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Relationship between Self-Reported Symptoms of Fatigue and Cognitive Performance: Switch Cost as a Sensitive Indicator of Fatigue

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Abstract

In two correlational studies, we investigated the relationship between symptoms of mental fatigue connected with the ordinary daily activity of undergraduate students and the performance level in tasks engaging executive and attentional processes. We found that mild or moderate levels of fatigue are associated with only a few impairments in cognitive functioning, which suggests that the consequences of such a level of fatigue can be easily compensated by protection strategies adopted by participants. A notable exception was a significant positive correlation between the level of fatigue and higher accuracy switch cost in the Plus-minus task. Our participants also reported an increase in fatigue symptoms after performing several cognitive tasks and this change was larger for those who were more engaged in a sustained attention task. In a follow-up experiment, we investigated the effects of fatigue induced by the time on sustained attention task on switching task performance and reported symptoms of cognitive and executive fatigue. We confirmed that the level of accuracy switch cost is significantly higher in the participants who performed the sustained attention task than in the participants from the control group. We pointed out some possible practical implications of studies on the relationship between fatigue and cognition for such activities as driving a car.

Keywords: mental fatigue, sustained attention, switch cost, executive function, task engagement, time-on-task effect

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Introduction

Mental fatigue is a change in psychophysiological state that manifests in reduced willingness to perform, preference for less resource-demanding and less analytical processing, and changes in mood (Massar, Csathó, & van der Linden, 2018; van der Linden, Frese, & Meijman, 2003). Mental fatigue is an often experience of healthy individuals and a permanent condition in some diseases (e.g., DeLuca, Genova, Hillary, & Wylie, 2008; Millikin, Halman, Power, & Rourke, 2003), it finds expression in subjective symptoms as well as in objectively measurable deterioration in performance (Gergelyfi, Jacob, Olivier, & Zénon, 2015). Many studies assessed the consequences of fatigue on cognitive processes, especially, in the context of intensive effort and prolonged workload (i.e., "time-on-task effect", e.g., Esposito, Otto, Zijlstra, & Goebel, 2014; van der Linden et al., 2003) or sleep deprivation (e.g., Caldwell et al., 2005; Jackson, Croft, Kennedy, Owens, & Howard, 2013). These conditions induce a relatively high level of fatigue, which is not characteristic of everyday life activity. The main goal of our study is to investigate the relationship between mild or moderate levels of mental fatigue manifested in subjective symptoms and objective performance in cognitive tasks sensitive to controlled-processing efficiency. Another aim of this research is to study the consequences of an intensive but relatively short engagement in the execution of cognitive tasks for the symptoms of fatigue. We were interested to see whether performing tasks that engage controlled processing is sufficiently taxing to increase mental fatigue and what kind of symptoms would appear.

An important issue is whether subjective symptoms of fatigue that are commonly observed during a workday are associated with cognitive functioning impairments that might influence some important daily activities (such as driving a car). On the one hand, we should expect that resource-dependent activities are not performed as effectively when we are tired as when we are rested, even if the level of fatigue is not deep. From this perspective, it is interesting to find out which particular cognitive processes are more easily impeded by fatigue and which self-observed symptoms of fatigue are good predictors of a decrease in objectively tested performance. On the other hand, self-observed symptoms of fatigue can motivate the person to increase effort to maintain the level of performance unchanged. Such a mobilization is more probable for priority activities, that is, for example, those cognitive tasks that are vital for safety (as when driving a car) or for self-presentation (as when we are being assessed by a psychologist). However, it is possible that the regulatory role of motivation is effective only for certain cognitive processes while being ineffective for others.

We base our research on an assumption that cognitive functions, which should be particularly affected by fatigue, are those functions which are "resource-dependent" or "effortful" (Hasher & Zacks, 1979). Mental fatigue is a state when resources are less available (Gergelyfi et al., 2015), hence, fatigue should first impair effortful goal-directed activity. In contrast, simple and automatically executed activities may remain unaffected by fatigue, even over long periods of time (van der Linden et al., 2003). In other words, participants that are fatigued are more susceptible to cognitive overload and their performance is heavily dependent on the capabilities of the central executive (in terms of the theory of working memory by Baddeley & Hitch, 1974) or controlled attention (in terms of the approach of Engle, Kane, & Tuholski, 1999). When two tasks have to be executed simultaneously or switched alternately under cognitive load, they interfere with each other, competing for general and/or specific cognitive resources (e.g., Nieznański, Obidziński, Zyskowska, & Niedziałkowska, 2015).

Studying the consequences of fatigue-induced cognitive impairment carries high practical significance. Such resource-dependent processes as selective attention, executive functions, and working memory – the processes we investigated in the present study – are of great importance for daily activity of driving a car (for review see Terelak, 2015). Mäntylä, Karlsson and Marklund (2009) showed that individual differences in executive/frontal function are related to driving performance, particularly, that lane-change performance in the simulated driving task was significantly correlated with the updating component of the executive function (measured by the N-Back and matrix monitoring tasks). However, the influence of distracting stimuli on goal-directed performance can be minimised in participants with high working memory capacity (WMC). In Ross et al. (2014) study on driving behaviour, researchers showed that lane-change performance deteriorated with increasing working memory load (induced by the auditory N-Back task), but drivers with higher verbal WMC were influenced less by this factor. In other words, the relationship between working memory load and lane-change performance was moderated by WMC. Probably, participants with high WMC prioritize the processing of task-relevant stimuli more efficiently (cf. de Fockert, Rees, Frith, & Lavie, 2001), which is particularly important when attentional resources are scarce in a fatigue state (Gergelyfi et al., 2015). The issue of the relationship between WMC and fatigue we investigate in our Study 1.

Many studies showed important consequences of fatigue for sustained attention impairments. For example, Jackson et al. (2013) indicated that psychomotor vigilance performance decrements due to sleep deprivation predicted impairments in simulated driving task performance (i.e., changes in lateral lane position). They suggested that sleep-deprived participants can perform at a relatively high level until a period of inattention occurs; therefore, the main problem resulting from sleep deprivation is an increase in the frequency of “attention lapses”. Similarly, Van Dongen and Belenky (2012) suggested that cognitive impairment due to fatigue does not necessarily mean a gradual performance decline but is rather characterized by performance instability.

The problem of the relationship between fatigue and lapses of sustained attention is also considered from the perspective of the mechanisms of vigilance decrement. Two competing theories are currently discussed in the field (Head & Helton, 2014; Helton & Russell, 2011). In the first approach, called the resource depletion or mental fatigue theory of vigilance decline, detection errors result from the scarcity of resources, building up over time. In the second approach, called boredom or mindlessness theory, vigilance decline is attributed to a lack of exogenous support for attention; the monotony of the vigilance task disengages attention from the task, participants become engaged in task-unrelated thoughts (mind-wandering), and detection errors occur as a result of a kind of goal-neglect (cf. Kane & Engle, 2003). According to van der Linden et al. (2003), fatigue may lead to insufficient activation of goals when a participant performs complex tasks involving executive control. In their study, fatigued participants, who had to work on a scheduling task for two hours showed deficits in tasks requiring flexibility and planning. In detail, the lowered flexibility of tired participants was indicated by a significant increase in the frequency of perseverative errors in the Wisconsin Card Sorting Test, whereas the planning deficit was reflected in the delayed first-move reaction time (RT) in the Tower of London task.

