 5.91$, $p < .01$, $f = .46$]. This is explained primarily by the interaction between task load and task motivation [$F(2, 52) = 7.00$, $p < .01$, $f = .52$], and the strong linear component of the interaction $F(1, 26) = 17.75$, $p < .001$, $f = .81$]. As can be seen in Fig. 5 (b), the increase in reported fatigue over the three levels of task load occurs much more strongly under the *enhanced motivation* condition.

After-effects on Fault Finding Task (FFT)

The FFT probe task was included as an independent test of the predicted effects of task motivation. An increased in effort expended on CAMS (and a resultant increase in fatigue) was predicted to have cognitive after effects characterised by an aversion to the use of high effort strategies on FFT. Three measures of FFT performance are shown in Fig. 6: (a) *time to* *first choice,* (b) *solution time*, and (c) *number of choices to solution*. High effort strategies involve greater levels of planning before making the first and subsequent responses, and the systematic use of hypothesis testing, as opposed to relying on tracing back from faulty nodes or random guessing (Morrison & Duncan, 1988; Rouse, 1978). Thus low effort strategies are indicated by faster *times to first choice* (less planning prior to action), as well as longer overall *solution times* and more *choices before solution* (less systematic planning and hypothesis testing). In these three analyses, as with anxiety and fatigue, change scores (post-CAMS – pre-CAMS) are used to adjust FFT measures for pre-existing individual differences in task skill.



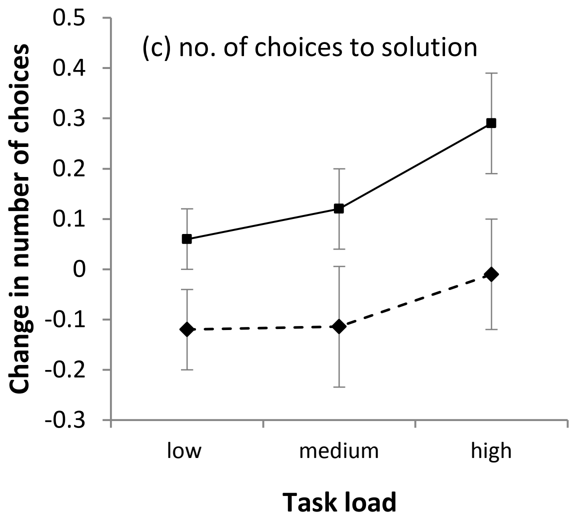


Fig. 6. The impact of *task load* and *task motivation* on probe task performance: *(a) time to first choice, (b) time to solution, (c) number of choices to solution*: dotted line = standard motivation, solid line = enhanced motivation; positive values indicate slower post-task performance in (a) and (b) and greater increase in choices in (c) (error bars signify +/- 1 SE of the mean)

The findings are strongly supportive of predictions. Under enhanced task motivation participants took significantly shorter times to make their first choice [$F(1, 23) = 5.16$, $p < .05$, $f = .46$], as well as making significantly more choices before solving the task [$F(1, 23) = 9.97$, $p < .01$, $f = .65$] and having longer overall solution times [$F(1, 23) = 8.40$, $p = .01$, $f = .59$]. There were no main effects of task load for any measure: time to first choice [$F(2, 46) = 2.74$, $p > .05$, $f = .35$]; number of choices [$F(2, 46) = 1.13$, $p > 0.05$, $f = .22$]; solution time ($F <$

1). The indicative interaction for solution times was not significant [$F(2, 48) = 2.45$, $p > 0.05$, $f = .31$], and there were no other interactions; time to first choice [$F(2, 46) = 1.54$, $p > 0.05$, $f = .25$]; number of choices, ($F < 1$). Overall, the findings from the *FFT* support the interpretation of increased fatigue from greater effortful engagement under enhanced task motivation resulting in cognitive after effects of a shift towards the use of low effort strategies.

