Journal of Experimental Psychology:
Human Perception and Performance

0096-1523/16/$12.00 http://dx.doi.org/10.1037/xhp0000189

Shifts in Attention During Mental Fatigue: Evidence From Subjective, Behavioral, Physiological, and Eye-Tracking Data

Jesper F. Hopstaken, Dimitri van der Linden,
and Arnold B. Bakker
Erasmus University Rotterdam

Michiel A. J. Kompier
Radboud University

Yik Kiu Leung
Erasmus University Rotterdam

There is an increasing amount of evidence that during mental fatigue, shifts in motivation drive performance rather than reductions in finite mental energy. So far, studies that investigated such an approach have mainly focused on cognitive indicators of task engagement that were measured during controlled tasks, offering limited to no alternative stimuli. Therefore it remained unclear whether during fatigue, attention is diverted to stimuli that are unrelated to the task, or whether fatigued individuals still focused on the task but were unable to use their cognitive resources efficiently. With a combination of subjective, EEG, pupil, eye-tracking, and performance measures the present study investigated the influence of mental fatigue on a cognitive task which also contained alternative task-unrelated stimuli. With increasing time-on-task, task engagement and performance decreased, but there was no significant decrease in gaze toward the task-related stimuli. After increasing the task rewards, irrelevant rewarding stimuli where largely ignored, and task engagement and performance were restored, even though participants still reported to be highly fatigued. Overall, these findings support an explanation of less efficient processing of the task that is influenced by motivational cost/reward tradeoffs, rather than a depletion of a finite mental energy resource.

Keywords: attention, mental fatigue, motivation, self-control, task engagement

For many years, scholars have tried to explain the phenomenon of mental fatigue. During the early years, fatigue has mainly been interpreted as the result of a loss in energetic resources after excessive work and been used as a performance indicator (Griffith, Kerr, Mayo, & Topal, 1950; Ryan, 1947). With this interpretation of fatigue in mind, the concept of mental energy served as a requirement for motivation and action. According to this classical view, when energy is lacking people are less able to initiate or sustain behavior effectively. As a result, performance decreases. More recently, this approach has been challenged by findings of recovered effective behavior when people are externally motivated, even though they were previously too fatigued to continue (Boksem, Meijman, & Lorist, 2006; Hockey, 2013; Hopstaken, van der Linden, Bakker, & Kompier, 2015a). This has led to a new interpretation of mental fatigue as a stop emotion, signaling us to stop working long before our actual ability to work runs out (van der Linden, 2011). In line with this idea, Hockey (2013) suggested that fatigue is an adaptive state signaling a conflict in deciding between what is being done and what else might be done. This underpins the influence of self-control and motivation in the experience of mental fatigue.

Inzlicht, Schmeichel, and Macrae (2014) have emphasized that problems with maintaining task engagement (e.g., in a fatigued state) are often the product of evolutionary pressures that motivate organisms to balance their desires for exploitation of the task at hand versus exploration of the environment. This desire for exploitation versus exploration derives from a trade-off between the expected costs and rewards of a task (Aston-Jones & Cohen, 2005; Cohen, McClure, & Yu, 2007). When the cost/reward trade-off is favorable, exploitation of the task rewards by engaging into the task is stimulated. In that case, even though asserting cognitive control is aversive, the task provides enough intrinsic (e.g., pleasure, excitement) and/or extrinsic (e.g., monetary benefits) rewards to make it worth the effort. However, when the trade-off becomes unfavorable, the person will tend to disengage from the task. Instead of exploiting the task rewards, it becomes more likely that one starts to explore the environment to find potentially more rewarding tasks. This increases the probability of failures in self-

---

Jesper F. Hopstaken, Dimitri van der Linden, and Arnold B. Bakker, Department of Work and Organizational Psychology, Institute of Psychology, Erasmus University Rotterdam; Michiel A. J. Kompier, Behavioural Science Institute, Radboud University; Yik Kiu Leung, Department of Work and Organizational Psychology, Institute of Psychology, Erasmus University Rotterdam.

This work is part of the research programme 400-08-015, which is (partly) financed by the Netherlands Organisation for Scientific Research (NWO).

Correspondence concerning this article should be addressed to Jesper F. Hopstaken, Department of Work and Organizational Psychology, Institute of Psychology, Erasmus University Rotterdam, Burgemeester Oudlaan 50, 3062 PA Rotterdam, The Netherlands. E-mail: jesperhopstaken@gmail.com

control and task-related behavior that are often observed during mental fatigue (van der Linden, Frese, & Meijman, 2003). Both the fatigue and the self-control literature explain the link between motivational cost/reward trade-offs (Boksem & Tops, 2008) and the effects of diminished performance via the process of attentional disengagement (Hopstaken et al., 2015a; Inzlicht et al., 2014).

Although there is substantial empirical evidence for the involvement of motivational cost/reward trade-offs in mental fatigue (Boksem et al., 2006; Boksem & Tops, 2008; Hopstaken et al., 2015a), it is less clear what attentional disengagement during mental fatigue actually entails. For example, an important question that remains open is whether fatigued individuals who have been engaging in a task for a considerable amount of time direct their attention to other, and potentially more rewarding tasks. In other words, are they exploring the environment for other, more interesting stimuli? Or, alternatively, do they still try to stay focused on the task, but do so in a less effective way? Although the answers to these questions have important implications for designing fatigue prevention interventions, so far, fatigue studies have mainly focused on cognitive indicators of engagement that are measured during controlled tasks that offer limited to no alternative stimuli to direct attention to. In these studies, it is often observed that when participants become fatigued, (neuro)physiological indicators suggest task disengagement, which is associated with compromised task performance (Boksem, Meijman, & Lorist, 2005; Hopstaken et al., 2015a; Inzlicht & Gutsell, 2007). Nevertheless, it remains unclear whether attention is diverted to stimuli that are not related to the task, or whether fatigued individuals still focused on the task but were unable to use their cognitive resources efficiently.

Schmeichel, Harmon-Jones, and Harmon-Jones (2010) pointed out that fatigued participants, working under conditions that required high levels of attentional control, were more effective in correctly identifying reward-relevant visual symbols (i.e., dollar signs), than participants who worked on tasks that required lower levels of control. For reward-irrelevant symbols (i.e., percent signs), however, this difference was absent. The authors explained this difference by suggesting that fatigued individuals are more sensitive to detect alternative rewarding stimuli that signal a potential desired distraction from the task they were already working on for an extended time. In other words, fatigued individuals would have a tendency to explore the environment for more rewarding activities. In addition to these observations, the opportunity cost model of Kurzban, Duckworth, Kable, and Myers (2013) does not only suggest exploration of the environment when the cost/reward trade-off becomes unfavorable, but also describes that the presence of competing tasks can be considered as costs themselves. When there are more, and especially more rewarding, competing tasks, more control of attention is needed to stay focused on the task at hand. This underpins the relevance of the question whether fatigued individuals disengage from a task to explore other options, or still focus on the task stimuli but do so less effectively.

The absence of competing and potentially rewarding stimuli in most previous studies may have restricted participants in the possibility to explore, by only allowing focus on either the task stimuli or other areas of the lab room that did not contain any rewarding stimuli. Such a design would be limited, given the results of Schmeichel et al. (2010) that suggest that fatigue could possibly lead to increased attention toward unrelated, but rewarding alternative stimuli. Therefore, the goal of the present study is to create a more comprehensive understanding of attentional disengagement during mental fatigue, by introducing alternative rewarding stimuli to the relatively isolated task environment that traditional mental fatigue experiments tend to have. Similarly to previous studies, we use physiological measures to access cognitive disengagement, but we also include eye tracking techniques to investigate in detail how participants divide their gaze over the different stimuli with increasing levels of mental fatigue. In addition, we manipulate task motivation to test how increased external rewards for engaging in the task affects the direction of participants' gaze. Through the utilization of eye-tracking measures, our aim is to provide a more precise and comprehensive understanding of attentional disengagement during mental fatigue.

Mental Fatigue and Shifts in Attention

Continuously working on a demanding cognitive task for an hour or more has repeatedly been found to induce mental fatigue and to result in decreased task performance (Boksem et al., 2006; Hopstaken et al., 2015a; Lorist, 2008). In the present study, we will induce mental fatigue using such a time-on-task paradigm and introduce alternative stimuli to the experimental environment. Specifically, we present images of faces on the far sides of the screen during parts of the experiment. It has been widely acknowledged that faces are inherently rewarding to look at even when they are not task-relevant, because they have an evolutionary adaptive role and potentially contain important social information (Johnson, 2005; Schmidt & Cohn, 2001). Because the face stimuli constitute alternative rewarding stimuli to the environment, eye-tracking can be used to observe the focus of gaze with increasing time-on-task and mental fatigue.