Overview of the Present Studies

The present work consists of three studies, their general aim was to find cognitive functions or measures of performance that are able to reflect moderate or even mild levels of fatigue in a group of healthy undergraduates. In Studies 1 and 2 we focused on correlational analyses concerning relationships between subjective symptoms of mental fatigue and objective level of performance in cognitive tasks. In Study 3 we experimentally manipulated the presence and duration of the fatigue-inducing task to verify sensitivity of one of the selected measures to resources depletion. Generally, we expected that significant deteriorations of cognitive performance are not easy to be observed because of compensatory strategies adopted by the participants. However, based on cognitive and experimental psychology literature review, we chose as candidate functions those which are described as resource-dependent or control-demanding cognitive processes, hence, their sensitivity to modest limitations of available resources in a workaday-fatigue-state of an undergraduate are conceivable. In Study 1, we used a version of a popular Stroop task which measures inhibition of prepotent response as well as the goal-neglect in cognitive performance. We also used the Rotation Span task to measure working memory capacity. As suggested by the research mentioned earlier, it can be hypothesised that fatigue is associated with goal maintenance problems, however, high WMC participants are probably less susceptible to resources availability limitations in fatigue states. In Study 2, we concentrated on executive functions categorised as inhibition (measured using another version of the Stroop task), shifting (Plus-minus task), and updating (2-Back task) (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). In general, we expected that the higher symptoms of fatigue are reported, the worse the performance in executive tasks will be observed.

Anticipating, we found that shifting ability reflected in the accuracy switch cost is the most salient correlate of fatigue among studied functions. Both in Study 2 and 3, we explored the relevancy of attentional-resource depletion associating fatigue, using the Sustained Attention to Response Task as an index of performance (Study 2) or as a task inducing mental fatigue (Study 3). In the present work we applied a new scale assessing self-reported mental fatigue which captures various subjective symptoms of fatigue, both directly connected with cognitive functioning as well as encompassing other, motivational, emotional, physiological or self-confidence aspects of mental fatigue.

Study 1

In the first study, we investigated the relationship between the fatigue symptoms reported by our participants using the Fatigue Symptoms Scales and their performance on a test of WMC (the Rotation Span task) and a version of the Stroop task that emphasizes the role of goal-maintenance for effective performance.

There are many different instruments intended to measure mental fatigue. However, the aim of constructing the Fatigue Symptoms Scales (FSS; Gasiul, Strus, Nieznański, Rowiński, & Kobos, 2019) was to embrace the relatively widest range of different symptoms of the subjective experience of fatigue, both at the level of the current state (FSS-S) and at the trait level (FSS-T). The FSS construction was based on theoretical and empirical analyses and examination of other existing methods. Among these instruments were: (1) the Karolinska Sleepiness Scale which was shown to correlate with some physiological indices of sleepiness (Åkerstedt & Gillberg, 1990), (2) a scale measuring daily fatigue based on the Patient-Reported Outcomes Measurement Information System (PROMIS; Christodoulou, Schneider, Junghaenel, Broderick, & Stone, 2014), (3) the Appraisal of Fatigue in Relation to Performance based on adaptation-oriented and emotion-related ways of appraising fatigue and performance (van Dam, Keijsers, Eling, & Becker, 2011), (4) the Subjective Fatigue Scale which consists of concentration thinking difficulty, languor, reduced activation, reduced motivation, drowsiness, and feeling of physical disintegration subscales (Kobayashi, Demura, & Nagasawa, 2003), (5) the Chalder's Fatigue Scale assessing severity of physical and mental fatigue symptoms (Chalder et al., 1993), and (6) the Fatigue Impact Scale which assess the patients' perception of the effects of fatigue on their quality of life (Fisk et al., 1994; cf. Naschitz et al., 2004). However, all these instruments are relatively short (up to 29-items) and focused on rather specific aspects or domains of fatigue. The FSS, used in the current study consists of 60 items grouped into six subscales which gives a more wide range of different types of symptoms than in most other self-report scales and enables searching for associations between specific aspects of mental fatigue and objective indices of performance. The validity of the FSS was verified (Gasiul et al., 2019) in relation to the UWIST Mood Adjective Checklist (UMACL, measuring three dimensions of the core affect: hedonic tone, tense arousal, and energetic arousal, Matthews, Jones, & Chamberlain, 1990), the Spielberger State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), the Pavlovian Temperament Survey (PTS, measuring strength of excitation, strength of inhibition, and mobility of nervous processes; Strelau, Angleitner, & Newberry, 1999), as well as the BIS/BAS scales (measuring sensitivity of the Behavioral Inhibition System and the Behavioral Approach System; Carver & White, 1994).

Working memory capacity can be defined as the effectiveness of the central executive subsystem of working memory in the coordination with various cognitive functions (e.g., McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). It is usually measured using complex span tests, that is, tasks that require the retention of several items in the face of interference from a secondary task. In our study, we used the Rotation Span task which is one of the established complex span tasks used in many studies on WMC (e.g., Foster et al., 2014; Harrison et al., 2013; Kane et al., 2004).

Another test used in Study 1, the Stroop colour interference task (Stroop, 1935; cf. Friedman & Miyake, 2004; Jackson & Balota, 2013; Kane & Engle, 2003) is a popular experimental paradigm in which the participants name the colour in which the words are printed. In one type of trials, the colour and word are incongruent, such as the word GREEN printed in red; in the other type of trials, the word and its colour are concordant, as the word RED printed in red. Colour naming is slower and less accurate in incongruent trials than in congruent ones. The Stroop task performance is determined by at least two mechanisms (Kane & Engle, 2003). One of them can be classified as a type of inhibition, namely, the prepotent response inhibition (Friedman & Miyake, 2004) because the participants have to inhibit the dominant tendency to read the words. This determinant of performance is closely connected with "attentional selection" because the participants have to actively select the colour dimension of each stimulus instead of its meaning; it is assumed that this competition resolution process is time-consuming (Jackson & Balota, 2013). Another critical determinant of performance is a breakdown in the ability to maintain task goals across trials. Failures of this process are reflected primarily in errors committed when the participant neglects the goal of naming the font colour and habitually reads the word. According to Kane and Engle (2003), a version of the Stroop task including many congruent trials makes the task more sensitive to goal-neglect because on congruent trials participants do not have to maintain the goal of ignoring the word meaning.

Method

Participants

Sixty-four participants volunteered in the study in exchange for course credits. The group consisted of undergraduates from a rather homogenous population of well-functioning university students. All participants were native speakers and declared normal colour vision. Four participants were excluded because they completed only one page of the FSS. The mean age of the participants was 20.6 years (ranging from 20 to 25 years); 12 were men.

