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Research report

Cognitive fatigue: A Time-based Resource-sharing account

Guillermo Borragán [*,1], Hichem Slama [1], Mario Bartolomei and Philippe Peigneux [*]

UR2NF, Neuropsychology and Functional Neuroimaging Research Unit at CRCN, Centre de Recherches en Cognition et Neurosciences and UNI — ULB Neurosciences Institute, Université Libre de Bruxelles (ULB), Belgium, Brussels, Belgium

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ABSTRACT

Cognitive Fatigue (CF) is an important confound impacting cognitive performance. How CF is triggered and what are the features that make a cognitive effort perceived as exhausting remain unclear. In the theoretical framework of the Time-based Resource-sharing (TBRS) model (Barrouillet et al., 2004), we hypothesized that CF is an outcome of increased cognitive load due to constrained time to process ongoing cognitive demands. We tested this cognitive load-related CF hypothesis across 2 experiments manipulating both task complexity and cognitive load induced by the processing time interval. To do so, we used the TloadDback paradigm, a working memory dual task in which high and low cognitive load levels can be individually adjusted. In Experiment 1, participants were administered a high cognitive load (HCL, short processing time interval) and a low cognitive load (LCL, large processing time interval) conditions while complexity of the task was kept constant (1-back dual task). In Experiment 2, two tasks featuring different levels of complexity were both administered at the individual's maximal processing speed capacity for each task (i.e., short processing time interval). Results disclosed higher CF in the HCL than in the LCL condition in Experiment 1. On the contrary, in Experiment 2 similar levels of CF were obtained for different levels of task complexity when processing time interval was individually adjusted to induce a HCL condition. Altogether, our results indicate that processing time-related cognitive load eventually leads to the subjective feeling of CF, and to a decrease in alertness. In this framework, we propose that the development of CF can be envisioned as the result of sustained cognitive demands irrespective of task complexity.

* *Corresponding authors.* UR2NF, Neuropsychology and Functional Neuroimaging Research Unit at CRCN, Centre de Recherches en Cognition et Neurosciences and UNI — ULB Neurosciences Institute, Université Libre de Bruxelles (ULB), Belgium, CP191, Avenue F.D. Roosevelt 50, B-1050 Brussels, Belgium.
E-mail address: gborraga@ulb.ac.be (G. Borragán).

[1] GB and HS are co-first authors.

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1. Introduction

Coping with sustained cognitive demands for extended periods of time represents a major challenge. Inescapably, a feeling of exhaustion and lack of energy will develop over time, which will eventually hamper cognitive performance. Having a break or shifting onto another, less demanding cognitive task may mitigate the subjective feeling of fatigue, at variance with a state of sleepiness that needs sleep to be relieved (Kumar, 2008). Mental or Cognitive Fatigue (CF) can be defined as the decrease in cognitive resources developing over time on sustained cognitive demands, independently of sleepiness (Trejo, Kochavi, Kubitz, Montgomery, Rosipal, & Matthews, 2005). CF is observed in various attentional and executive function areas with developing difficulties to suppress irrelevant information during selective attention (Faber, Maurits, & Lorist, 2012), increased perseverations and time needed to plan (van der Linden, Frese, & Sonnentag, 2003), weakened cognitive control (Lorist, Boksem, & Ridderinkhof, 2005) and decreased high-level information processing (Tanaka, Shigihara, Funakura, Kanai, & Watanabe, 2012) or even declining physical performance (Marcora, Staiano, & Manning, 2009). Notwithstanding, CF is not always associated with performance impairment (Ackerman & Kanfer, 2009) and can be modulated by individual traits such as personality, interests (Ackerman & Kanfer, 2009) and motivation (Ackerman & Kanfer, 2009; Boksem, Meijman, & Lorist, 2005; Lorist et al., 2005). In this respect, triggering CF is also a function of the self-predicted costs and rewards involved by the ongoing effort (Stewart, Wright, Azor Hui, & Simmons, 2009). Indeed, the more positive the benefit-costs an action entails, the lower the intensity of the mental effort perceived by the organism (Boksem & Tops, 2008). Nonetheless, even when costs and benefits are controlled (i.e., stable levels of cognitive demand and reward during the task), performance is often affected through time (Gergelyfi, Jacob, Olivier, & Zénon, 2015) suggesting the influence of other parameters such as the specificity of the cognitive demands or the availability of cognitive resources. Although CF arises from virtually any sustained cognitive effort, the determinants of CF (i.e., the mechanisms making a cognitive demand more exhausting) have been barely studied. This lack of knowledge raises a critical issue in experimental psychology, as CF can be a major confound in a wide variety of cognitively demanding situations.