Alongside eye-tracking, we also monitor subjective ratings of fatigue and engagement, physiological indicators of engagement (i.e., P3 amplitude and baseline pupil diameter), and task performance. The combination of these measures allows us to observe the amount of task disengagement with increasing time-on-task, as has been done in previous studies (e.g., Hopstaken et al., 2015a; Murphy, Robertson, Balsters, & O'Connell, 2011), but also to observe the direction of the participant's gaze, which presents information about possible shifts in attention. This will result in a more precise insight in disengagement of attention during mental fatigue and may answer the question whether performance decrements during fatigue are caused by a less efficient processing of the task, or distraction from the task and exploration of alternative stimuli. An increase in gaze position toward the alternative stimuli would point toward the exploration explanation. In this case, general engagement, or the ability to process information, is not necessarily compromised but rather redirected toward other stimuli. When gaze is still prominently directed toward the task-related stimuli, this would imply that although participants are still focusing their eyes on the task, the processing of the stimuli they look at may be less efficient. The first research aim of this study is investigate whether engagement is redirected during mental fatigue, or participants are still attending the task-related stimuli but process them less efficiently.

The second aim of the present study is to investigate the flexibility of the mechanisms that direct disengagement during mental fatigue. We examine whether increasing motivation for task engagement can reverse the effects of mental fatigue. To test this, we have included a manipulation in which the rewards for engagement are increased after the participants have already worked on the task for 90 min. Following the exploration explanation, we would expect that increasing the rewards of the task would redirect engagement toward it. Following the less efficient processing explanation, there are still two distinct possible explanations. First, fatigue could be associated with depleted energy resources. In this case, the increase of motivation is expected to lead to no, or only very minor, improvements of performance. Specifically, if resources are depleted it would take recuperation (e.g., resting or doing something different) to replenish these resources. The second explanation is that fatigue effects are related to more flexible motivational mechanisms. In this case, we expect that performance may show strong improvements or even go back to initial levels after the motivational manipulation. Only this latter explanation predicts that increasing the benefits of task engagement will result in reengagement in the task. Therefore, we also expect that there could be an increase in the subjective and physiological indicators of task engagement, and possibly the amount of time gaze is directed toward the task, to maximize the newly established benefits of the task that are introduced by the manipulation.

Method

Participants

Forty-seven undergraduate students (15 males, 32 females), between the age of 18 and 25 (*M* = 20.5 years, *SD* = 1.8) participated for study credits. All participants were well-rested and in good health as measured by self-report. The participants reported to have slept seven or more hours and were asked to withhold the intake of caffeine and alcohol during the 24 hr before the experiment. All participants had normal or corrected to normal vision. Written informed consent was obtained prior to the study.

Stimuli and Data Acquisition

Participants were seated in a comfortable chair in a dimly lit and sound-attenuated room facing an eye-tracking screen at a distance of approximately 65 cm. During the experiment, pupil diameter, gaze position, and EEG were measured continuously. Participants performed a visual letter 2-back task. They were asked to decide whether the letter presented on the screen was a target or nontarget stimulus. In the 2-back task a stimulus is a target when the presented letter is the same as the letter presented two letters before. Accordingly, they responded on the corresponding button at the keyboard in front of them. The stimuli were presented in the center of the screen and consisted of the letters B, C, D, E, G, J, P, T, V, and W in the font Palatino Linotype point size 60. In the Dutch language these letters are phonologically similar to prevent sound-related retrieval strategies. The letters were presented randomly with a target rate of 25%. The 2-back task has been used successfully in previous experiments to induce mental fatigue (Hopstaken et al., 2015a; Massar, Wester, Volkerts, & Kenemans, 2010). It is a cognitively demanding task that requires the sustained engagement of working memory and attention to uphold adequate levels of performance (Watter, Geffen, & Geffen, 2001).

Pictures of human faces were presented on both sides of the screen alongside the letters of the 2-back task as alternative task-unrelated distractor stimuli in some parts of the experiment (see procedure). These face stimuli where greyscale photos with a size of 256 × 384 pixels, selected from the Face Recognition Technology (FERET) program database. FERET is a large database of facial images developed by the National Institute of Standards and Technology for testing face recognition algorithms and other research purposes. The database consists of 9,457 photos containing 1,199 unique individuals. Seven hundred thirty-two unique individuals with neutral expression were selected for the present study. Half of the images selected were male and different ethnicities were selected and randomly presented during the task to minimize potential gender and cultural biases.

Procedure

Before the experiment, participants filled out questionnaires about their general health, current level of fatigue and task motivation (see below). After the calibration of the eye-tracking device, participants were instructed on the 2-back task. Participants practiced until they reached a minimum of 70% accuracy. The experimental task was divided in seven time-on-task blocks. Each block consisted of 139 trials 2-back task and lasted for about 15 min (depending on random intervals). The 2-back stimuli were displayed for 500 ms with an interstimulus interval randomized at 5 to 5.5 s. The length of this interval was long enough to ensure that the pupil diameter returned to baseline levels (Beatty, 1982; Stern, Ray, & Quigley, 2000). We displayed the face images at the far left and right side of the screen during the 500 ms the 2-back stimuli were presented. We alternated blocks that contained the face stimuli with blocks that contained only task-related stimuli. To counterbalance conditions, participants were randomly assigned to Version 1 or Version 2. In Version 1, faces were presented in Blocks 2, 4, ad 6 and in Version 2 faces were presented in Blocks 1, 3, and 5. After each block, participants had to indicate their current level of fatigue and task engagement. The participants only had limited time to respond, to make sure they would not rest.

Reward manipulation. After participants completed six blocks, a reward manipulation was introduced. We told them that the remaining time of the experiment would depend on their performance relative to their performance on the previous blocks. We explained that if they would perform better than the previous blocks, the remaining time could be as short as about 5 min. However, we also told them that if they performed similar or worse the remaining time could run up to about 40 min (i.e., it could range from somewhere between 5 and 40 min depending on their performance). Previous studies point out that after about 90 min of continuous performance, such a manipulation provides a strong incentive to optimize performance (Esterman, Reagan, Liu, Turner, & DeGutis, 2014; Hopstaken et al., 2015a). In reality the length of this last block was the same as the first six blocks (i.e., 15 min) for each participant. During this last block, face stimuli were shown in each of the two versions of the experiment. Doing so, we were able to investigate the effect of the manipulation on task-related attention, relative to the attentional pull that the face stimuli may have. After the experimental task, the participants were asked to fill in questionnaires about their level of fatigue and were debriefed.

Measures and Data Processing

Subjective measures. Subjective fatigue was measured before, during and after the task in order to monitor its temporal progression. Before and after the task participants filled in the Rating Scale Mental Effort (RSME; Zijlstra, 1993), which consists of seven vertical scales assessing different aspects of mental fatigue (e.g., difficulty to keep attention on the task, difficulty to exert further effort in the task). The scales have numerical (0 to 150) and verbal ("not at all" to "extremely") anchors.

To measure subjective experience of fatigue during the experiment, participants were asked "How tired do you feel?" after each time-on-task block. They had to reply by moving a slider from 0 to 100, with increments of five. The slider had no anchors, but the extreme ends were labeled with "very much" and "not at all." Immediately after this question, we also asked "How engaged were you in the task?" after each time-on-task block, to investigate subjective engagement during the experiment. The participants again had to reply by moving a slider from 0 to 100, with increments of five. The slider had no anchors except for the extremes "very much" and "not at all."

Behavioral measures. The most relevant behavioral measure of performance on the n-back task was accuracy. As described by signal detection theory, the d-prime was calculated as an indication of accuracy. First we calculated the sensitivity to target stimuli of the participants (i.e., the ability to correctly identify the targets) by dividing their correct identifications of target stimuli by the total number of targets that where displayed during each block. This is called the hit rate of the n-back task. Similarly, we also calculated the participants' false alarm rate (i.e., how many nontargets are incorrectly indicated as targets). By subtracting the standardized false alarm rate from the standardized hit rate we calculated d-prime, which can be used a sensitivity measure of the accuracy of participants (cf. Wickens, 2001). While accuracy was the most important focus for the participant during the task, we wanted to make sure accuracy effects were not clouded by accuracy/speed trade-offs. Therefore, we also examined reaction times (RTs).