Materials

Fatigue Symptoms Scales – State (FSS-S). The FSS consists of 60 items describing various symptoms of fatigue that form a total score, as well as six subscales:

1) cognitive symptoms (12 items, e.g., *Difficulty in thinking*. or *Absent-mindedness*.);
2) executive symptoms (5 items, e.g., *Decline in coordination of movement*.);
3) emotional symptoms (12 items, e.g., *Irritation and annoyance*.);
4) motivational symptoms (10 items, e.g., *Exhaustion and lack of energy to act*.);
5) self-confidence symptoms (5 items, e.g., *Decline in self-confidence*.); and
6) physiological symptoms (13 items, e.g., *The ache in head, muscles or stomach.*)

In the state version (FSS-S), the participants are asked to indicate to what extent they experience a particular symptom at the current moment on a 5-point rating scale ranging from 0 (*not at all*) to 4 (*very strongly*). The validation study (Gasiul et al., 2019) showed that the FSS-S subscales are strongly intercorrelated and exploratory factor analysis (EFA) indicated one-factor (accounting for 81 % of the variance) structure of the measure. This justifies the use of the total score and treatment of the subscales as aspects of the same phenomenon. In the current Study 1, the reliabilities of the FSS-S subscales measured by Cronbach's alpha coefficients range between .82 (executive symptoms subscale) and .96 (total score). Table 1 presents these coefficients as well as medians, means and *SD* scores of FSS-S subscales obtained by the participants in Study 1. Intercorrelations of FSS-S subscales obtained in the current sample ranged from .46 to .91.

Table 1

Descriptive Data for the Fatigue Symptoms Scales – State and Cognitive Measures from Study 1

Fatigue Symptoms Scale-State	Median	Mean	(*SD*)	Alpha
Total fatigue symptoms	55	60.97	(35.08)	.96
Cognitive symptoms	12	12.51	(7.85)	.90
Executive symptoms	4	4.82	(3.65)	.82
Emotional symptoms	11	12.39	(7.83)	.85
Motivational symptoms	13	13.15	(7.54)	.86
Self-confidence symptoms	3	3.85	(3.94)	.86
Physiological symptoms	8	10.56	(8.35)	.87

	Median	Mean (*SD*)	Alpha
Cognitive Tasks			
Stroop 25 %: Errors	2	2.35 (2.00)	
Stroop 25 %: RT (ms)	788.2	809.59 (156.61)	
Stroop 25 %: RT Difference (ms)	229.8	240.91 (131.36)	
Rotation Span: Capacity Score	24	24.40 (8.90)	

Note. Errors: number of errors committed in incongruent trials; RT: mean reaction time for all correct responses, RT Difference: the difference between mean RT in congruent and incongruent trials; Capacity: the number of correctly recalled arrows' orientations.

Cognitive Tasks

Stroop task. We used a computer version of the Stroop task – the participants were instructed to classify the font colour of a stimulus as quickly and accurately as they can (pressing specific keys on a keyboard). The task began with instructions and a short practice session with feedback provided to the participants after each trial concerning the accuracy of their reactions. Next, two target sessions were performed by the participants, each consisting of 64 trials separated by a one-minute break. As the materials, we used four words/colours (blue, red, green, and purple); all the stimuli were presented on a black screen, and each word was preceded by a fixation point visible for 350 ms, and followed by a blank slide for 650 ms. In order to increase the role of the goal maintenance ability for task performance, only 25 % of the trials were incongruent, and the rest were congruent. The dependent measures were the mean correct RT on all trials, the RT difference between congruent and incongruent trials, and the number of errors committed on incongruent trials.

Rotation Span. The main goal required in this task is to maintain and recall a sequence of arrows pointing from the centre of the screen in one of eight directions. The interfering task, performed between the arrow presentations, consists of judging whether a rotated letter presented on the screen is standard or mirror-reversed. After the rotation judgment, the participant sees a new arrow or a recall screen. Each arrow is presented for 900 ms. On the recall screen, all the possible arrow directions are displayed and marked by numbers. The participant indicates the order of the arrows using these numbers. The participants are instructed to use the space bar if they do not remember the arrow from a particular position. The letters displayed between the arrow presentations are R, G, and J, rotated at 0°, 45°, 90°, 135°, 180°, 225°, 270°, or 315°. The test begins from detailed instructions being given to the participant and three training trials. On the target task, between 2 and 6 arrows are presented on each trial, and there are a total of 13 trials: three 2-arrows trial, three 3-arrow trials, three 4-arrow trials, three 5-arrow trials, and one 6-arrow trial. Performance is assessed by summing the number of arrows correctly recalled in the correct order in all the trials, hence, the highest possible score is 48. Table 1 shows the descriptive data for the cognitive measures and Table 2 presents their intercorrelations. When reporting correlations among measures, in both Study 1 and 2, we used non-parametric

Spearman's *rho* rank order correlations due to non-normal distribution of most of the variables[1].

Table 2

Spearman's Rho Rank Order Correlations between Cognitive Performance Measures and the Scores from the Fatigue Symptoms Scales – State in Study 1

	Stroop 25 %			Rotation Span
	Errors	RT	RT Difference	Capacity
Stroop 25 %: Errors	-			
Stroop 25 %: RT (ms)	-.222	-		
Stroop 25 %: RT Difference (ms)	-.088	**.502**[b]	-	
Rotation Span: Capacity Score	.003	**-.478**[b]	-.070	-
FSS-S: Total fatigue	-.051	.129	.096	-.095
Cognitive	.040	.112	.040	-.102
Executive	-.054	**.255**[a]	.061	-.073
Emotional	-.177	.150	.070	-.153
Motivational	-.114	.109	.082	-.028
Self-confidence	.091	.161	.100	**-.322**[a]
Physiological	-.022	.106	.078	.099

Note. Significant correlations are indicated in bold font; [a] $p < .05$; [b] $p < .001$.

Procedure

All the participants were examined between 1 p.m. and 4 p.m. at individual workstations in the University Lab. The participants started with completing the FSS concerning their current state. Next, they performed the Stroop task and ended with the Rotation Span task. Cognitive tasks were designed and applied using E-Prime 2.0 (Psychology Software Tools, Inc.).

Results and Discussion

As shown in Table 2, the correlation coefficient between the number of errors committed by the participants and the RT difference between congruent and incongruent trials was close to zero, which suggests that these two indices taken from

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[1] In Study 1, a Kolgomorov-Smirnov test indicated that the following measures were significantly deviant from a normal distribution: Errors in Stroop task, Executive symptoms, Self-confidence symptoms, and Physiological symptoms FSS-S subscales. In Study 2, distributions of all subscales of FSS-S (measured before session) and of almost all subscales of FSS-T (except Cognitive and Emotional symptoms) were significantly non-normal; among cognitive measures only the RT switch cost variable and false alarms rate of SART were distributed normally, the rest were significantly non-normal.

the Stroop task probably capture different processes. This is consistent with our assumption that the accuracy score is based on the ability to maintain the goal of the task, whereas the difference in RTs between congruent and incongruent trials reflects the inhibition ability. The intercorrelations between the cognitive measures also showed that the participants with the higher WMC responded faster in the Stroop task.

The results of main interest in this study are shown in the bottom half of Table 2. There were only two significantly different from zero correlation coefficients – fatigue symptoms grouped in the executive subscale correlated with RTs in the Stroop test, and the participants with higher WMC reported significantly fewer symptoms of self-confidence fatigue. Therefore, we did not confirm the relationship between fatigue and goal-neglect in our group of participants. The lack of any significant association between the RT difference between congruent and incongruent trials and fatigue indices was quite surprising, taking into account the reports in the literature (e.g., Faber, Maurits, & Lorist, 2012; Guo et al., 2018). However, the contribution of inhibition ability in the version of the Stroop task with 25 % incongruent trials may not be reliably captured; hence, in Study 2, we used a version of the task that uses only incongruent and neutral trials.