Discussion

The main focus of the paper is on the relationship between effort and fatigue. We intended to enhance operator motivation to maintain task goals by manipulating effort directly through instructions. As expected, this had little impact on the already very high level of performance on CAMS, except at the highest level of load. Nevertheless, the requirement to attend even more fully to the goals of the task had marked effects on both effort and fatigue. Effort was increased across the whole range of task loads, confirming the validity of the manipulation. For fatigue, the most relevant finding is the interaction. Under standard motivation conditions, fatigue appears to show little effect of higher task loads, but there is a pronounced increase under enhanced motivation. There is also a suggestion of reduced fatigue at the lowest load. One possibility is that this may reflect the advantages of increased engagement in highly skilled performers, even in a demanding work context when there is a sufficient challenge to engage personal skills without anxiety. Such circumstances may allow at least some participants to experience brief peak experiences akin to flow (Bakker, 2008; Csikszentmihalyi, 1990).

These observations are supported by the findings on the after-effects probe task, which confirm the aversion to further effort taken to be central to the state of fatigue (Hockey, 2013; Holding, 1983). These show evidence of increased dependence on low-effort strategies in the high fatigue group: shorter delays until first action, increased number of choices, and longer times to solution. All these are indicative of the use of less systematic (effort-demanding) strategies. Of course, the use of such strategies is not all or none; it is clear from the detailed performance data that participants move between them from trial to trial. Rather, what seems to occur over the total set of trails is a change in the balance of strategies under fatigue, resulting in a shift towards a preference for low effort options. The findings add to the growing literature showing after-effects of fatigue on tasks carried out following the fatigue induction procedure (Hockey & Earle, 2006; van der Linden, et al., 2003; Webster, Richter & Kruglanski, 1996). The great advantage of such methods is that they provide an independent test of the development of fatigue, and—in the present study—of the effect of increased effort on fatigue. Under increased task motivation, participants not only report a greater increase in fatigue under demanding task conditions but also show their vulnerability to the continued impact of this state on their response to later demands.

The general conclusion from the study is that fatigue is a consequence not of work demands *per se,* but of the engagement of effort in meeting these demands. We are aware of a number of limitations of the study. The relatively small sample sizes meant that our analyses were generally underpowered. Unfortunately, it proved difficult to recruit large numbers of students because of the relatively time-consuming nature of the study; we were therefore limited to those who were prepared to do this, as well as satisfying a number of stringent selection and training criteria. Nevertheless, the relatively large size of many of the observed effects means that the findings are generally unambiguous. One reason for this is likely to be the high level of training and task realism, which helped to focus orientation on the task and minimize loss of engagement. A second limitation is that we relied on subjective reports to measure the effects of task activity on effort and fatigue, rather than making use of physiological markers. There is now considerable evidence that cardiovascular (CV) variables such as systolic blood pressure and heart rate variability may provide converging evidence on the effects of effort and after-effects of fatigue (e.g., Gendolla & Richter, 2010; Hockey, Nickel, Roberts & Roberts, 2009; Waldstein, Bachen & Manuck, 1997; Wright, Junious, Neal, Avello, Graham, Herrmann, et al., 2007), and are able to differentiate between threat and challenge responses to task demands (Blascovich, 2008). Because of the unavailability of suitable facilities, we were unable to include such independent evidence of the success of the manipulation. We would have expected to find the increased task engagement under the enhanced motivation to result in increased CV responsiveness. Of course, the after-effects on the fault finding task themselves act as an independent source of support for the inferences concerning the effort→fatigue linkage. However, we recognize the value of employing physiological measures in future studies. In summary, the present findings make a significant contribution to the understanding of the role of effort in the development of fatigue.

References

Bakker, A.B. (2008). The work-related flow inventory: construction and initial validation of the WOLF. *Journal of Vocational Behavior*, 72, 400-414.

Baumeister, R. F., Vohs, K. D., & Tice, D. (2007). The strength model of self-control. *Current Directions in Psychological Science*, 16 (6), 351-355.

Blascovich, J. (2008). Challenge and threat. In: Elliot, A.J. (Ed.), *Handbook of Approach and Avoidance Motivation*. Psychology Press, New York, pp. 431–445.