Area of interest, pupil, and EEG measures. Pupil diameter and gaze position were recorded continuously during the entire length of the experimental task with a SMI RED250 eyetracker with a sample rate of 60 Hz. For the recording of the EEG we used a BioSemi Active-Two with Ag/AgCl active electrodes at 32 + 2 scalp sites (International 10–20 system). There were six additional electrodes attached. Two electrodes were placed on the left and right mastoids as reference electrodes. To allow for correction of ocular movement artifacts we placed two electrodes next to the outer side of the eyes for horizontal electrooculogram (HEOG) and two above and below the left eye for vertical electrooculogram (VEOG). Online signals were recorded with a sample rate of 512 Hz and 24-bit A/D conversion. Because of technical problems, movement artifacts, and/or calibration errors some of the eye-tracking and EEG data failed to record correctly for the entire 90 min of the experiment. We excluded these data from the analysis of that specific source. Because of this, we used 37 participants in the EEG analysis and 35 participants in the eye-tracking and pupil diameter analysis.

Information about gaze position was obtained by defining and comparing gaze toward task-related areas, two face-stimulus areas and the rest of the remaining areas containing a black background. The task-related stimulus (the 2-back letter) was positioned in the center of the screen surrounded by an area of interest of 320 × 320 pixels. The face images were vertically centered and positioned at the far left and right side of the screen. They were each surrounded by an area of interest of 380 × 520 pixels and analyzed as one area (i.e., by adding up the gaze toward each of the two areas). With a screen resolution of 1680 × 1050 the space between the task and face areas of interest was 300 pixels, ensuring enough discriminability. Relative gaze time toward the task, face, and other areas of the screen during the 500 ms the stimuli were displayed was aggregated on the block level and exported to SPSS. We also exported the percentage of missing data during each block as an indication of off-screen gaze or closed eyes.

To measure baseline pupil diameter, we averaged the pupil diameter in the 200 ms before stimulus onset. During this period the participants saw a black screen with a fixation cross. Therefore, there was no interference from pupillary reflexes to the environmental lighting during the baseline recording. Baseline pupil diameter for each time-on-task interval was exported to SPSS for further analysis.

Extensive research of the P3 shows the distinction between the P3a and P3b potential (Polich, 2007). The P3a is linked to novelty detection and best seen at the Cz and Fz electrodes. The P3b is linked to salience processing and is best seen at the Pz electrode. Because we were interested in the latter we analyzed the EEG signal at the Pz electrode. Reviewing the voltage maps confirmed that the amplitude of the P3 was indeed largest at Pz. The EEG data were analyzed in Brain Vision Analyzer (Brain Products, Gilching, Germany). The ERPs were averaged offline after rejection of out of range artifacts and eye movements, using the Gratton and Coles method (Gratton, Coles, & Donchin, 1983). Segments with amplitudes higher than 200 μV and lower than -200 μV and voltage steps above 50 μV/ms were removed. The data were also inspected on low activity (below 0.1 μV) and filtered (low cutoff at 0.1 Hz and high cutoff at 40 Hz). After baseline correction for the 200 ms before the stimulus onset, we aggregated the data per condition and measured the positive peak between 300 and 450 ms after the onset of the stimulus. Trials in which performance errors occurred were excluded. The mean P3 peak activity for each time-on-task interval was then exported to SPSS for further analysis.

Statistical Analysis

The subjective, behavioral, gaze, and psychophysiological data were exported to SPSS and statistically analyzed using repeated measures analysis of variance (ANOVA). Because each participant did three blocks with face stimuli and three without face stimuli, we used a 3 × 2 design with time-on-task and the presence or absence of face stimuli as within subject factors. We tested the main and interaction effect of time-on-task (Block 1, 2, and 3) and face stimulus (blocks with and without alternative stimulus). Also, we tested the effect of the reward/motivation manipulation by comparing the last block with face stimuli before the manipulation, with the block after the manipulation (which also contained the face stimuli).

In addition to the repeated measures ANOVA, we analyzed the data using a multilevel approach with Mplus statistical software. A multilevel approach to experimental data has rarely been used in previous fatigue studies but can be a very useful addition. Specifically, repeated measures data can be treated as multilevel data, with the repeated measures nested within individuals. We calculated the correlation between the various outcome measures on the individual level with the nested structure of the data taken into account (i.e., blocks nested within-persons). We used a two-level model with time-on-task block at the first level (Level 1; $n = 238$), and individuals at the second level (Level 2; $n = 34$). In this operationalization, a high correlation between dependent variables, means that a change in one variable corresponds with a similar change in another variable for each time-on-task block within individuals.

Results

Subjective Measures

Pre- and posttask analyses of the RSME confirmed that our fatigue manipulation was successful as participants reported significantly higher levels of subjective fatigue after the experiment than before, $t(46) = -19.8$, $p < .001$. Figure 1 shows the progression of subjective fatigue and task engagement during the course of the experiment. This figure shows the effect of time-on-task and the reward manipulation on both of the subjective measures, while also clearly showing the similarity in blocks with and without face stimuli. During the experiment, subjective fatigue increased over time in the blocks before the reward manipulation, $F(2, 92) = 71.5$, $p < .001$, $\eta^2 = .61$, but decreased after the reward manipulation, $F(1, 46) = 15.2$, $p < .001$, $\eta^2 = .25$. We neither found a main effect of the face stimuli, $F(1, 46) = .06$, *ns*, $\eta^2 < .01$, nor a Face × Time-on-Task interaction effect, $F(2, 92) = .6$, *ns*, $\eta^2 = .01$, on subjective fatigue.

Subjective task engagement significantly decreased with increasing time-on-task before the reward manipulation, $F(2, 92) = 49.2$, $p < .001$, $\eta^2 = .52$. After the reward manipulation, there was a significant increase, indicating reengagement into the task, $F(1, 46) = 15.2$, $p < .001$, $\eta^2 = .25$. Similarly to subjective fatigue, we did not find a main effect of the face stimuli, $F(1, 46) = 4.0$, *ns*, $\eta^2 = .08$, or A Face × Time-on-Task interaction, $F(2, 92) = 1.9$, *ns*, $\eta^2 = .04$.

Behavioral Measures

As Figure 2 clearly shows, the results of the performance measure were largely in line with the findings on the subjective measures. Specifically, we found that d-prime decreased from the first to the sixth block, $F(2, 92) = 22.5$, $p < .001$, $\eta^2 = .33$, suggesting that fatigue compromised cognitive performance. After the reward manipulation in block seven d-prime clearly increased again, $F(1, 46) = 46.4$, $p < .001$, $\eta^2 = .50$. Also similar to the results of the subjective measures was the absence of a main effect of the face stimuli, $F(1, 46) = 1.7$, *ns*, $\eta^2 = .04$, and the interaction between time-on-task and the faces, $F(2, 92) = .8$, *ns*, $\eta^2 < .01$, on task performance. We did find a decrease in RT before the reward manipulation as well, suggesting a (partial) speed/accuracy trade-off, $M_1 = 960$ ms, $M_2 = 884$ ms, $M_3 = 858$ ms, $F(2, 92) = 16.3$, $p < .001$, $\eta^2 = .26$. However, after the reward manipulation RT did not change significantly ($M_{\text{pre}} = 845$ ms, $M_{\text{post}} = 848$ ms), $F(1, 46) = .1$, *ns*, $\eta^2 < .01$, while accuracy improved. This indicates that before the reward manipulation participants performed suboptimal even after slowing down their RT, which makes it less likely that the results before the manipulation were solely caused by a speed/accuracy trade-off.

