Mental Fatigue and Motivation

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Chapter 1

Introduction

Introduction

In many cases, workers are compelled to work hard, perform well, and take overtime to satisfy work demands. For instance, many companies in Japan require their workers to work 60 hours a week minimally (Beckers et al., 2004), and the length of 12-hour shifts has been regarded as commonplace in Europe (Estryn-Béhar & van der Heijden, 2012).

With an increase in work demands and challenges in the past decade, the risk of workers experiencing fatigue has escalated and later leads to fatigue-related health problems. In the United States, two-thirds of the labor force reported fatigue in the workplace (Ergonomic Trends, 2018), and 46.6 million adults reported mental illness (National Institute of Mental Health, 2017). More than six hundred thousand people in the UK are stressed at work due to work pressures (Health and Safety Executive, 2019), and overwork has caused an increase in the number of deaths of Japanese workers called karoshi (Kanai, 2009). Furthermore, chronic fatigue increases the risk of accidents (Mizuno et al., 2011; van der Linden, 2011) and cardiac abnormalities (Appels & Mulder, 1988).

The economic cost of fatigue is substantial. In the UK, fatigue-related problems inflict financial cost in the form of lost employment, which is a serious issue raised by many companies (McCrone, Darbishire, Ridsdale, & Seed, 2003). The total of lost productivity due to chronic fatigue in the United States was $9.1 billion in 2002, in which 25 percent resulted from lost labor force productivity (Reynolds, Vernon, Bouchery, & Reeves, 2004). Similarly, another study showed that fatigue costs employers more than 136 billion dollars annually in the United States (National Safety Council, 2020).

Fatigue is a term to describe two different things: the subjective feeling of tiredness and a performance decrement (Wessely, Hotopf, & Sharpe, 1998). As a subjective feeling, fatigue is measured using subjective measures such as self-report questionnaires in which workers are asked the degree to which they feel exhausted (Christodoulou, 2005). On the other hand, error rates, response times, and accuracy are often used to measure performance changes associated with fatigue. In addition, physiological measures, e.g., heart rates, blood pressure, pupillometry, and other physiological criteria, are utilized to measure fatigue (Borg, 1982; Chen, Lu, & Mao, 2019; Robertson, Mullinax, Brodowicz, & Swafford, 1996; Stern, Boyer, & Schroeder, 1994; Wijesuriya, Tran, & Craig, 2007).

In general, there are two types of fatigue at work: physical fatigue and mental fatigue. Physical fatigue is a condition when muscles are no longer able to do physical activity (Gawron, French, & Funke, 2001; Hagberg, 1981). For example, individuals have limits on how long they can perform physical tasks such as in construction workers, janitors, and other manual labor. In physical fatigue, scales measuring the impairment in muscular activity, deficiency, and pain are typically used (Stein, Martin, Hann, & Jacobsen, 1998), and the most common one is a behavioral measure associated with muscle fatigue (Christodoulou, 2005). In contrast, mental fatigue is a condition that occurs after performing a demanding cognitive task for a prolonged time (Boksem, Meijman, & Lorist, 2006; Helton & Russell, 2017). Cognitive performance is assessed typically on decrements in vigilance, concentration, decision making, planning ability, and working memory (Christodoulou, 2005; Gergelyfi, Jacob, Olivier, & Zenon, 2015; Jain & Nataraja, 2019; Helton & Russell, 2015; van der Linden, Frese, & Meijman, 2003). In addition, mental fatigue is often associated with subjective effort in which effort is seen as a mediator of mental fatigue (Goodman et al., 2011; Van Cutsem et al., 2017).

Although the cause of each type of fatigue is specific, physical and mental fatigue are interrelated. For instance, physical activities increase the effects of mental fatigue (Xu et al., 2018), and mental fatigue impacts performance during physical activities (Mehta & Parasuraman, 2013; Tanaka, Ishii, & Watanabe, 2014).

In recent years, companies have become more dependent on knowledge workers, i.e., white-collar workers, than manual ones, and many tasks require more mental effort than physical effort (Boksem & Tops, 2008; Okogbaa, Shell, & Filipusic, 1994). This trend has led to the increased case of mental fatigue at work (Åkerstedt et al., 2004). As mentioned previously, prolonged cognitive loads can cause mental fatigue (Helton & Russell, 2015; Mizuno et al., 2011); however, several studies suggest that not all prolonged mental tasks induce mental fatigue and decrease performance (Hockey, 2011; Kurzban, Duckworth, Kable, & Myers, 2013; van der Linden, 2011). This raises the question of whether mental fatigue is similar to physical fatigue as it seems, or that it has different causes and properties.