Study 2

In this study, we used four cognitive tasks intended to measure sustained attention and various executive functions. When choosing an approach to assess executive function, we followed a well-known analysis by Miyake et al. (2000), who indicated that three partially separable factors support executive performance. Their confirmatory factor analysis showed that a three-factor model of executive functions fits the data significantly better than a one-factor or two-factor model. The three components are inhibition, shifting, and updating. Inhibition is the ability to inhibit the automatic or prepotent reactions on presented stimulus when necessary for effective performance. Mental set-shifting is responsible for the ability to effectively switch between multiple tasks or mental states. Information updating is connected with the monitoring and encoding of incoming information – it is not a passive storing but an active manipulation of the relevant information (cf. Nieznański et al., 2015).

To measure the three components of executive function we used the Stroop task described in Study 1, the Plus-minus task, and the N-Back task. The Plus-minus task is a task-switching procedure intended to compare performance when participants alternate between tasks (i.e., arithmetic operations of adding and subtracting) with performance when repeating a single operation. The difference in speed or accuracy of the performance is called a “switch cost” or “shift loss” (Jersild, 1927). Individual differences in the switch cost may be interpreted as a reflection of the ability of executive control processes to reconfigure task-sets or as a manifestation of the ability to overcome a type of proactive interference. This interference (called "task-set inertia", Allport, Styles, & Hsieh, 1994) results from the competition between the tasks – one task-set persists over time and interferes with the performance of a new task (Kiesel et al., 2010; Logan, 2003; Miyake et al., 2000).

The N-Back task requires participants to monitor a stream of stimuli and to respond whenever a stimulus is presented that is the same as the one shown N trials before (e.g., Jaeggi, Buschkuehl, Perrig, & Meier, 2010; Kane, Conway, Miura, & Colflesh, 2007). The task is typically used as a working memory paradigm, especially in neuroimaging studies (e.g., Awh et al., 1996; Jonides et al., 1997; Owen, McMillan, Laird, & Bullmore, 2005); it requires maintaining and updating a memory set.

Apart from the executive tasks, we also assessed the participants' ability to sustain attention. As mentioned in the introduction, boredom/monotony and fatigue/overload theories have been proposed to explain lapses of sustained attention (Head & Helton, 2014). According to the boredom theories, monotony causes participants to disengage from a task – sustained attention should be supported by exogenous stimulation to be maintained over time. The second approach argues that focusing attention is cognitively demanding so it depends on the amount of mental resources that are available. Following the latter approach, we expect that resource depletion due to fatigue will affect sustained attention task performance.

The Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) that we used in this study, is a kind of continuous performance paradigm in which the participant responds to more frequent non-targets and withholds his/her responses to rare targets. Such a task requires a high level of conscious attention to the response, endogenous modulation of alertness and it is sensitive to transient lapses in attention. In other words, SART is a measure of mind-wandering and sustained attention or vigilance (e.g., Cheyne, Solman, Carriere, & Smilek, 2009; Head & Helton, 2014; Robertson et al., 1997). However, in the SART, repeated responding to non-targets becomes automatic and this prepotent motor response has to be occasionally withheld to targets. Therefore, participants' performance in the SART is also dependent on the ability to inhibit a motor response (e.g., Carter, Russell, & Helton, 2013; Wilson, Russell, & Helton, 2015).

To assess self-reported symptoms of fatigue, we used the Trait and State versions of the FSS completed by the participants before they performed the cognitive tasks. The participants were also asked to complete the State version of the FSS after they had finished the cognitive tasks. In this way, we intended to assess the influence of this intensive but relatively short cognitive effort on fatigue symptoms. We aimed to find which fatigue symptoms are affected by this effort. If an increase in fatigue symptoms will be restricted to cognitive symptoms – for example, finding it difficult to concentrate, the participant presumably just interprets the errors or difficulties she/he has noticed during task performance as resulting from fatigue. Therefore, an increase in reported cognitive fatigue may just reflect the participant's dissatisfaction with their performance in the cognitive tasks. However, if the participant reports an increase also in other kinds of fatigue symptoms – for example, a drop in motivation, it is probable that these symptoms reflect a genuine mental-resource depletion due to engagement in cognitive activity.

Method

Participants

Sixty-four undergraduate students participated in the study in exchange for course credits. Among them, cognitive-test data were lost for 2 participants due to equipment failure. Moreover, one participant failed to follow the instructions in the Plus-minus task, and another one in the SART. In the case of the FSS, one participant completed only the first page of the scale at the beginning of the study, and three other participants made the same mistake at the end of the study. The mean age of the participants was 20.1 years (ranging from 19 to 25 years), among them 17 were men.

Materials

Fatigue Symptoms Scales. In contrast to the state version, FSS-S – described above (Study 1) – the trait version, FSS-T assesses the susceptibility to fatigue, and the participants use a 5-point scale (ranging from 0 – *never or very rarely* to 4 – *very often*) to indicate how often they experience the particular fatigue symptom while doing their job. Apart from the total score and 6 subscales (measuring: cognitive, executive, emotional, motivational, self-confidence, and physiological symptoms), the FSS-T additionally includes the neurotic fatigue subscale (using 8 items) measuring the propensity for experiencing fatigue during everyday life without visible reason. As expected on the grounds of similarly to the FSS-S, the FSS-T subscales are strongly intercorrelated and the measure is one-factor structured (a single factor explains 86 % of the variance in EFA; Gasiul et al., 2019). In the current study, Cronbach's alpha coefficients of the FSS-T subscales ranged between .57 (executive symptoms subscale), and .95 (total score; see Table 3 presenting the results of the FSS-T subscales obtained in Study 2). Table 4 presents the alpha coefficients as well as descriptive data of FSS-S subscales obtained by the participants in Study 2 before and after the cognitive-tasks block. Intercorrelations of FSS-T subscales obtained in the current sample ranged from .52 to .92.

Table 3

*Descriptive Data for the Fatigue Symptoms Scales – **Trait** and Cognitive Performance Measures from Study 2*

Fatigue Symptoms Scales-**Trait**	Median	Mean (*SD*)	Alpha
Total fatigue symptoms	84.5	84.30 (31.94)	.95
Cognitive symptoms	16.5	17.66 (7.23)	.83
Executive symptoms	6	6.87 (2.65)	.57
Emotional symptoms	15	15.86 (6.97)	.80
Motivational symptoms	16	17.27 (6.96)	.85
Self-confidence symptoms	5	5.37 (3.53)	.70
Physiological symptoms	15	16.70 (8.09)	.84
Neurotic fatigue	12	12.83 (5.93)	.81
Cognitive Tasks			
Plus-Minus: Switch cost RT (*ms*)	58.5	69.77 (258.02)	
Plus-Minus: Switch cost Errors	0.5	0.623 (1.724)	
SART: FAR	0.556	0.550 (0.190)	
SART: OMR	0.023	0.045 (0.054)	
SART: *CV* RT	0.327	0.351 (0.128)	
Stroop: Errors	2	2.270 (2.097)	
Stroop: RT (*ms*)	855.35	873.48 (221.03)	
Stroop: Interference (*ms*)	107.81	131.83 (77.06)	

Note. FAR: false alarm errors rate; OMR: omission errors rate; *CV*: coefficient of variability; Interference: the difference between mean RT in incongruent and neutral trials.