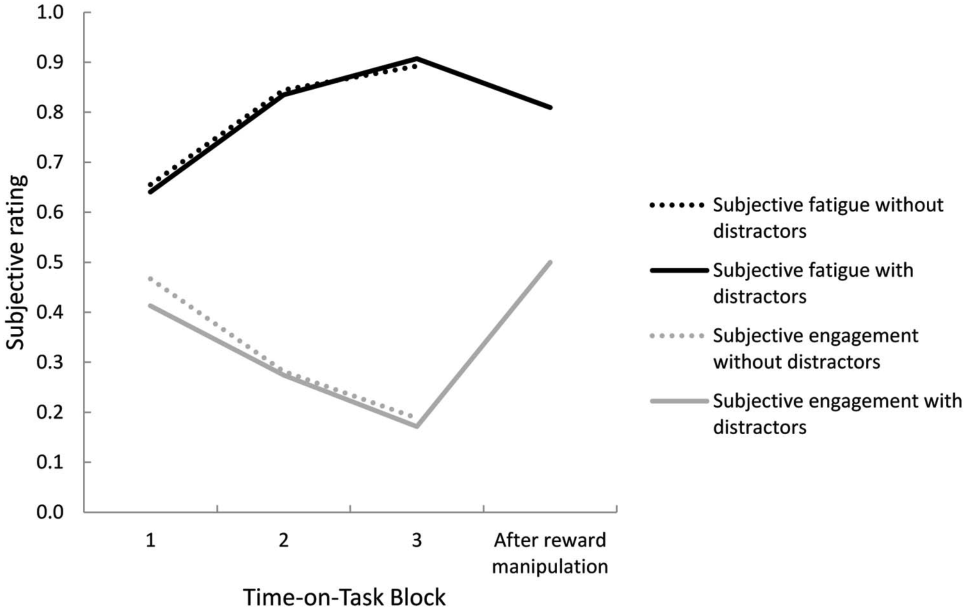


Figure 1. Subjective ratings of fatigue and task engagement with increasing time-on-task.

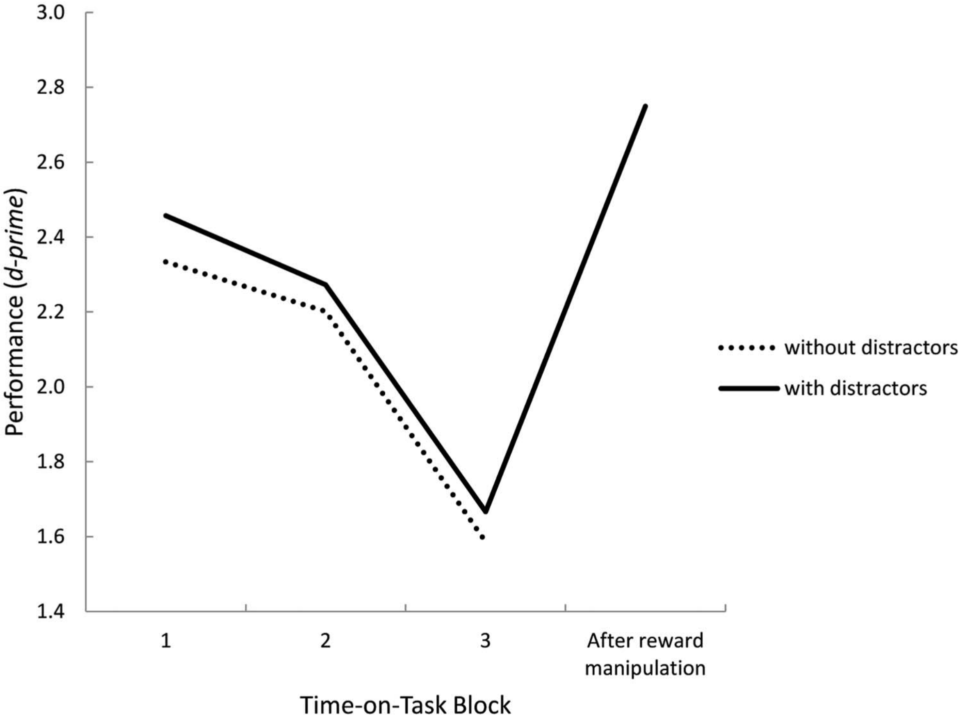


Figure 2. Performance with increasing time-on-task.

Gaze Data

Table 1 shows the percentage of the gaze toward each of the areas of interest during each of the time-on-task blocks. Using repeated-measures ANOVA, we found that the percentage of off-screen and missing gaze position significantly increased from Block 1 through Block 6, $F(2, 68) = 10.0$, $p = .001$, $\eta^2 = .23$, while the change over time in the other areas did not reach significant levels—task: $F(2, 68) = 2.4$, $p = .10$, $\eta^2 = .07$; faces: $F(2, 68) = 1.2$, *ns*, $\eta^2 = .03$; rest of screen: $F(2, 68) = 1.2$, *ns*, $\eta^2 = .04$. This shows that increased fatigue is not necessarily associated with decreased time focused on the task-related area of the screen or an increase toward the task-unrelated rewarding alternatives (i.e., the faces). After the reward manipulation in the last block, the percentage of off-screen or missing gaze position, $F(1, 34) = 15.3$, $p < .001$, $\eta^2 = .3$, and gaze toward the faces, $F(1, 34) = 18.2$, $p < .001$, $\eta^2 = .35$, significantly decreased, whereas gaze toward the task significantly increased, $F(1, 34) = 10.1$, $p < .01$, $\eta^2 = .23$. This is in line with the explanation of a flexible motivational system, which predicts that participants reengage in the task after increasing the rewards of the task. The percentage of gaze toward the rest of the screen (which was already very small) remained stable after the reward manipulation, $F(1, 34) = .5$, *ns*, $\eta^2 = .01$.

We found a significant main effect of the face stimuli for all areas of interest. In blocks that contained face stimuli (vs. blocks that did not contain faces), participants looked more at the face areas, $F(1, 34) = 7.0$, $p < .05$, $\eta^2 = .17$, but surprisingly also looked more at the task related stimuli, $F(1, 34) = 5.0$, $p < .05$,

Table 1
Percentage of Gaze Towards Each of the Areas of Interest With Time-on-Task

Gaze direction	Block 1	Block 2	Block 3	After reward manipulation
Area of interest: task				
Without faces	70.5	67.2	65.1	—
With faces	73.4	73.9	70.4	78.8
Area of interest: faces				
Without faces	.6	.6	.7	—
With faces	3.5	2.7	4.3	.9
Area of interest: rest				
Without faces	22.9	24.0	22.4	—
With faces	18.5	18.3	15.4	16.3
Off-screen and missing				
Without faces	5.9	8.3	11.8	—
With faces	4.7	5.2	9.9	4.0

$\eta^2 = .13$. At the same time, they looked relatively less at the rest of the screen, $F(1, 34) = 18.3, p < .001, \eta^2 = .35$, and there were less off-screen and missing gaze positions, $F(1, 34) = 4.8, p < .05, \eta^2 = .13$. This means that the presence of the faces seems to influence gaze position, but that it did not lead to decreased time focused on the task-related area of the screen. We did not find any interaction effects between time-on-task and the faces—task area: $F(2, 68) = .8$, *ns*, $\eta^2 = .02$; face areas: $F(2, 68) = .8$, *ns*, $\eta^2 = .02$; rest of screen areas: $F(2, 68) = .6$, *ns*, $\eta^2 = .02$; off-screen/missing: $F(2, 68) = 1.0$, *ns*, $\eta^2 = .03$.

Pupil Diameter

As displayed in Figure 3, baseline pupil diameter significantly decreased with time on task throughout the first six blocks of the experiment, $F(2, 68) = 8.2, p < .01, \eta^2 = .20$, and significantly increased again after the reward manipulation in the last block, $F(1, 34) = 13.7, p = .001, \eta^2 = .29$. This is in line with earlier findings that pupil diameter is sensitive to time-on-task fatigue effects (e.g., Hopstaken et al., 2015a). We also found a main effect for the presence of the face stimuli, $F(1, 34) = 13.9, p = .001, \eta^2 = .29$. Blocks with the alternative face stimuli had lower baseline pupil diameter than blocks without the face stimuli. However, this effect is likely caused by the fact that the blocks with the alternative stimuli had a higher average screen luminosity, and it is well known that luminance of the screen and surroundings has profound impact on pupil size. Although the baseline pupil diameter was measured during the period before the stimulus onset (i.e., during a black screen) it is possible that the pupils adapted to the brighter stimuli that were displayed throughout the blocks duration. We did not find an interaction effect between time-on-task and the alternative face stimuli, $F(2, 68) = .14, p = .83, \eta^2 < .01$.