There are two main theories that can explain the cause of mental fatigue (Hockey, 2011). The first is the resource depletion theory. As with physical fatigue (Gandevia, 2001), it is established on a similar assumption that individuals have limited and depletable resources (Helton & Russell, 2017; Kurzban et al., 2013). The notion came from many sources. For example, a comprehensive review by Muraven and Baumeister (2000) suggests that self-control performance is impaired when the resources are depleted after previously exerting self-control. Similarly, Warm, Parasuraman, and Matthews (2008) reviewed the effects of sustained attention tasks on task performance, suggesting that performing these tasks expends resources and impairs performance. In the theory, performance can be improved by having a rest break to restore depleted resources (Helton & Russell, 2015, 2017; Finkbeiner, Russell, & Helton, 2016).

Contrary to the first theory, the motivation theory suggests that impaired performance is not caused by depleted or limited resources but because individuals cannot maintain the motivation to stay engaged with the task (Boksem & Tops, 2008; Hockey, 2011; van der Linden, 2011). The notion was supported by many studies. For instance, after performing a tedious task, task performance decreased but returned to its initial level in the last block due to an increase in motivation (Boksem et al., 2006). Another study showed a similar result that task performance improved after being offered a rewarding stimulus in the last block (Hopstaken, van der Linden, Bakker, &

Kompier, 2015). Even though motivation can help individuals maintain performance, its actual mechanism is not fully understood.

1.1. Research questions

To understand and explain why individuals can still maintain performance when motivated, we develop new paradigms to the relation between mental fatigue and motivation. Therefore, the main concern of this thesis was to investigate motivation as a factor in mental fatigue, what roles does motivation contribute to mental fatigue, what are the effects of continuous changes in the level of motivation on performance, what are the effects of extrinsic and intrinsic motivation on performance, and what is the mechanism of motivation by which it affects performance? Furthermore, we aimed to develop a model that can provide precise predictions about motivation and mental fatigue.

1.2. Approach of the thesis

The first objective of the thesis was to understand the effects of motivation on mental fatigue. For this reason, we took an experimental approach and performed two experiments in which each experiment investigated two different types of motivation: the first experiment investigating extrinsic motivation and the second investigating intrinsic motivation. With regard to motivation, there are two types of motivation (Deci & Ryan, 2008; Di Domenico & Ryan, 2017). Extrinsic motivation is a type of motivation to attain rewards and to avoid punishments, whereas intrinsic motivation is a type of motivation to do an activity because of the inherent enjoyment of the activity (Ryan & Deci, 2000). To continuously assess the influence of motivation on task performance, we alternated two conditions in both experiments: one condition representing low motivation and another representing high motivation. We predicted that if motivation was an important aspect in mental fatigue, task performance would remain stable in high but not in low motivation conditions. However, if motivation was not relevant, task performance would decline over time in both low and high motivation blocks.

To explain the mechanisms of motivation on mental fatigue comprehensively, we also developed a detailed cognitive model of the mechanisms behind mental fatigue: How can motivation maintain performance even when individuals are mentally fatigued. We decided this was necessary, as most mental fatigue models that have been developed so far trying to explain these mechanisms are mainly descriptive. For example, Hockey (2013) developed the motivational control model. The model suggests that individuals are willing to invest more effort if the perceived benefits of performing a particular task exceed its costs, resulting in stable performance levels regulated in a module called the effort monitor. Another mental fatigue model was proposed by Kurzban and colleagues (2013) named the opportunity cost model. Their model supports the notion of motivation in mental fatigue and resembles the model proposed by Hockey (2013), suggesting that individuals will prioritize an action that maximizes benefits over others.

We are aware of only one computational cognitive model trying to explain the effects of mental fatigue, which was developed by Jongman (1998) in a cognitive architecture named ACT-R (Anderson et al., 2004). In the model, mental fatigue is depicted as a problem of cognitive control and motivation. As a cognitive control phenomenon, impaired performance was the result of lowering the value of a global parameter in ACT-R named source activation. The manipulation implies that a lower value of the source activation represents a higher chance that the relevant information to perform a task will be unavailable, resulting in a decrease in task performance. Moreover, the manipulation assumed that the function of cognitive control represented by the level of source activation is depletable. As a motivational problem, the model manipulated a parameter in ACT-R named goal activation, suggesting that a motivated individual will choose a strategy that maximizes the chance of success. However, the model did not implement the manipulation of goal activation to see its effects on task performance.