Brehm, J. W., & Self, E. A. (1989). The intensity of motivation. *Annual Review of Psychology*, 40 (1), 109-131.

Broadbent, D. E. (1979). Is a fatigue test now possible? *Ergonomics*, 22(12), 1277-1290.

Carver, C. S., Scheier, M. F., & Weintraub, J. K. (1989). Assessing coping strategies: A theoretically based approach. *Journal of Personality and Social Psychology*, 56, 267-283.

Carver, C. S., & Scheier, M. F. (1990). Origins and functions of positive and negative affect: A control process view. *Psychological Review*, 97, 19-35.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2nd ed.)*. Hillsdale, NJ: Erlbaum.

Cohen, S. (1980). After-effects of stress on human performance and social behavior: a review of research and theory. *Psychological Bulletin*, 88, 82-108.

Csikszentmihalyi, M. (1990). *Flow: the psychology of optimal experience*. New York, NY: Harper & Row.

Earle, F. (2004). *The construct of psychological fatigue: A psychometric and experimental analysis*. Doctoral dissertation, University of Hull, Hull, UK.

Eysenck, M. W. (1992). *Anxiety: The cognitive perspective*. Hove, UK: Erlbaum.

Frankenhaeuser, M. (1986). A psychobiological framework for research on human stress and coping. In M.H. Appley & R. Trumbull (Eds.): *Dynamics of stress: physiological, psychological and social perspectives*. New York, NY: Plenum.

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

Gendolla, G. H. E., & Richter, M. (2010). Effort mobilization when the self is involved: Some lessons from the cardiovascular system. *Review of General Psychology*, 14(3), 212-226.

Henry, J. P. & Stephens, J. M. (1977). *Stress, health and the social environment: A sociobiological approach to medicine*. New York: Springer Verlag.

Hancock, P. A., & Desmond, P. A. (2001). *Stress, workload and fatigue*. Mahwah, NJ: Lawrence Erlbaum.

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

Hockey, G. R. J. (2013). *The psychology of fatigue: work, effort and control*. Cambridge, UK: Cambridge University Press.

Hockey, G. R. J., & Earle, F. (2006). Control over the scheduling of simulated office work reduces the impact of workload on mental fatigue and task performance. *Journal of Experimental Psychology: Applied*, 12, 50-65.

Hockey, G. R. J., Nickel, P., Roberts, A. C., & Roberts, M. H. (2009). Sensitivity of candidate markers of psychophysiological strain to cyclical changes in manual control load during simulated process control. *Applied Ergonomics*, 40,1011-1018.

Hockey, G. R. J., Wastell, D. G. & Sauer, J. (1998). Effects of sleep deprivation and user interface on complex performance: A multilevel analysis of compensatory control. *Human Factors*, 40, 233-253.

Holding, D. H. (1983). Fatigue. In G.R.J. Hockey (Ed.), *Stress and Fatigue in Human Performance*. New York: John Wiley & Sons Ltd.

Inzlicht, M., Schmeichel , B. J., & Macrae, C. N. (2013) Why self-control seems (but may not be) limited. *Trends in Cognitive Sciences*, 18 (3) 127-133.

Jackson, P. R., Wall, T. D., Martin, R., & Davids, K. (1993). New measures of job control, cognitive demand and production responsibilities. *Journal of Applied Psychology*, 78(5), 753-762.

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

Kalsbeek, J. W. H. (1968). Measurement of mental workload and of acceptable load: possible applications in industry. *International Journal of Production Research*, 7, 33-45.

Kane, M. J. & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: an individual-differences perspective. *Psychonomic Bulletin and Review*, 9, 637-671.

Kool, W., McGuire, J. T., Rosen, Z. B., & Botvinick, M. M. (2010). Decision making and the avoidance of cognitive demand. *Journal of Experimental Psychology: General*, 139, 665–682.

Kruglanski, A. W., Bélanger, J. J., Chen, X., Köpetz, C., Pierro, A., & Mannetti, L. (2012). The energetics of motivated cognition: a force-field analysis. *Psychological Review*. 119, 1-20.