Table 4

Medians, Means, Standard Deviations (SD), and Cronbach's Alphas for the Fatigue Symptoms Scales - State Used before and after Cognitive-Task Session and the Comparison of These Scores (Study 2)

	Before			After			Change		Wilcoxon signed-rank test
FSS-S	Median	Mean (*SD*)	Alpha	Median	Mean (*SD*)	Alpha	Median	Mean (*SD*)	
Total fatigue symptoms	39	47.32 (31.95)	.96	80	78.79 (43.36)	.97	29.5	32.90 (34.38)	**z = 6.25**
Cognitive symptoms	7	8.97 (7.14)	.89	17	17.25 (10.40)	.93	8	8.69 (8.64)	**z = 5.98**
Executive symptoms	3	3.81 (3.01)	.75	9	9.28 (4.78)	.87	5	5.53 (3.97)	**z = 6.44**
Emotional symptoms	8	9.94 (7.71)	.88	12	14.23 (9.26)	.90	4	4.28 (5.85)	**z = 4.74**
Motivational symptoms	8	9.62 (7.49)	.87	13	13.08 (7.67)	.86	2.5	3.73 (6.41)	**z = 4.06**
Self-confidence symptoms	2	2.97 (3.47)	.83	4	4.52 (3.71)	.79	1	1.65 (3.30)	**z = 3.69**
Physiological symptoms	7	9.14 (8.25)	.88	14	16.82 (10.88)	.91	7	8.22 (8.43)	**z = 6.04**

Note. All differences are significant with $p < .001$.

Cognitive Tasks

Stroop task. In Study 2, we used a version of the Stroop task with incongruent and neutral trials only, with no congruent trials. Neutral words were chosen to match the colour words in length and in frequency of occurrence in the language, and they started with letters other than the colour words. We presumed that such a version of the Stroop task emphasizes the role of inhibition ability more than goal maintenance ability. Other elements of this task procedure were the same as in Study 1.

Plus-minus task. The task we used here, was a computer version of the one used by Miyake et al. (2000); it consisted of three blocks of 30-trials. On each trial, a plus or minus sign was placed between a two-digit number (ranging from 13 to 96) and the number 3. Two-digit numbers in consecutive trials never ended with the same digit. The task started with several practice trials displayed on a computer screen (e.g., 79 + 3 = ?). The target task started with a 30-trial block in which the participants were only adding 3 to the two-digit numbers. In the second block, they were only subtracting 3, and finally, in the third block, they had to shift between the two arithmetic operations. On each trial, the participants indicated the outcomes of each operation using a keyboard; their responses appeared on a computer screen to the right of the equals sign. Between slides, a blank slide was displayed for 500 ms. The participants were instructed to work quickly and accurately. The costs of switching between the arithmetic operations were indexed by RT cost and accuracy cost. The former was calculated as the difference between the mean RT of a trial in the alternating block and the average of the mean RTs of addition trials and subtraction trials in the homogenous blocks. Accuracy cost was calculated as the difference in the number of errors committed in the alternating block and the mean of errors made in the two homogenous blocks.

2-Back task. We used a 2-Back version of the N-Back task, which means that the participants should respond positively if a letter matches the letter presented two trials ago. As stimuli, we used the letters: B, F, K, M, R, and X; they were presented one at a time, for 500 ms each, followed by a blank 1500 ms interstimulus interval. The sequence of the stimuli consisted of 243 trials, among which 60 were targets. The dependent variables were the proportion of false alarms and the proportion of omission errors.

Sustained Attention to Response Task. The SART procedure used here followed the procedure created by Robertson et al. (1997). In this task, 243 single digits were presented visually on a computer screen. The digits ranged from 1 to 9, and each was presented 27 times in random order across the task. Each digit was presented for 250 ms, followed by a 900 ms mask #. Digits were presented in the *Symbol* font in five different sizes (48, 72, 94, 100, 120 points). Participants were instructed to respond using the ENTER key to all digits except the digit 3. The task started with a short practice session. The metrics of interest in the SART were errors of commission, errors of omission, and variability of RT. Errors of commission (the proportion of responses to non-target, the digit 3) are failures to withhold to response; therefore, we treat this index as an indicator of the ability of motor response inhibition more than sustained attention. Errors of omission (cessation of responding to targets) we interpret as being reflective of lapsing attention and breaks from task engagement. The coefficient of variability ($CV = SD$/Mean) is a measure of variability in RTs, which is independent of the mean differences. Increased *CV* reflects an alternating speeding and slowing of reactions. Cheyne et al. (2009) interpreted this coefficient as describing the “state of occurrent task inattention”, that is, a brief or partial waning of processing of dynamically changing stimuli. Table 3 provides the medians, means and standard deviations for the cognitive measures used in Study 2.

Procedure

The participants were examined in the University Lab, at various times of the day, from 10 a.m. to 5 p.m. The participants started with completing the FSS-T concerning how they usually feel (Trait version), and then completed the FSS-S concerning their current state. After that, they performed five cognitive tasks. The first task was an episodic-memory task, which was not connected with the present study and is not reported here (see: Nieznański & Obidziński, 2019). Then, the participants performed the Plus-minus task, the SART, the Stroop task, and the 2-Back task. These four tasks were arranged in four different orders across the participants so that each order of the tasks was given to an equal number of participants. The whole session took approximately 50 minutes.

Results and Discussion

The intercorrelations between the cognitive indices are shown in Table 5. It should be noted that the interference measure from the Stroop task did not correlate with any of the SART indices. It appears that the SART reflects, firstly, sustained attention rather than response inhibition or at least a different kind of inhibition than that captured by the RT interference index of the Stroop task (for discussion see Carter et al., 2013; Cheyne et al., 2009; Wilson, Finkbeiner, de Joux, Russell, & Helton, 2016).

The correlations between the initial scores in the State and Trait FSS and the cognitive tests are shown in Table 6. It seems that the total score in the FSS was not significantly correlated with any of the cognitive performance measures used in Study 2. A trend-level association was found between the total score in the FSS-T and the accuracy switch cost in the Plus-minus task. Taking into account the subscales of the FSS, we found trend-level or significant positive correlations between the accuracy switch cost and cognitive symptoms of the FSS-S and FSS-T, executive symptoms of the FSS-T, and self-confidence symptoms of the FSS-S. We also found that the participants who reported more self-confidence fatigue symptoms of the FSS-S responded significantly more slowly in the Stroop task. In the case of the FSS-T, the participants reporting less motivational symptoms of fatigue received significantly higher index of RT variability in the SART. Similarly, the executive symptoms were significantly negatively correlated with the omission errors and variability in RTs in the SART.

Table 5

Spearman's Rho Rank Order Intercorrelations among Cognitive Performance Measures in Study 2

		Plus-Minus		SART			Stroop			2-Back	
		Switch cost RT	Switch cost Errors	FAR	OMR	*CV* RT	Errors	RT	Interference	FAR	OMR
Plus-Minus	Switch cost RT	-									
	Switch cost Errors	**.33** ^{c}	-								
SART	FAR	.07	-.15	-							
	OMR	.03	-.04	**.53** ^{d}	-						
	CV RT	-.15	-.14	**.40** ^{d}	**.69** ^{d}	-					
Stroop	Errors	.03	.03	.18	.22 ^{a}	**.27** ^{b}	-				
	RT	-.04	-.08	-.02	.20	.14	-.15	-			
	Interference	.06	-.15	.08	.05	-.05	-.07	**.44** ^{d}	-		
2-Back	FAR	.13	.22 ^{a}	.10	.11	.03	-.10	.11	.04	-	
	OMR	.04	.14	-.03	.10	.04	-.15	**.47** ^{d}	.22 ^{a}	**.41** ^{d}	-

Note. Significant correlations are indicated in bold font; ^{a} $p < .10$; ^{b} $p < .05$; ^{c} $p < .01$; ^{d} $p \leq .001$.