P3 Amplitude

We measured P3 amplitudes as a known physiological indicator of task engagement (Hopstaken et al., 2015a; Murphy et al., 2011; Nieuwenhuis, De Geus, & Aston-Jones, 2011). We first confirmed that the P3b was largest at electrode Pz as can be seen in the voltage maps in Figure 4, which show the localization of the P3 ERP during each time-on-task block. The P3b amplitude showed a strong significant main effect for time-on-task, $F(2, 72) = 28.6, p < .001, \eta^2 = .44$. Figure 5 shows the declining P3 with increasing time-on-task for blocks with and without the presence of face stimuli. Similar to the subjective, behavioral, and pupil data, the P3 amplitude showed a reverse in pattern after the reward manipulation in the last block and increasing significantly as hypothesized, $F(1, 36) = 26.5, p < .001, \eta^2 = .42$. Raw P3 ERPs are displayed in Figure 6. No main effect of the alternative stimulus was found for the P3 amplitude ($F(1, 36) < .01, p = 1, \eta^2 < .01$), and an interaction between time-on-task and the alternative stimulus was also absent, $F(2, 72) = .03, p = .96, \eta^2 < .01$.

Multilevel Analysis of the Subjective, Performance, and Physiological Measures

Although the previously reported findings, obtained by ANOVA, were able to shed light on the progression of mental

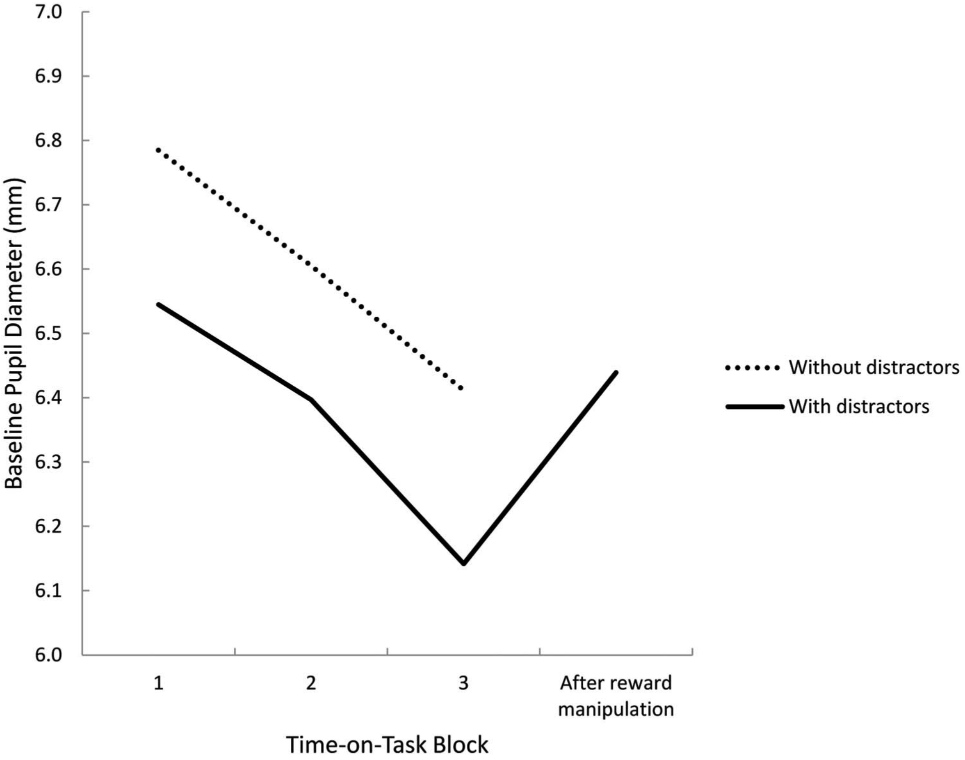


Figure 3. Baseline pupil diameter with increasing time-on-task.

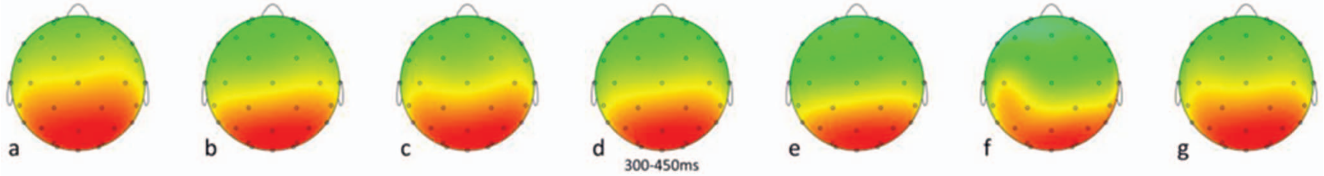


Figure 4. EEG voltage maps in the 300-450 ms range showing that the P3 is largest at electrode Pz on each of the time-on-task blocks. See the online article for the color version of this figure.

fatigue effects over time, this method did not provide direct insight into the associations between the various measures used in the present study. Therefore, to address whether shifts in gaze are related to the various measures of disengagement we utilized multilevel analysis with Mplus statistical software. Using the multilevel approach, we were able to correlate the different measures we have used in this study and directly compare measures within individuals while taking the nested structure (i.e., time-on-task blocks are nested within individuals) of the data into account. This allows us to directly compare the subjective, performance, and physiological measures of engagement to the measures of gaze position during the different phases of the experiment. The use of multilevel analyses is justified when there is sufficient variance explained at two or more levels of analysis. The intraclass correlation (ICC), which is displayed in Table 2, indicates that there indeed was sufficient variance explained on both levels for each observed variable.

Table 2 also shows the correlations for each pair of observed variables. From this table it becomes clear that there are strong correlations between the P3 amplitude, d-prime, pupil diameter, and both subjective measures of fatigue and disengagement. This statistically confirms that a change in one type of measure (e.g., P3 amplitude) was accompanied by a change in another measure (e.g., d-prime), underlining the link between these variables regardless of when this change took place. We found high positive correlations between the percentage of gaze toward the task, several measures of task engagement (i.e., subjective task engagement, P3 amplitude, pupil diameter), and task performance. High negative correlations were found between the amount of gaze toward the faces, off-screen and measures of task engagement and task performance. This indicates that high subjective engagement and physiological engagement are indeed consistently related to attending the task related stimuli. These results also point out that after the task is manipulated to be perceived as more rewarding, and task engagement strongly reappears, gaze toward task-unrelated stimuli (even though they are inherently rewarding and attention-grabbing) is nearly absent.

Discussion

With a combination of subjective, EEG, pupil, eye-tracking, and performance measures the present study tested the influence of

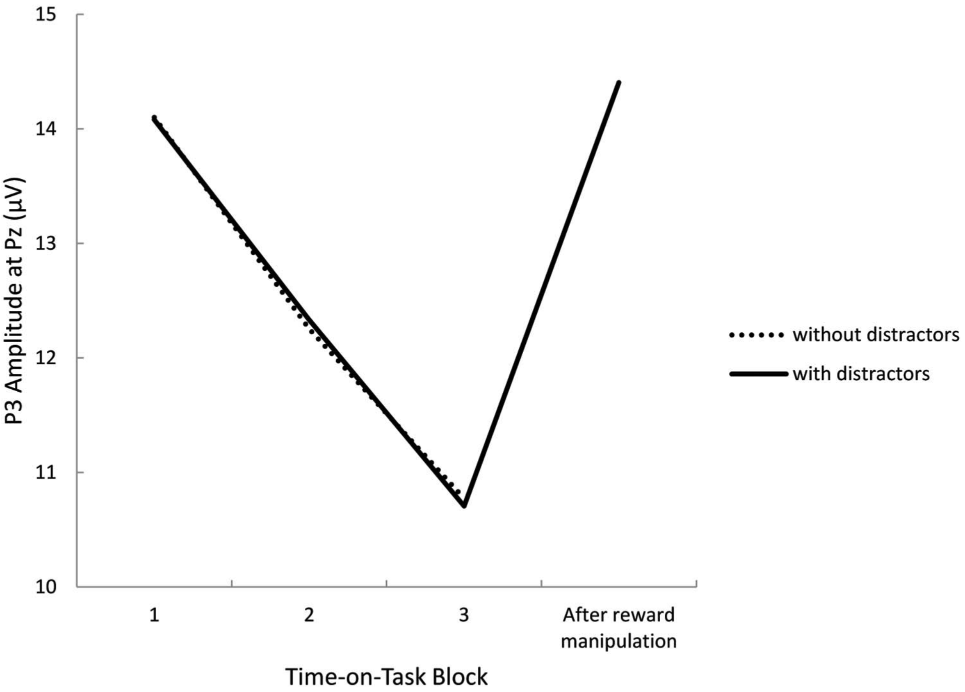


Figure 5. P3 amplitude at electrode Pz with increasing time-on-task.

