Mental Fatigue and Motivation

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Chapter 5

Discussion

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The present thesis aimed to investigate whether motivation is an essential factor in explaining the effects of mental fatigue on task performance and to examine the underlying mechanisms by which it does or does not affect performance. For this reason, we conducted two mental fatigue experiments to test the effects of two types of motivation, i.e., extrinsic and intrinsic, on mental fatigue. Because our results consistently showed that motivation affected task performance, we built cognitive models to help clarify the underlying mechanisms and proposed goal competition as a mechanism that may explain the effects of motivation on mental fatigue. In the end, we intend to contribute more to the existing theory of mental fatigue.

We will start the discussion by summarizing the main findings of the thesis. Next, we will connect, incorporate, and explain what impacts these findings have that can contribute to answering our research questions. We also compare our findings with the existing literature and recent studies of mental fatigue. Last, we summarize the implications of the thesis and discuss possibilities for future research.

5.1. Main findings

5.1.1. Extrinsic motivation and mental fatigue

In chapter two, we performed a 2.5-hr experiment in which we investigated the effects of extrinsic motivation on mental fatigue. In the experiment, we asked participants to perform a demanding working memory task continuously and alternated two different conditions in the experiment: reward conditions in odd blocks and nonreward conditions in even blocks. In reward conditions, participants were offered monetary rewards for good performance. To measure task disengagement, we played a distracting video continuously in both conditions. To have thorough analyses, we used three types of measures: subjective (fatigue and effort), performance (response time and accuracy), and physiological measures (heart rate variability and pupillometry).

Overall, the results showed that extrinsic motivation represented by monetary rewards in reward conditions affected task performance. Even though participants reported becoming fatigued, they were more engaged with the task as indicated by a higher number in the frequency of eye movements to the task, and performance levels remained stable in these conditions throughout the study. Moreover, the mid-frequency power of heart rate variability suggested that participants invested more mental effort to stay engaged with the task, maintaining performance. In contrast, when monetary rewards were absent in nonreward conditions, participants invested less mental effort physiologically and were less engaged with the task, causing performance to decrease.

The results suggested that extrinsic motivation is an essential factor in mental fatigue: When individuals are motivated by an extrinsic stimulus for doing a particular task, they will maintain performance levels by investing more mental effort into the task, even though they are mentally fatigued.

5.1.2. Intrinsic motivation and mental fatigue

In chapter three, we performed an experiment in which we investigated the effects of intrinsic motivation on mental fatigue. Participants who liked playing Sudoku puzzles were asked to play the puzzles for three hours in two alternating conditions: low-level motivation (LL) and high-level motivation (HL) conditions. In LL conditions, the puzzles were designed to be less enjoyable, whereas in HL conditions, participants played the puzzles normally. As with the previous extrinsic motivation experiment, we played a distracting video continuously in both conditions to measure task disengagement. To have depth analyses, we used three types of measures: subjective measures of mental fatigue, effort and workloads, performance measures measuring response times, accuracy, and the number of attempts of solving Sudoku puzzles, and physiological measures of mental effort using heart rate variability and eye movements using pupillometry. In addition, to examine whether extrinsic and intrinsic motivation share the same process, we compared the results of our extrinsic motivation experiment with the results of the intrinsic motivation experiment.

In general, the results showed that although participants did feel fatigued in the high-level motivation conditions, they were able to maintain performance levels by investing more mental effort. On the other hand, participants invested less mental effort and were more susceptible to distractions in the low-level motivation conditions.

Moreover, after comparing the results of two experiments, the comparison suggested that both extrinsic motivation and intrinsic motivation might share the same process: Participants exerted more mental effort when motivated to maintain task performance, represented by a similar pattern of the mid frequency (MF) power of heart rate variability: The MF power was lower in the high motivation conditions representing more effort but higher in the low motivation conditions representing less effort (Aasman, Mulder, & Mulder, 1987; Mulder & Mulder, 1981). In contrast, when they were less motivated, they were more susceptible to distractions and less engaged with the task, represented by the higher number of visual distraction frequency in the low motivation conditions.

5.1.3. Cognitive models of mental fatigue

Based on the results from the previous studies and from the existing models of mental fatigue (Hockey, 2013; Jongman, 1998; Kurzban, Duckworth, Kable, & Myers, 2013), we hypothesized that the decrease in task performance in mental fatigue is the result of a reduction in task motivation, and the decrease in motivation is reflected in a reduction in activation of the task goal over time. Individuals constantly seek for a more rewarding outcome, i.e., to choose the best action that maximizes benefits (Boksem & Tops, 2008; Hockey, 2011, 2013; Kurzban et al., 2013). Consequently, there will be a continuous competition between goals, i.e., between the recent task goal and other goals unrelated to the task such as external and internal distractions.