Table 6

Spearman's Rho Rank Order Correlations between Cognitive Performance Measures and the Scores from the Fatigue Symptoms Scales – State and -Trait Versions as well as the Change Scores in the Fatigue Symptoms Scales - State

	Plus-Minus		SART			Stroop			2-Back	
	Switch cost RT	Switch cost Errors	FAR	OMR	*CV* RT	Errors	RT	Interference	FAR	OMR
*Fatigue Symptoms Scales- **State***										
Total fatigue symptoms	-.10	.19	.02	-.01	-.05	.02	.02	.03	.04	-.07
Cognitive symptoms	-.01	**.25** ^{b}	.05	.06	-.02	.11	-.11	.05	.12	-.12
Executive symptoms	-.19	.23 ^{a}	-.12	.01	.03	.06	.09	-.00	.15	.08
Emotional symptoms	-.11	.13	.07	.01	-.08	-.06	-.00	.02	.03	-.15
Motivational symptoms	-.09	.19	-.04	-.00	-.00	.03	.04	-.03	.08	-.04
Self-confidence symptoms	-.08	**.27** ^{b}	.09	.09	.04	.04	**.27** ^{b}	.11	.11	.17
Physiological symptoms	.00	.07	.15	-.02	.08	.12	-.18	-.11	-.04	-.06

	Plus-Minus		SART			Stroop			2-Back	
	Switch cost RT	Switch cost Errors	FAR	OMR	*CV* RT	Errors	RT	Interference	FAR	OMR
*Fatigue Symptoms Scales- **Trait***										
Total fatigue symptoms	.01	.23^{a}	.01	-.11	-.18	-.09	.11	.11	.01	-.12
Cognitive symptoms	.05	**.28^{b}**	.12	.01	-.14	.05	.07	.10	.04	-.13
Executive symptoms	.01	**.30^{b}**	-.25^{a}	**-.27^{b}**	**-.39^{c}**	-.03	.03	.06	.07	-.08
Emotional symptoms	-.10	.07	.10	.02	-.08	-.18	.15	.03	.03	-.23^{a}
Motivational symptoms	.02	.21^{a}	-.07	-.16	**-.26^{b}**	.07	.05	.10	-.08	-.22^{a}
Self-confidence symptoms	.01	.09	-.04	-.24^{a}	-.20	-.07	.21^{a}	.16	-.03	-.06
Physiological symptoms	.07	.13	.14	-.09	-.07	.02	.10	.23^{a}	.03	-.01
Neurotic fatigue	.03	.11	-.02	-.13	-.24^{a}	.01	.14	.17	-.01	-.15
***Change** in Fatigue Symptoms Scales-State*										
Total fatigue symptoms	.15	.07	.06	-.11	-.13	-.10	-.12	.06	.12	-.07
Cognitive symptoms	**.25^{b}**	.14	-.06	**-.36^{c}**	**-.40^{c}**	-.17	-.19	-.09	.05	-.07
Executive symptoms	.15	.12	-.01	**-.31^{b}**	**-.27^{b}**	-.12	-.21^{a}	-.09	-.01	-.11
Emotional symptoms	.10	.04	-.00	-.15	-.25^{a}	-.10	-.16	.00	.16	.08
Motivational symptoms	-.01	-.15	.08	-.07	-.18	-.07	-.16	.03	-.00	-.10
Self-confidence symptoms	.21^{a}	.15	-.08	-.12	**-.27^{b}**	-.10	-.13	-.06	.07	-.08
Physiological symptoms	.07	.06	.04	-.10	-.04	-.06	-.08	.08	.15	-.15

Note. Significant correlations are indicated in bold font; ^{a} $p < .10$; ^{b} $p \leq .05$; ^{c} $p < .01$.

A comparison between the FSS-S scores obtained from the participants before and after performing the cognitive tasks clearly indicates a significant increase both in the total score as well as in all the subscales of the FSS-S (see Table 4). This suggests that the participants not only interpreted their problems in task performance as reflecting their fatigue but also felt a general depletion of their mental resources after intensive engagement in cognitive tasks. The correlations between the size of change in the FSS-S scores and cognitive performance level are shown at the bottom of Table 6. The participants who reported a greater increase in cognitive and executive symptoms committed significantly fewer omission errors and responded with lower variability in the SART. Moreover, a greater increase in self-confidence symptoms was correlated with lower variability in the SART and a greater increase in cognitive symptoms was correlated with an increase in the RT switch cost. Presumably, greater engagement in the SART performance was responsible for an increase in cognitive and executive symptoms of fatigue; in contrast, faster performance in the Plus-minus task was connected with decrease of cognitive fatigue.

Study 3

In our third study, we followed up the correlational results obtained in Studies 1 and 2, this time using an experimental design. Study 2 indicated that better performance in the SART is associated with an increase in fatigue symptoms reported by the participants. We assume that this better performance was a consequence of greater involvement of attentional resources during this task, which, in turn, led to an increase in cognitive/executive fatigue symptoms. Moreover, among many indices of cognitive performance applied in Studies 1 and 2 only the accuracy switch cost in the Plus-minus task showed noticeable correlations with some of the subscales of the FSS-S. Therefore, in the current experiment, we induced a mild level of fatigue by a shorter or longer time spend on the SART performance, and we measured the effects of this time-on-task on the subjective level of cognitive and executive fatigue symptoms and objective level of cognitive performance in the Plus-minus task. On the basis of Study 2 results, we predict that switch cost measured by accuracy index (but not RT), is sensitive to task-induced fatigue.

Method

Participants

Fifty-five participants volunteered in the study in exchange for course credits, they were recruited from the same population of undergraduates as in the two previous studies. They were randomly assigned to three groups: one control group (N = 17), and two experimental groups (N = 19, each) differing in the length of the fatigue-inducing task. The mean age of the participants was 20.6 years (20.5, 20.6, and 20.6 years for the control group, the 5-minute-on-task experimental group and the 10-minute-on-task experimental group, respectively). Among participants 5 were men.

Materials

Cognitive Tasks

In all three groups we used the same version of the Plus-minus task as in Study 2. In experimental groups we used a version of the SART with several modifications intended to make the task more difficult. In comparison with Study 2, the stimuli were presented not only in the centre of the computer screen but also moved by one or two space bars from this central position. The mask included three # signs instead of one. This change implemented a kind of spatial uncertainty as to the location of the stimuli (Warm, Dember, & Hancock, 1996). We also changed the font colour of presented numbers to make them less sharp – that is, targets were in grey (instead of white) font colour on the black background. We assumed that the difficulty of the sustained attention task should increase with a decrease in the salience of the signals to be detected (as suggested in Warm et al., 1996). Despite our attempts to make the task more difficult, the decrease in performance was nonsignificant, both in terms of the false alarm rate (FAR) (*Mdn* = .593; *M* = 0.530; *SD* = 0.245) and the omission error rate (OMR) (*Mdn* = .023; *M* = 0.088; *SD* = 0.216) in the 5-minute experimental group in comparison with Study 2 (Mann-Whitney *U* = 569.0 and 577.0, for FAR and OMR, respectively). The participants in the shorter time-on-task experimental group performed the same number of trials (243) as the participants in Study 2 which lasted about 5 minutes. In the longer time-on-task experimental group, the number of trials was doubled (486), and the task lasted about 10 minutes.