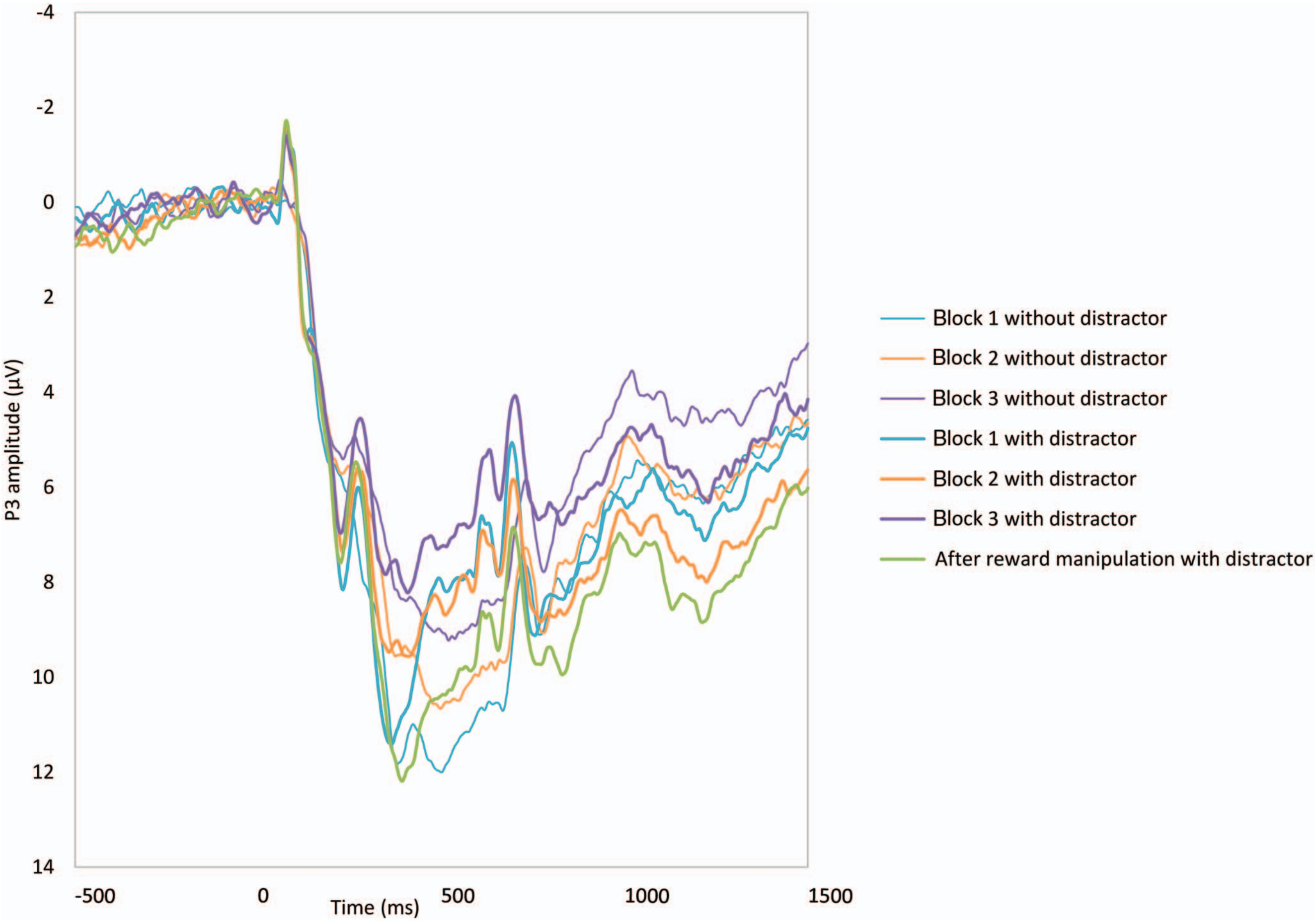
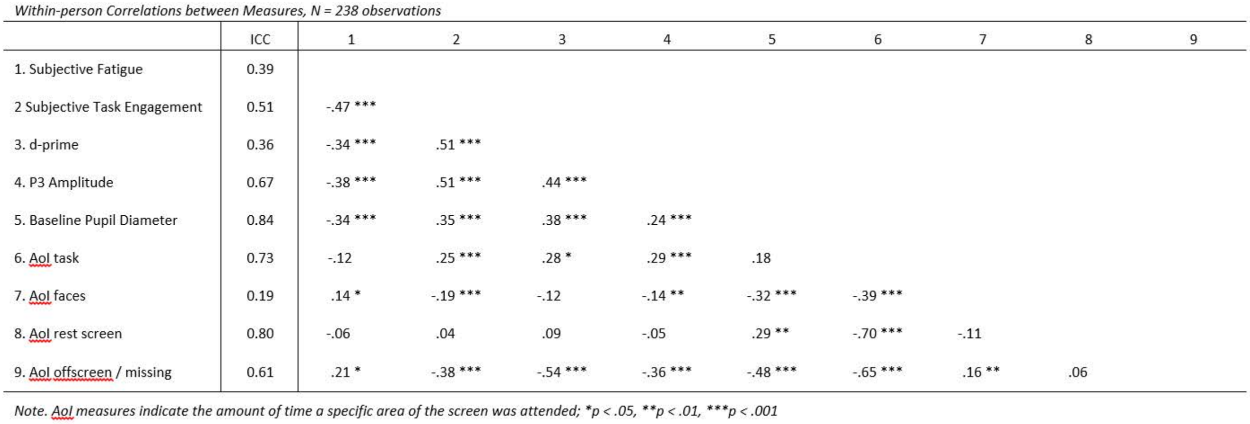


Figure 6. Raw P3 amplitudes at electrode Pz. See the online article for the color version of this figure.

mental fatigue on cognitive task performance. The goals of the study where to examine (a) whether task disengagement and decreased task performance where related to explorative shifts in attention versus less efficient processing of the task and (b) whether mental fatigue reflects a depletion of finite energy resources or more likely reflects a motivational mechanism that protects individuals from overspending energy when the benefits are relatively low. During several parts of the experiment, face stimuli were presented as a potentially rewarding alternative to the task-related stimuli. Although we found that task disengagement was related to an increase of gaze toward these face stimuli, there was no significant decrease in gaze toward the task-related stimuli with increasing time-on-task. Compared to parts of the experiment without faces, the presence of face stimuli also had no additional negative effect on task performance. Therefore, we cannot conclude that the effect of fatigue on task performance was related to

Table 2



Within-person Correlations between Measures, N = 238 observations

	ICC	1	2	3	4	5	6	7	8	9
1. Subjective Fatigue	0.39									
2 Subjective Task Engagement	0.51	-.47 ***								
3. d-prime	0.36	-.34 ***	.51 ***							
4. P3 Amplitude	0.67	-.38 ***	.51 ***	.44 ***						
5. Baseline Pupil Diameter	0.84	-.34 ***	.35 ***	.38 ***	.24 ***					
6. AoI task	0.73	-.12	.25 ***	.28 *	.29 ***	.18				
7. AoI faces	0.19	.14 *	-.19 ***	-.12	-.14 **	-.32 ***	-.39 ***			
8. AoI rest screen	0.80	-.06	.04	.09	-.05	.29 **	-.70 ***	-.11		
9. AoI offscreen / missing	0.61	.21 *	-.38 ***	-.54 ***	-.36 ***	-.48 ***	-.65 ***	.16 **	.06	

*Note. AoI measures indicate the amount of time a specific area of the screen was attended; *p < .05, **p < .01, ***p < .001* exploration of the task-unrelated stimuli, and the explanation of less efficient processing of the task stimuli seems to provide a better explanation of the results. Additional insight into the nature of this less efficient processing was provided by the reward manipulation at the end of the experiment. We found that increasing the rewards for task engagement strongly directed gaze toward task-related stimuli. Although participants still reported to be highly fatigued, irrelevant rewarding stimuli where largely ignored after increasing the task rewards. Subjective and psychophysiological engagement were restored and task performance was even higher than at the start of the experiment. This suggests that participants were able to overcome their subjective state of fatigue and reengage in the task, supporting the view that mental fatigue is a mostly motivationally driven protection mechanism in order to restrain individuals from spending cognitive resources on tasks that are not worth the effort. This directly contradicts the view that fatigue effects are explained by an inability to engage in the task (or explore the alternative stimuli) caused by depleted resources. Direct comparison of the various measures using a multilevel analysis, showed that they were related over the course of the experiment. That is, an increase in subjective fatigue and task disengagement was accompanied by indications of lowered physiological task engagement (i.e., task directed gaze, P3, pupil diameter) and decreased task performance. In what follows, we will discuss the contributions and limitations of the study in more detail.