Kurzban, R., Duckworth, A., Kable, J. W., & Myers, J. (2013). An opportunity cost model of subjective effort and task performance. *Behavioral and Brain Sciences*, 36, 661–726.

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal, and coping*. New York: Springer Publishing.

Locke, E. A. & Latham, G. P. (1990). Work Motivation and Satisfaction: Light at the End of the Tunnel. *Psychological Science*. 1, 240-246.

MacDonald, K. B. (2008). Effortful control, explicit processing, and the regulation of human evolved predispositions. *Psychological Review*, 115, 1012–1031.

Matthews, G. (2011). Personality and individual differences in cognitive fatigue. In P.L. Ackerman (Ed.), *Cognitive Fatigue: Multidisciplinary Perspectives on Current Research and Future Applications*. APA: Washington, DC.

Morrison, D. l. & Duncan, K. D (1988). Strategies and tactics fault diagnosis, *Ergonomics*, 31 (5), 761-784.

Mulder, G. (1986). The Concept and Measurement of Mental Effort. In G.R.J. Hockey, A.W.K. Gaillard & M.G.H. Coles (eds.) *Energetics and Human Information Processing*, 175-198.

Mulert, C., Menzinger, E., Leicht, G., Pogarell, O., & Hegerl, U. (2005). Evidence for a close relationship between conscious effort and anterior cingulate cortex activity. *International Journal of Psychophysiology*, 56, 65–80.

Oatley, K. & Johnson-Laird, P. N. (1987). Towards a cognitive theory of emotions. *Cognition and Emotion*, 1, 29‑50.

Obrist, P. A. (1976). The cardiovascular-behavioral interaction - as it appears today. *Psychophysiology*, 13, 95-107.

Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: detecting the snake in the grass. *Journal of Experimental Psychology: General*, 130, 466-478.

Reid, G.B. & Nygren, T.E. (1988). The Subjective Workload Assessment Technique: A Scaling Procedure for Measuring Mental Workload. *Advances in Psychology*, 52, 185-218.

Rouse, W. B. (1978). Human problem solving performance in a fault diagnosis task. *IEE Transactions on Systems, Man, and Cybernetics*, 8, 258-271.

Sarter, M., Gehring, W. J., & Kozak, R. (2006). More attention must be paid: the neurobiology of attentional effort. *Brain Research Review*, 51 (2), 145–160.

Schmidtke, H. (1976). Vigilance. In E. Simpson & P. C. Weiser (Eds.), *Psychological and physiological correlates of work and fatigue* (pp. 193–219). Springfield, IL: Charles C Thomas.

Ursin, H. & Eriksen, H. R. (2004). The cognitive activation theory of stress. *Psychoneuroendocrinology*, 29, 567–592.

van der Linden, D., Frese, M., & Meijman, T. F.(2003). Mental fatigue and the control of cognitive processes: effects on perseveration and planning. *Acta Psychologica*, 113, 45- 65.

Waldstein, S. R., Bachen, E. A., Manuck, S. B., (1997). Active coping and cardiovascular reactivity: a multiplicity of influences. *Psychosomatic Medicine*, 59, 620–625.

Webster, D. M., Richter, L. & Kruglanski, A. W. (1996) On leaping to conclusions when feeling tired: Mental fatigue effects on impressional primacy. *Journal of Experimental Social Psychology*, 32 (2), 181‑195.

Wickens, C. D. & Hollands, J. (2000). *Engineering Psychology and Human Performance, 3rd edition*: Upper Saddle River, NJ: Prentice Hall.

Wright, R. A. (2008). Refining the prediction of effort: Brehm's distinction between potential motivation and motivation intensity. *Social and Personality Psychology Compass*, 2, 682-701.

Wright, R. A., Junious, T. R., Neal, C., Avello, A., Graham, C., Herrmann, L., et al. (2007). Mental fatigue influence on effort-related cardiovascular response: difficulty effects and extension across cognitive performance domains. *Motivation and Emotion*, 31, 219-231.