To test our hypothesis and the notion of goal competition, we modeled three mental fatigue studies that directly manipulated the level of motivation: our first experiment of chapter 2, a monitoring task (Boksem, Meijman, & Lorist, 2006), and an N-back task (Hopstaken, van der Linden, Bakker, & Kompier, 2015). We built these models in a cognitive architecture named PRIMs (Taatgen, 2013).

To model different levels of motivation, we adjusted the goal activation of the task in each model, so that the activation value of the task goal remained constant in high motivation conditions but decreased linearly in low motivation conditions. Moreover, we added task-unrelated stimuli to continuously compete with the task goal: a distracting video in the first model as an external distraction and mind-wandering in the remaining models as an internal distraction. We predicted that performance of the models would remain constant because the activation values of the task goal exceeded the value of task-unrelated stimuli (distractions) in high motivation conditions. However, when activation values of the task goal fell below the activation values of distractions, performance levels of the models in the low motivation conditions would decrease. After running the models in PRIMs, the results indicated that we were able to model performance changes in three mental fatigue studies with large similarities between the models and the experimental data.

5.2. Motivation and resources

Excluding sleep deprivation (Åkerstedt et al., 2004), there are two main theories of mental fatigue: the resource depletion and the motivational theory of mental fatigue. The resource depletion theory is established on a similar assumption as in physical fatigue that mental fatigue occurs due to depleted resources and a failure in allocating resources (Helton & Russell, 2017). The theory has been used extensively to explain performance decrements in vigilance tasks (Craig & Klein, 2019; Helton et al., 2007; Warm, Parasuraman, & Matthews, 2008). The theory suggests task performance can be improved by having rest breaks to recover depleted resources (Finkbeiner, Russell, & Helton, 2016). In addition, support for the theory came from an experiment where performing a demanding task for a prolonged time suppressed the brain activity (Helton et al., 2007). However, the definite physiological mechanism of the depletion is unclear (Helton & Russell, 2017).

In contrast, the motivational theory suggests that performance decrements in mental fatigue are not due to depleted resources but due to lack of motivation (Hockey, 2011, 2013; Kurzban et al., 2013). In addition, effort is seen as the mediator of the relationship between motivation and performance (Goodman et al., 2011; Westbrook & Braver, 2015). Therefore, individuals who are motivated to do an activity will exert more effort to stay engaged with the activity. On the other hand, when they are no longer motivated, they will exert less effort and more likely disengage from the activity searching for another that is more rewarding (Hockey, 2013). Support for the theory came from two studies: a study of Boksem and colleagues (2006) and a study of Hopstaken and colleagues (2015). In both experiments, task performance improved after participants were offered extrinsic stimuli in the end of the experiments (i.e., in the last block) even if participants already showed performance decrements in previous blocks.

The key aspect that differs motivation from resource depletion is the notion that task performance can still be improved and not be influenced by depletable reservoirs, which in the resource theory is the main cause of decreased performance called mental resources (Kurzban et al., 2013). Consequently, as long as individuals can maintain their motivation by maintaining their self-motivation or by looking for another source of motivation such as monetary rewards, job promotions, acknowledgement from colleagues, competition, and others sources (Di Domenico & Ryan, 2017; Locke & Schattke, 2018; Ryan & Deci, 2000), they can still be willing to exert effort, maintaining their attention to the task, resulting in stable performance. However, this is said not to be possible in the resource account: When the resources are depleted, performance will decrease, and external stimuli such as extrinsic rewards will have no effect on task performance. Even though the term resources used in the theory can have many interpretations (Kurzban et al., 2013), one strong argument used in the theory was from Baumeister and Vohs (2007): "If the tank were truly and thoroughly empty, it is unlikely that increasing incentives would counteract depletion" (p. 125). Furthermore, the depletion can (only) be counteracted, to the extent of the most recent literature of the resource depletion theory, by having rest breaks (Finkbeiner, Russell, & Helton, 2016; Helton & Russell, 2015), allowing performance to recover. In addition, rest is thought to be the best alternative to recover performance with a full break showing the most promising effect (Helton & Russell, 2017).

The findings of this thesis, particularly our experiments in chapter 2 and chapter 3, mainly support the notion of the motivation account and suggest that motivation, both extrinsic and intrinsic, is indeed essential in mental fatigue. The findings also suggest that both extrinsic and intrinsic motivation may share a similar process: The way that motivation affects task performance even when individuals are mentally fatigued is from their willingness to keep exerting mental effort. This occurs only when performing a task is viewed as beneficial and viable (Hockey, 2013; Kurzban et al., 2013; Wright, Mlynski, & Carbajal, 2019). In contrast, when the perceived cost of performing the task is too high, individuals may choose a different action, i.e., by watching a distracting video more often in both experiments, resulting in poor task performance.