Fatigue symptoms. To assess self-reported symptoms of fatigue, we used two subscales taken from a shortened version of the FSS-S. This version consists of 40 items selected after validation study (Gasiul et al., 2019) from the full 60-item version. In the current study, we used only the cognitive symptoms subscale (9 items) and the executive symptoms subscale (4 items) from the FSS-S-40, and we administered it in the form of questions appearing sequentially on a computer screen, instead of a paper-pencil version used in Studies 1 and 2. The reliabilities of these FSS-S-40 subscales measured by Cronbach's alpha coefficients were .91 and .80 for the cognitive symptoms subscale and the executive symptoms subscale, respectively. The subscales were significantly intercorrelated (*rho* = .79, *p* < .001).

Procedure

As previously, the study was conducted in the University Lab. Participants in the control group started with performing all three blocks of the Plus-minus task and ended with answering to what extent they experience cognitive and executive symptoms of fatigue. Participants from both experimental groups started with two homogenous blocks of adding and subtracting of the Plus-minus task. Next, they performed shorter (about 5-minute) or longer (about 10-minute) version of the SART. After completing SART they received the alternate block of the Plus-minus task. They ended, as the control group, with answering to cognitive and executive items of the FSS-S.

Results and Discussion

Table 7 shows medians, means, and standard deviations of the Plus-minus test indices and the FSS-S-40 subscales scores obtained by the participants from the control group and the two experimental groups. Non-parametric Kruskal-Wallis test indicated significant differences between groups in both indices of switch costs. Post-hoc paired-comparisons using non-parametric Mann-Whitney tests showed that RT switch cost was significantly lower in the 5-minute-on-task experimental group than in the control group and in the 10-minute-on-task experimental group (*z* = 3.85, *p* < .001; *z* = 2.29, *p* = .02, respectively); RT switch cost was also lower in the 10-minute-on-task experimental group than in the control group ($z = 2.27$, $p = .02$). The accuracy switch cost was significantly lower in the control group than in the 5-minute-on-task experimental group and the 10-minute-on-task experimental group ($z = 2.27$, $p = .02$; $z = 3.33$, $p = .001$, respectively). The difference between experimental groups did not reach significance ($z = 1.32$). In the case of the FSS-S-40 subscales, Kruskal-Wallis test did not indicate any significant difference between groups. Only a trend-level difference was found for the level of executive symptoms. Kruskal-Wallis tests showed no differences in the initial levels of mean RTs and Errors rate in homogenous blocks of the Plus-minus task ($H = 1.33$; $H = 3.31$, respectively) between groups.

Table 7

Comparison between Control and Experimental Groups in Study 3

	Control group (*N* = 17)		5-minute-on-task experimental group (*N* = 19)		10-minute-on-task experimental group (*N* = 19)		*H* Kruskal-Wallis
Dependent Variable	Median	Mean (*SD*)	Median	Mean (*SD*)	Median	Mean *(SD)*	
Plus-Minus							
Switch cost RT (ms)	133	188.0 (319.17)	-285	-289.7 (297.54)	-88	-30.6 (306.5)	**16.75** ^{a}
Switch cost Errors	-1	-0.38 (1.219)	0	1.18 (2.583)	2	1.92 (2.162)	**11.89** ^{b}
Fatigue Symptoms Scales-State-40							
Cognitive symptoms	11	13.3 (7.97)	17	14.9 (7.80)	21	18.3 (9.32)	3.34
Executive symptoms	6	6.7 (3.72)	8	8.1 (3.14)	10	9.4 (3.75)	5.62 ^{c}

Note. Significant differences are indicated in bold font; ^{a} $p < .001$; ^{b} $p < .01$; ^{c} $p = .06$.

The result of main interest is the experimentally confirmed influence of performing the sustained attention task on the accuracy switch cost. We showed that even short engagement in the SART results in a significant increase in errors in the switching task. At the same time, we observed that participants responded more quickly after performing the SART, which may be interpreted as a kind of cognitive warm-up (Śpiewak, 2006) or a fatigue-induced hastiness in performance. Our experiment did not confirm the influence of attentional effort on self-reported symptoms of cognitive fatigue, however, the level of executive symptoms tended to be higher in the experimental group than in the control group.

General Discussion

In our studies, we aimed to find whether mild or moderate symptoms of fatigue are associated with cognitive tasks performance deterioration. Such findings would be applicable to everyday life activities such as driving a car, which depend on executive and attentional efficiency (e.g., Jackson et al., 2013; Mäntylä et al., 2009). We expected that even low levels of fatigue may result in some problems with such executive functions as prepotent response inhibition, task switching or updating of the memory set. However, we found only a few significant correlations indicating that participants reporting symptoms of fatigue perform worse in cognitive tasks.

In detail, participants with more self-confidence fatigue symptoms performed worse in the task measuring WMC, responded slower in the Stroop task, and committed more errors due to task switching in the Plus-minus test. The participants with higher cognitive and executive symptoms of fatigue also committed more errors in the Plus-minus test. Contrary to our expectations based on literature (Faber et al., 2012; Guo et al., 2018), we found that such executive processes as updating and inhibition are not correlated with the symptoms of fatigue. For example, Faber et al. (2012) showed that mental fatigue influences selective attention/inhibition of irrelevant information. They induced fatigue by prolonged task performance and observed the changes in the processing of irrelevant stimuli in the Flanker task. Analyses based on behavioural data and EEG recordings suggested that mental fatigue decreased the ability to block out irrelevant information. Faber et al. (2012) used both accuracy and RT measures of performance, however, the accuracy measure better captured the influence of fatigue on attentional modulation. They suggested that fatigue primarily impedes the suppression of irrelevant signals (but not the processing of relevant stimuli) leading to an increase in the number of errors. In a similar recent ERP study, Guo et al. (2018) indicated that mental fatigue influence response inhibition in a Go/No Go task, that manifests in both increased RT and miss rates. In the present study, we did not use the Flanker test or Go/No Go task, however, indices from the Stroop test and commission errors in the SART are measures that capture the selective attention ability and require suppression of irrelevant information. Despite this, we did not find significant correlations between fatigue and these measures, neither for scores based on RT nor accuracy. In our Study 1, we also did not confirm the expected association between fatigue and goal maintenance efficiency. A version of the Stroop task that includes many (75 %) congruent trials, which was intended to capture goal maintenance ability, did not correlate with any of the symptoms of fatigue. However, in comparison with our study, previous studies that demonstrated associations between fatigue and lapses of attention, induced much deeper levels of fatigue (e.g., due to sleep deprivation, Jackson et al., 2013).