1.1. *Current approaches to induce CF*

Most experimental investigations of CF have been conducted manipulating either task duration (Lorist, Klein, & Nieuwenhuis, 2000; Lorist et al., 2005; Mizuno, Tanaka, Fukuda, Imai-Matsumura, & Watanabe, 2011; van der Linden, Frese, et al., 2003) also known as Time-on-Task (ToT) (Ackerman & Kanfer, 2009; Lim, Wu, Wang, Detre, & Dinges, 2010), or task demands (Cook, O'Connor, Lange, & Steffener, 2007; Shigihara, Tanaka, Ishii, Kanai, et al., 2013). In the ToT approach, a stable cognitive demand is sustained over time. For instance, CF can be induced asking participants to reorganize fictional employee schedules for about 2 h (van der Linden, Frese, & Meijman, 2003), to perform mental arithmetic problems for up to 3 h (Trejo et al., 2005) or to achieve a range of cognitive tasks, including working memory, inhibition tasks, arithmetic problems and brainteasers during 90 min (Klaassen et al., 2014). This approach is rather successful in inducing CF, suggesting that any sustained cognitive effort will, sooner or later, lead to this phenomenon independently of the degree of cognitive demands requested by the task (Ackerman & Kanfer, 2009). However, other studies show that CF does not increase to the same extent in all demanding situations (Nakagawa et al., 2013; Shigihara, Tanaka, Ishii, Tajima, et al., 2013). These studies manipulate task demands to induce different levels of CF, under the assumption that higher cognitive demands will tax more on cognitive resources, eventually leading to higher CF levels. For example, varying the complexity of a working memory N-back task leads to different levels of CF after 30 min of practice (Shigihara, Tanaka, Ishii, Tajima, et al., 2013). In these studies, CF manifested at the behavioral level with more errors in a cognitive flexibility task (Trail Making Test) administered after the end of practice but also with post-task changes in spontaneous beta power in frontal regions (Shigihara, Tanaka, Ishii, Kanai, et al., 2013). Accordingly, higher task demands associated with higher subjective fatigue ratings were associated with a reduced P300 amplitude and increased alpha power in frontal and parietal areas (Käthner, Wriessnegger, Müller-Putz, Kübler, & Halder, 2014). Hence, along with ToT, the cognitive load arising from the features of the ongoing cognitive demands is also a strong modulatory factor in the induction of CF. Consequently, higher cognitive load should lead to faster and/or higher CF levels, which opens up the question on the variable(s) primarily subtending cognitive load.

1.2. *Determinants of cognitive load*

Cognitive load theories posit a limited processing capacity (Atkinson & Shiffrin, 1968; Moreno & Park, 2010; Sweller, 1988). At the perceptual level, this can be probed using interference paradigms where distractors are presented in different cognitive load situations. When the task condition involves a high perceptual load (e.g., by increasing complexity), distractors will cause less interference, an effect interpreted as reflecting the fact that the system does not have enough capacity to process irrelevant information (Lavie, 2010; Nilli Lavie, 2006). A common approach for intensifying cognitive load in a task is to increase the number of elements to process. For instance, in the N-back paradigm (Kirchner, 1958), increased cognitive load is associated with an increased number of elements to update in working memory to correctly perform comparisons between the ongoing and past elements in the series. Alternatively, the Time-based Resource-sharing model (TBRS; Barrouillet, Bernardin, & Camos, 2004) proposes that the available time to process ongoing cognitive demands is actually the major factor responsible for inducing cognitive load. More specifically, the TBRS model conceptualizes attention as a limited resource, which is needed to process incoming information. The model posits that the performance is related to the proportion of time needed for the attention to process ongoing information. Therefore, cognitive demand or