Even though our findings mainly support the motivational theory of mental fatigue, it is still possible that the resource depletion may account for why participants were able to maintain performance in high motivation blocks, but with a caveat. Since we alternated two conditions in the experiments: low motivation conditions in odd blocks and high motivation conditions in even blocks, participants might have recovered resources in the low motivation blocks and used it to recover resources. However, using the resource theory to explain the results of our experiments requires a critical assumption. The recovery of resources must be a fast process and can be done even while still doing the task at a lower level of effort, regardless of the duration of the task. This assumption is hardly applicable in our experiments, because there is no evidence that the recovery of resources can occur instantly (see Helton & Russell, 2017), and empirically, participants in our experiments still engaged with the task in low motivation conditions indicated by actively eye movements of saccades: Participants did not totally disengage from the task, and they still paid attention to the task in low motivation conditions—which is far from similar to having a total break, which can give the best effect for resources to recover (Helton & Russell, 2017). Therefore, in this thesis, we preferred the motivation account to explain the effects of mental fatigue on task performance.

5.3. Implications of the models

We have previously elaborated that our experiments are in line with the motivation account. However, our experimental findings still did not answer one important question: How does motivation affect task performance when individuals are mentally fatigued? What is the mechanism behind it? To explain the mechanism, we took a modeling approach by building three cognitive models, reproducing the results of three different mental fatigue studies, to help clarify the underlying mechanisms.

How does motivation affect task performance? Müller & Apps (2019) performed a systematic review on the relation between motivation and mental fatigue. The review suggests that performing a cognitively demanding task, exerting a significant amount of effort such as in vigilance tasks or working memory tasks, for a prolonged time increases the feeling of fatigue. As it increases, individuals will be less willing to stay engaged with the task, i.e., less motivated to continue performing the task. Consequently, a lower level of motivation impairs performance.

Because motivation drops over time due to an increased feeling of fatigue, therefore, to maintain performance, there should be a mechanism to protect motivation from dropping. One model trying to explain the mechanism is the motivational control model proposed by Hockey (2013). In the model, motivation is thought to be an integral part of the information processing system. That is, motivation influences goal-directed behavior by evaluating the cost/benefits of future actions. Moreover, goals represent the expected behavior and the desired end-state. Therefore, goals and motivation are related: A goal gives direction, while motivation drives human behaviors towards that goal.

Individuals can have many goals, and the context of goals can be broad: family goals, financial goals, career goals, and any other goals. However, to avoid complexity, we narrow down the term goal to be task-specific. Therefore, in the context of performing a task, the task itself has an activation value that represents how important, how rewarding, and how urgent the task is for the performer. Other future possible actions, for example, attending distracting stimuli (internal or external), staying still, or doing nothing, also have activation values. In the end, the action that an individual takes is the one that is perceived as the most rewarding action at that moment, represented by its activation value being the highest.

We incorporated Hockey's conceptual model and translated goal activation as a representation of motivation in a cognitive architecture named PRIMs (Taatgen, 2013). Thus, in the context of performing a task, a motivated individual will have a task goal with a higher activation but that activation will be lower when demotivated. More specifically, we manipulated the activation of task goal according to the level of motivation.

We used goal competition as a mechanism in our models. To choose the best action that maximizes benefits, we implemented the mechanism of goal competition, so that the action with the highest activation value will win the competition. Moreover, we used distractions, i.e., external distractions in the first model and internal distractions in the second and third model. We designed the distractions to constantly compete with the task goal.

Motivation maintains the activation value of the task goal in our models. In high motivation conditions, the activation value of the task goal was initialized to be constant over time. On the other hand, the activation value of the task goal was adjusted to decrease over time in low motivation conditions. The activation value of distractions was fixed over time. As a result, we were able to model performance changes in three mental fatigue studies with large similarities between the models and the experimental data: The models showed high performance in high motivation conditions but low performance in low motivation conditions.

In addition, the fitting of the task goal activation values showed a linear decrease in all models, suggesting that the decrease in motivation over time while doing a prolonged task is linear (Müller & Apps, 2019).

Another key aspect of our models is that the main assumption of the resource depletion theory is not applicable in the cognitive architecture that we used, i.e., PRIMs. In PRIMs, the working memory module, a module that is responsible for the information retrieval process, is not depletable. Therefore, as our models were able to simulate the experimental results, they give computational support for the motivation account.