It is possible that the influence of mild or moderate levels of fatigue on cognitive performance was regulated by a "performance protection strategy" adopted by the participants (see Hockey, 1997; Hopstaken, van der Linden, Bakker, Kompier, & Leung, 2016). In a recent study on the influence of motivation manipulation on sustained-attention task performance (Seli, Schacter, Risko, & Smilek, 2019), significant reductions in mind-wandering rates were shown for highly motivated participants. It seems that mind-wandering during a sustained attention task is determined by task-engagement rather than by an attentional deficit. A compensatory effort can protect performance in various kinds of tasks but sometimes is not effective, as indicated by the accuracy switch cost in Studies 2 and 3. Moreover, we can also speculate that such a strategy may be not effectively adopted by participants who do not trust that they can regulate their performance. Probably, this is why we observed associations between a higher level of self-confidence symptoms of fatigue and poor performance in the Rotation Span task, slow RTs in the Stroop task, and the accuracy switch cost in the Plus-minus task.

In our research, we also studied the consequences of intensive but short cognitive effort. In Study 2, we found an increase in the level of all the symptoms of fatigue after performing several cognitive tasks. However, performance of a single sustained attention task, in Study 3, influenced only self-reported executive symptoms but not cognitive symptoms of fatigue. We also observed (in Study 2) that better performance in the SART – that is, fewer omission errors and lower variability in RTs, predicted a greater increase in the symptoms of fatigue. It seems that greater concentration and engagement in the sustained attention task made participants more tired. Our Study 3, indicated that even relatively short engagement of attention can cause a state of cognitive resources reduction, influencing accuracy in a task-switching procedure. These findings are consistent with neurocognitive studies describing the after-effects of mental exhaustion on resting brain activity. For example, Esposito et al. (2014) observed – using functional magnetic resonance imaging – that the fronto-parietal networks were suppressed in the exhausted, compared to the relaxed states. In their study, mental fatigue was induced by a 4-hour session in a helicopter simulator, a task that required continuous attention and intensive cognitive control. After this task, the functional connectivity of the fronto-parietal networks was impaired, and the participants had to invest a significantly higher amount of mental effort to maintain their performance level in the N-Back task.

Our correlational studies suggest that mild or moderate levels of fatigue are not good predictors of performance in most cognitive tests, even these regarded as highly resource-dependent. Nevertheless, there seems to be one exception – our results demonstrated that the accuracy switch cost is a relatively more sensitive indicator of fatigue than other indices because it is both correlated with some of the subjective symptoms of fatigue and detects resources depletion after short engagement of sustained attention.

In Study 2, we observed a significant increase in subjective fatigue after cognitive effort, and this increase correlated mostly with the SART indices. This suggests that a higher level of concentration and vigilance engaged in the SART performance was associated with a higher fatigue reported by the participants after effortful performance. It supports the view that vigilance task is not a little-demanding monotonous task but requires hard mental work and is stressful (Warm, Parasuraman, & Matthews, 2008). This finding is also in agreement with theories of overload or resource depletion as a reason for vigilance decrement and does not support the boredom/monotony account (cf. Head & Helton, 2014). These conclusions find support also in our experimental study on the effect of performing the SART on the Plus-minus task. It seems unlikely that task monotony might result in an increased accuracy switch cost after finishing a boring task; the more probable explanation refers to cognitive resources depletion. However, the switch cost was limited to accuracy which deteriorated after just five minutes of engagement in a sustained attention task performance. An increase from five- to ten-minute effort did not reveal further deterioration in the accuracy of performance.

Our results concerning accuracy deterioration are consistent with accounts indicating an important role of attention in error processing – they suggest that fatigue and reduced sustained attention states are likely the cause of an error processing impairment (Xiao et al., 2015). Study 3 also showed an unexpected effect of performing SART on RT switch cost. The fatigue-inducing condition resulted in faster rather than slower responses in the Plus-minus switching task. This suggests a speed/accuracy trade-off - it seems that due to fatigue the participants respond faster at the expense of committing errors. Therefore, we showed that the fatigue state induced by the SART performance affects accuracy and speed components of switching task differentially (cf. Healy, Kole, Buck-Gengler, & Bourne, 2004).

Lack of significant correlations between symptoms of fatigue and the version of the Stroop task measuring the goal-maintenance ability does not support the account claiming that fatigue results in "attention lapses" or "goal-neglects" (Jackson et al., 2013; Van Dongen & Belenky, 2012), we also found no evidence for the association between WMC and regulation of fatigue symptoms. However, our results do not rule out these hypotheses since they were based on research on more severe levels of fatigue than occurring in our study.

In the present work, we used a new scale to assess the level of subjective fatigue instead of a well-established instrument which is a potential weakness of our research. Nevertheless, taking into account the aim of our research, the FSS puts together several features that make it preferable over other available fatigue scales (Kulik, 2013); FSS is intended for healthy adult people (instead of suffering from chronic fatigue syndrome or other medical conditions), encompasses many different symptoms (including cognitive and executive symptoms of fatigue), and enables separate measurement of state and trait fatigue (Gasiul et al., 2019). Our results indicated that cognitive performance deterioration is associated with various self-reported symptoms of fatigue to a different degree. It seems that cognitive, self-confidence and executive symptoms of the FSS-S are among those symptoms that can be regarded as correlates of cognitive performance deterioration.

There are some practical implications of this research that we already signalled in the introduction. It seems that even mild or moderate levels of fatigue can induce errors in our activities requiring switching between tasks; for example, fatigue after usual work activity can disturb our driving performance when we switch to (even "voice-based") interactions with our smart-phones (cf. Strayer, Cooper, Turrill, Coleman, & Hopman, 2017). Another practical implication is about the kind of cognitive activity that causes fatigue – it seems that tasks requiring concentration on dynamically changing stimuli are most fatigue-inducing and should be avoided in, for example, classroom settings (e.g., Ko, Komarov, Hairston, Jung, & Lin, 2017). However, the practical implications of our laboratory studies have to be confirmed in a more ecologically valid setting as, for example, on-the-road or simulated driving studies.

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Povezanost samoprocjene simptoma zamora i kognitivne izvedbe: Cijena točnosti prebacivanja unutar zadatka kao pokazatelj zamora

Sažetak

U dvije je korelacijske studije kod studenata ispitana povezanost simptoma mentalnog zamora vezanog uz svakodnevne aktivnosti i izvedbe na zadacima koji uključuju izvršne procese i pažnju. Rezultati pokazuju da su blage ili umjerene razine zamora povezane s minimalno narušenom izvedbom, što sugerira da se posljedice takvih razina zamora mogu kompenzirati primjenom zaštitnih strategija. Iznimka je pritom značajna pozitivna povezanost razine zamora i veće cijene točnosti prebacivanja u zadatku plus-minus. Također, potvrđen je porast simptoma zamora nakon izvođenja nekoliko kognitivnih zadataka, a ta je promjena bila veća za ispitanike koji su se više angažirali na zadatku održavanja pažnje. U naknadnom je eksperimentu ispitan efekt zamora koji je induciran dužinom zadatka održavanja pažnje na izvedbu u zadatku prebacivanja i samoprocjenu simptoma kognitivnog i izvršnog zamora. Potvrđeno je da je cijena točnosti prebacivanja značajno veća kod ispitanika koji su izvodili zadatak održavanja pažnje nego kod ispitanika iz kontrolne skupine. U radu se upućuje na moguće praktične implikacije rezultata istraživanja o povezanosti mentalnog zamora i kognitivne izvedbe u aktivnostima poput vožnje automobila.

Ključne riječi: mentalni zamor, održavanje pažnje, cijena prebacivanja, izvršne funkcije, angažman na zadatku, vrijeme provedeno na zadatku

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