Instead of just being descriptive, this thesis aimed for a more detailed attempt than the previous model proposed by Jongman (1998). Therefore, to answer the research question regarding the mechanism of motivation in mental fatigue, we took a modeling approach by building cognitive models in a cognitive architecture named PRIMs (Taatgen, 2013). PRIMs is a cognitive architecture based on ACT-R (Anderson et al., 2004), and it works in a similar way. As a computational architecture, PRIMs can make detailed predictions on common performance measures, also important in mental fatigue studies, such as response times, accuracy, and error rates. For this reason, PRIMs was suitable for the modeling approach used in the thesis.

In our modeling efforts, we utilized the assumptions of the existing mental fatigue models proposed by Hockey (2013) and Kurzban and colleagues (2013) in our models. We hypothesized that the decrease in task performance in mental fatigue is the result of a reduction in task motivation, and this decrease in motivation is reflected in PRIMS as a reduction in activation of the task goal over time. Normally, performance is maintained by maintaining focus on the task, trying not to be distracted by task-unrelated stimuli. As time on a task progresses, a reduction in task goal activation means that other goals may win the competition over the task goal, which will result in increasing distractibility and decreased task performance levels.

To test our hypothesis and this notion of decreased task goal activation and goal competition, we modeled three mental fatigue studies, including our first experiment, which manipulated motivation levels in their participants. If our models could replicate the behavioral and other results in these studies, we would gain confidence that the notion of reduced goal activation and competition are important to explain how motivation can counteract the effects of mental fatigue.

1.3. Overview of the thesis

Mental fatigue and motivation are the main focus of this thesis. The relationship between these two, particularly the mechanisms behind the effects of motivation in mental fatigue, has not been investigated further in any recent studies. In this thesis, we intended to contribute more to the existing theory formation of mental fatigue.

In chapter 2, we present a study to investigate the effects of extrinsic motivation on mental fatigue. Many studies have tried to investigate rewards as stimuli that can improve performance during mental fatigue (Boksem et al., 2006; Hockey, 2011; Hopstaken et al., 2015). Nevertheless, few experimental paradigms have effectively and continuously manipulated extrinsic motivation, which is essential to understand its effects on mental fatigue. In this experiment, we asked participants to perform a working memory task for two and a half hours continuously and alternated two different conditions: nonreward conditions in odd blocks and reward conditions in even blocks. In the reward conditions, participants would receive monetary rewards for good performance. Moreover, we played a distracting video to measure task disengagement continuously in both conditions. To gain a good understanding of the effects of mental fatigue, we used three different types of measures in the experiment: subjective measures of mental fatigue and effort, performance measures measuring response times and accuracy, and physiological measures of mental effort using heart rate variability and eye movements using pupillometry.

Most mental fatigue studies looked exclusively at the effects of extrinsic motivation but not of intrinsic motivation. Therefore, in chapter 3, we investigated the effects of intrinsic motivation on mental fatigue by performing a 3-hr experiment. In the experiment, we asked participants who liked Sudoku, that is, participants for who Sudoku was an intrinsically motivating game, to play Sudoku, which has been used previously to induce fatigue (Gergelyfi et al., 2015). We alternated two different conditions throughout the experiment: a condition that represented low intrinsic motivation in odd blocks and another that represented the opposite in even blocks. We also played a distracting video to measure task disengagement continuously in both conditions. As with the extrinsic motivation experiment, we used three different measures in this experiment: 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 chapter 4, we developed cognitive models to simulate the results of three mental fatigue studies that manipulated level of motivation. In these modeling attempts, we used goal competition as a paradigm to help explain the role of motivation in mental fatigue. We hypothesized that mental fatigue leads to lower motivation levels, which in our models corresponds to a lower goal activation value of doing a task. A lower goal activation implies that task-unrelated stimuli have a higher probability of interfering with the task. We argued that the degree of goal activation might influence the decision-making process and be reflected in performance changes.

To test the hypothesis, we built cognitive models of motivation in a cognitive architecture named PRIMs in which we quantified motivation as the level of goal activation. In addition, our models attempted to reproduce the results of three different mental fatigue studies: our first experiment of chapter 2, a monitoring task (Boksem et al., 2006), and an N-back task (Hopstaken et al., 2015).

In chapter 5, we summarize and discuss all findings regarding the research themes. In this chapter, we explain what the mechanisms behind performance changes are, and what implications the findings of this thesis have for the existing theory of mental fatigue.

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