5.4. Practical implications

Overall, our findings support the notion that the decrease in task performance while being mentally fatigued is not because of a decrease in the capacity of the cognitive system known as mental resources, but rather because individuals cannot find better alternative actions (Hockey, 2011, 2013). Instead of exerting unnecessary effort (Brehm & Self, 1989), it is beneficial only to choose the least demanding action (Hockey, 2011, 2013; Kurzban et al., 2013), e.g., maintaining focus but lowering performance, having a rest break, or doing nothing.

To retain performance levels and avoid being distracted by unrelated task stimuli, individuals need to maintain their levels of focus on and attention to the task. We have elaborated goal competition as a mechanism to explain how motivation can affect task performance in mental fatigue. However, there is a question needs to be answered: What are the practical implications of goal competition?

Kurzban and colleagues (2013) posit a notion that to choose an action, individuals will prioritize the chosen action based on the recent context and the expected outcome. This prioritization is the result of the cost/benefit calculation, i.e., a competition between potential future goals, and they assert that organisms have a counter that observes the result of the calculation over time (see Gallistel, 1990). For example, an individual who starts making a bonfire in cold condition may immediately change the current action, e.g., starts running, when the individual sees a bear runs towards him/her. In this example, there are two possible future actions: keep making a bonfire or start running away from the threat. These two actions have costs and benefits seen from the current context and the expected outcome. However, the running action seems to be more critical at the time; hence, the individual will most likely choose the running action.

As empirical support for the cost/benefit calculation, the calculation is suggested to occur in two brain areas (Hockey, 2013), i.e., the prefrontal cortex (PFC) and the anterior cingulate cortex (ACC). The PFC actively maintains goal selection and goal regulation (Miller & Cohen, 2001), whereas the ACC mainly evaluates conflicts between potential future goals (Rushworth, Behrens, Rudebeck, & Walton, 2007).

Even though we have no evidence, we speculate that the time to take the action depends on many factors. For instance, a man has an unhealthy eating habit in which he enjoys eating high-sugar foods. He continuously perceives that eating high-sugar foods offers many benefits, and the habit lasts for a few years. However, after a period of time, he starts feeling uncomfortable due to overweight and decides to stop his habit and starts doing exercises. In this example, the chosen action, i.e., to stop the habit and start doing exercise, does not happen immediately. The decision is made when the perceived costs (the feeling of being uncomfortable) are immense. On the other hand, if the perceived costs are not decisive, the individual may keep doing the same action until the perceived costs exceed the benefits. Moreover, the amount of effort of his action depends on the level of motivation and the difficulty of the task: As long as the action is perceived as beneficial and viable, the more difficult the action is, the more effort individuals will exert (Gendolla, Wright, & Richter, 2012; Wright et al., 2019).

We expect that the decision to take a particular action depends on the intention to gain benefits or avoid losses seen from the recent context. More specifically, a shift in the course of action is influenced by highly perceived benefits (e.g., the action offers a high amount of money) or highly perceived costs (e.g., a threat to human lives) the moment individuals make a decision. In the long run, individuals will more likely prioritize an action that maximizes perceived long-term benefits. However, since it is challenging to see projected long-term benefits, the current decision is mainly influenced by the recent context/situation.

In the context of mental fatigue at work, it is common that workers do not easily see the future benefits of performing a particular task. In order to maintain productivity, we encourage companies to help their workers understand their tasks, to know the vision and values of their companies, and to acknowledge their roles as a part of the companies. Therefore, they can prioritize their action, e.g., performing a daily task in the workplace, in a motivated condition regularly. Companies can also increase their motivation by offering extrinsic rewards such as job promotions, bonuses, and introduce competition among their workers. In addition, workers who enjoy doing their tasks in the workplace will be more willing to perform well, resulting in high and sustainable productivity.

5.5. Limitation and future research

In the thesis, we have shown that motivation, both extrinsic and intrinsic, is an essential factor in mental fatigue. We also have built three different cognitive models and shown that our models are able to mirror human performance well with large similarities between the models and the experimental data. However, one limitation of the thesis is that most results are based on laboratory environments. Therefore, future research should address real-life tasks (e.g., air traffic control, prolonged surgical procedures, prolonged video games). It is also beneficial to test the predictions of our models in new experiments, for example, to see whether our models' predictions also hold in studies with no rewards.

Nevertheless, we have provided significant empirical evidence and cognitive models that support one of the major theories in the research field of mental fatigue, i.e., the motivation account. Even though mental fatigue is a common phenomenon that affects productivity at work, high motivation is the way to counteract its effects.

"Family" - by Alika (5 years old)