Fatigue and Control of Attention

Based on the notion that individuals engage in and disengage from a task based on cost/reward trade-offs (Cohen et al., 2007), we predicted that with increasing time-on-task, attention may shift from task-related toward task-unrated stimuli. Our findings showed however, that the amount of gaze toward the task did not decrease significantly throughout the experiment. Combined with the finding that performance still deteriorated, but was restored after increasing the task rewards, this indicates that with increasing time-on-task, the outcome of the cost/reward trade-off for task engagement became less favorable and exploiting the task rewards became less attractive. As an alternative to exploitation of the task there are two options, exploration of the environment to find other activities that may have a more positive cost/reward trade-off, or disengaging in general to save resources for the time they may be more useful. These findings contradict Baumeister et al.'s (1998) theory, which assumes a depletion of a limited resource for self-control and is still very popular and often implemented in practice. Baumeister's resource depletion model states that engaging in effortful control of behavior depletes an inner capacity for self-control. Based on the results of this study, however, we favor an explanation in terms of a motivational cost/reward tradeoffs (e.g., Inzlicht et al., 2014; Kurzban et al., 2013). With increasing time-on-task, the rewards of the experimental task stay the same or may even decrease (i.e., because the task becomes less challenging or interesting), whereas the opportunity cost of not engaging in other possible activities increases. This results in an imbalance between the costs and rewards of the task and eventually leads to disengagement. When the motivation to engage in the task becomes too low, fatigue serves as a stop emotion that protects individuals from overspending energy, and conserve it for the moment that a more rewarding activity presents itself (Hockey, 2011; van der Linden, 2011). When sufficient rewards are presented (i.e., after the rewards manipulation), the imbalance between costs and rewards is restored and participants re-engage in the task. These eye-tracking data provide additional evidence for motivational disengagement, instead of depletion of resources, to best describe the effect of fatigue on attention and task performance.

In addition to the inclusion of eye-tracking, another strength of the present study is that we were able to observe and directly compare the time-on-task effect of several different measures of task engagement. With multilevel correlation analyses we were able to compare the change in one measure (e.g., subjective task engagement) to another measure (e.g., gaze toward task-related areas of the screen). Because we argue that the task was processed less efficiently with increasing fatigue, especially the combination of gaze data and P3 amplitudes was informative. We found that subjective task engagement, P3 amplitude and gaze toward task related areas of the screen correlated strongly and positively over the course of the experiment. Although gaze toward the task-related areas of the screen did not decrease significantly, P3 amplitudes did, which can be seen as evidence for lowered attention and processing of the observed stimuli. Recently P3 amplitudes have been associated with activity in the locus coeruleus and noradrenergic modulation of the brain (Murphy et al., 2011; Nieuwenhuis, Aston-Jones, & Cohen, 2005; Nieuwenhuis, 2011). Aston-Jones and Cohen (2005) distinguish between baseline and stimulus-evoked release of noradrenaline. By combining measures of baseline and stimulus-evoked noradrenaline release, they formulated two operating output modes for the locus coeruleus that lead to task engagement or explorative disengaged behavior. The present study leaves an interesting possibility for a third output mode that describes mental fatigue and leads to a more general disengaged behavior, without specifically exploring the environment for rewarding activities (cf. Hopstaken, van der Linden, Bakker, & Kompier, 2015b).

Relevance and Limitations

Although the present study adds further insight into attention during fatigue, there are also some limitations that should be taken into account. Specifically, although they were attended during the study, the face stimuli that were used as the competing alternative stimulus did not significantly influence task performance. The most important reason to use faces was that they are inherently and universally rewarding and therefore have a high chance of being explored (Johnson, 2005; Schmidt & Cohn, 2001). The downside of this, with regard to our study, is that recognizing and analyzing faces is such an important aspect of adaptive functioning that it has evolved in a 'special' separate system in the brain. Many researchers have argued that the processing of faces is an automatized process utilizing specific mostly autonomous brain regions and requires very little cognitive resources (Lavie, Ro, & Russell, 2003; Vuilleumier, Armony, Driver, & Dolan, 2003). The automatized nature of observing face stimuli could pose an alternative explanation for the absence of a clear exploration effect and the relatively unaffected task performance. In future studies it would be insightful to see whether other task-unrelated rewarding stimuli, that use more cognitive resources, are more likely to lead to exploration behavior during mental fatigue. Finding the right type distractor may deserve a line of research by itself, because it may be challenging to find a distractor that is universally rewarding (i.e., that possesses as a strong reward in a similar way to everybody). A possibility for such a stimulus might be self-rewarding material, although there are indications that this type of stimulus is also processed relatively automatically (Bargh, 1982).

Another thing that could be seen as a limitation is that we chose to adopt a within-subject design to examine our research aims. An important strength of the within-subjects design that we used is that it minimizes error variance and the influence of individual differences in reward evaluation. Because both the face stimuli and the rewards manipulation have a subjective aspect, we consider it methodologically sounder to evaluate fatigue effects within participants, rather than between participants. Although we have no specific reason to expect that a replication of the study with a between-subjects design would yield very different results, we encourage scholars to pursue such a replication that would extend our present contribution.[1]

In addition to the theoretical contributions, the present study also presents considerable implications for practical applications. Specifically the observation that, during mental fatigue, information is processed less efficiently and gaze could be diverted from focusing on task-related stimuli to exploration of the environment, impacts the direction of work safety and work performance interventions. For example, in the sector of transportation and industry fatigue prevention measures are, to large extent, still based on the presumption that fatigue is caused by a loss of energy resources. A common practice in the transportation sector to prevent fatigue related accidents, is to rest 15–20 min every couple of hours (European Commision Mobility & Transport, 2006; Federal Motor Carrier Safety Administration, 2014). Based on the results of this study, which points out the danger of disengagement when the cost/rewards trade-off becomes unfavorable, it seems worthwhile to also explore ways to motivate drivers to focus on the road again. This is particularly important, because resting for 15–20 min does not necessarily seem to change the costs or rewards for engaging in driving after the break. We think there may be an interesting opportunity for future research to compare the efficiency of such a motivational intervention directly to traditional resting interventions.

Conclusion

Although there has been an increasing amount of evidence for a more dynamic model of mental fatigue, which is based on shifts in motivation and attention compared to classical models of resource depletion (e.g., Hopstaken et al., 2015b; Inzlicht & Gutsell, 2007), this study is among the first to specifically address these shifts in attention by tracking gaze position during cognitive performance. Although the addition of alternative stimuli did not have a significant additional effect on task performance, the findings support both shifts in motivation and attention during mental fatigue. Opposed to classical resource depletion views, these shifts were explicitly linked to a motivationally driven inefficient processing of the task. This opens up possibilities for new interventions aimed at the prevention of fatigue and gives a more elaborate view of what impaired attention during mental fatigue actually entails. The finding that subjective task engagement, gaze at task-related stimuli, P3 amplitudes, and task performance correlate highly during the course of the experiment presents a more specific explanation for the often observed impaired task performance during fatigue. Namely, when individuals become fatigued because of sustained task performance, they disengage from the task to protect from overspending costly cognitive resources and save them for times where more rewarding activities present themselves.

---

[1] For an example of a fatigue study using such a design see Wright, Patrick, Thomas, and Barreto (2013).

References

Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus coeruleus-norepinephrine function: Adaptive gain and optimal performance. *Annual Review of Neuroscience, 28,* 403–450. http://dx.doi.org/10.1146/annurev.neuro.28.061604.135709

Bargh, J. A. (1982). Attention and automaticity in the processing of self-relevant information. *Journal of Personality and Social Psychology, 43,* 425–436. http://dx.doi.org/10.1037/0022-3514.43.3.425

Baumeister, R. F., Bratslavsky, E., Muraven, M., & Tice, D. M. (1998). Ego depletion: Is the active self a limited resource? *Journal of Personality and Social Psychology, 74,* 1252–1265. http://www.ncbi.nlm.nih.gov/pubmed/9599441. http://dx.doi.org/10.1037/0022-3514.74.5.1252

Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. *Psychological Bulletin, 91,* 276–292. http://www.ncbi.nlm.nih.gov/pubmed/7071262. http://dx.doi.org/10.1037/0033-2909.91.2.276

Boksem, M. A., Meijman, T. F., & Lorist, M. M. (2005). Effects of mental fatigue on attention: An ERP study. *Cognitive Brain Research, 25,* 107–116. http://dx.doi.org/10.1016/j.cogbrainres.2005.04.011

Boksem, M. A., Meijman, T. F., & Lorist, M. M. (2006). Mental fatigue, motivation and action monitoring. *Biological Psychology, 72,* 123–132. http://dx.doi.org/10.1016/j.biopsycho.2005.08.007

Boksem, M. A., & Tops, M. (2008). Mental fatigue: Costs and benefits. *Brain Research Brain Research Reviews, 59,* 125–139. http://dx.doi.org/10.1016/j.brainresrev.2008.07.001

Cohen, J. D., McClure, S. M., & Yu, A. J. (2007). Should I stay or should I go? How the human brain manages the trade-off between exploitation and exploration. *Philosophical Transactions of the Royal Society of London Series B, Biological Sciences, 362,* 933–942. http://dx.doi.org/10.1098/rstb.2007.2098

Esterman, M., Reagan, A., Liu, G., Turner, C., & DeGutis, J. (2014). Reward reveals dissociable aspects of sustained attention. *Journal of Experimental Psychology: General, 143,* 2287–2295. http://dx.doi.org/10.1037/xge0000019

European Commision Mobility and Transport. (2006). Regulation (EC) 561/2006. Retrieved from http://ec.europa.eu/transport/modes/road/social_provisions/driving_time/index_en.htm

Federal Motor Carrier Safety Administration. (2014). *Hours of service of drivers*. Retrieved from http://www.fmcsa.dot.gov/regulations/hours-service/hours-service-drivers

Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology, 55,* 468–484. http://dx.doi.org/10.1016/0013-4694(83)90135-9

Griffith, J. W., Kerr, W. A., Mayo, T. B., Jr., & Topal, J. R. (1950). Changes in subjective fatigue and readiness for work during the eight-hour shift. *Journal of Applied Psychology, 34,* 163–166. http://dx.doi.org/10.1037/h0053894

Hockey, G. R. J. (2011). A motivational control theory of cognitive fatigue. In P. L. Ackerman (Ed.), *Cognitive fatigue: Multidisciplinary perspectives on current research and future applications* (pp. 167–183). Washington, DC: American Psychological Association. http://dx.doi.org/10.1037/12343-008

Hockey, G. R. J. (2013). *The psychology of fatigue: Work, effort and control*. New York, NY: Cambridge University Press. http://dx.doi.org/10.1017/CBO9781139015394

Hopstaken, J. F., van der Linden, D., Bakker, A. B., & Kompier, M. A. J. (2015a). A multifaceted investigation of the link between mental fatigue and task disengagement. *Psychophysiology, 52,* 305–315. http://dx.doi.org/10.1111/psyp.12339

Hopstaken, J. F., van der Linden, D., Bakker, A. B., & Kompier, M. A. J. (2015b). The window of my eyes: Task disengagement and mental fatigue covary with pupil dynamics. *Biological Psychology, 110,* 100–106. http://dx.doi.org/10.1016/j.biopsycho.2015.06.013

Inzlicht, M., & Gutsell, J. N. (2007). Running on empty: Neural signals for self-control failure. *Psychological Science, 18,* 933–937. http://dx.doi.org/10.1111/j.1467-9280.2007.02004.x

Inzlicht, M., Schmeichel, B. J., & Macrae, C. N. (2014). Why self-control seems (but may not be) limited. *Trends in Cognitive Sciences, 18,* 127–133. http://dx.doi.org/10.1016/j.tics.2013.12.009

Johnson, M. H. (2005). Subcortical face processing. *Nature Reviews Neuroscience, 6,* 766–774. http://dx.doi.org/10.1038/nrn1766

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,* 661–679. http://dx.doi.org/10.1017/S0140525X12003196

Lavie, N., Ro, T., & Russell, C. (2003). The role of perceptual load in processing distractor faces. *Psychological Science, 14,* 510–515. http://dx.doi.org/10.1111/1467-9280.03453

Lorist, M. M. (2008). Impact of top-down control during mental fatigue. *Brain Research, 1232,* 113–123. http://dx.doi.org/10.1016/j.brainres.2008.07.053

Massar, S. A. A., Wester, A. E., Volkerts, E. R., & Kenemans, J. L. (2010). Manipulation specific effects of mental fatigue: Evidence from novelty processing and simulated driving. *Psychophysiology, 47,* 1119–1126.

Murphy, P. R., Robertson, I. H., Balsters, J. H., & O'Connell, R. G. (2011). Pupillometry and P3 index the locus coeruleus-noradrenergic arousal function in humans. *Psychophysiology, 48,* 1532–1543. http://dx.doi.org/10.1111/j.1469-8986.2011.01226.x

Nieuwenhuis, S. (2011). Learning, the P3, and the locus coeruleus-norepinephrine system. In R. B. Mars, J. Sallet, M. F. S. Rushworth, & N. Yeung (Eds.), *Neural basis of motivational and cognitive control* (pp. 209–222). Cambridge, MA: MIT Press. http://dx.doi.org/10.7551/mitpress/9780262016438.003.0012

Nieuwenhuis, S., Aston-Jones, G., & Cohen, J. D. (2005). Decision making, the P3, and the locus coeruleus-norepinephrine system. *Psychological Bulletin, 131,* 510–532.

Nieuwenhuis, S., De Geus, E. J., & Aston-Jones, G. (2011, February). The anatomical and functional relationship between the P3 and autonomic components of the orienting response. *Psychophysiology, 48,* 162–175. http://dx.doi.org/10.1111/j.1469-8986.2010.01057.x

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology, 118,* 2128–2148. http://dx.doi.org/10.1016/j.clinph.2007.04.019

Ryan, T. A. (1947). *Work and effort: The psychology of production*. Oxford, UK: Ronald Press Co.

Schmeichel, B. J., Harmon-Jones, C., & Harmon-Jones, E. (2010). Exercising self-control increases approach motivation. *Journal of Personality and Social Psychology, 99,* 162–173. http://dx.doi.org/10.1037/a0019797

Schmidt, K. L., & Cohn, J. F. (2001). Human facial expressions as adaptations: Evolutionary questions in facial expression research. *American Journal of Physical Anthropology, 116*(Suppl. 33), 3–24. http://dx.doi.org/10.1002/ajpa.20001

Stern, R. M., Ray, W. J., & Quigley, K. S. (2000). *Psychophysiological recording*. New York, NY: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780195113594.001.0001

van der Linden, D. (2011). The urge to stop: The cognitive and biological nature of acute mental fatigue. In P. L. Ackerman (Ed.), *Cognitive fatigue: Multidisciplinary perspectives on current research and future applications* (pp. 149–164). Washington, DC: American Psychological Association. http://dx.doi.org/10.1037/12343-007

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. http://dx.doi.org/10.1016/S0001-6918(02)00150-6

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2003). Distinct spatial frequency sensitivities for processing faces and emotional expressions. *Nature Neuroscience, 6,* 624–631. http://dx.doi.org/10.1038/nn1057

Watter, S., Geffen, G. M., & Geffen, L. B. (2001). The n-back as a dual-task: P300 morphology under divided attention. *Psychophysiology, 38,* 998–1003. http://www.ncbi.nlm.nih.gov/pubmed/12240676. http://dx.doi.org/10.1111/1469-8986.3860998

Wickens, T. D. (2001). *Elementary signal detection theory*. New York, NY: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780195092509.001.0001

Wright, R. A., Patrick, B. M., Thomas, C., & Barreto, P. (2013). When fatigue promotes striving: Confirmation that success importance moderates resource depletion influence on effort-related cardiovascular response. *Biological Psychology, 93,* 316–324. http://dx.doi.org/10.1016/j.biopsycho.2013.02.016

Zijlstra, F. (1993). *Efficiency in work behaviour: A design approach for modern tools*. Retrieved from http://www.narcis.nl/publication/RecordID/oai:tudelft.nl:uuid:d97a028b-c3dc-4930-b2ab-a7877993a17f

Received May 15, 2015
Revision received November 12, 2015
Accepted November 14, 2015 ■