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Mental fatigue disturbs local processing more than global processing

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Abstract Focusing of attention is influenced by external features such as the presence of global or local target stimuli, but also by motivation and mood states. In the current study, we examined whether working on cognitively demanding tasks for 2 h, which induces mental fatigue, subsequently had a differential effect on global and local processing. The results showed that, compared to non-fatigued participants, fatigued participants particularly displayed compromised local processing. This indicates that mental fatigue may also manifest itself as effects on attentional focusing. The findings of this study are in line with recent ideas about the nature of fatigue-related cognitive deficits, implying disturbances in the control over attention and behaviour.

Keywords Mental fatigue · Global and local information processing · Controlled versus automatic processing

Mental fatigue disturbs local processing more than global processing

It is widely established that in visual perception, one can focus attention on either global or local features of the environment (Ivry & Robertson, 1998; Navon, 1977, 2003). Several researchers used the zoom lens metaphor to describe the nature of such attentional focusing (e.g., Eriksen & James, 1986). Similar to a zoom lens, attentional focus can be broad which enhances the processing of global features (e.g., a stimulus is identified as a picture of a house). In contrast, attentional focus can also be narrow, which facilitates the processing of details, i.e., local features (e.g., the bricks of the house). Extensive research showed that global processing is executed in a relatively quick and automatic way, whereas local processing more strongly relies on top-down or 'executive' processing and is generally slower than global processing (Ivry & Robertson, 1998; Miller & Navon, 2002; Navon, 1977). This faster processing of global information, often combined with lower levels of errors, is called the global advantage. The relative size of this advantage depends on many factors such as the type of stimulus and the specific task setting (cf. Ivry & Robertson, 1998; Navon, 2003).

Interestingly, recent studies have indicated that motivation and mood states can also influence the scope of attentional focus (Derryberry & Reed, 1998, 2001; Derryberry & Tucker, 1994). Derryberry and Tucker (1994) argued that "... motivational processes recruit attentional mechanisms to adaptively regulate perceptual and conceptual processes." (p. 168). They found that anxiety causes a shift towards more local processing and euphoria leads to a more global attentional focus. In the current study, we examine a specific mood state that, to our knowledge, has not been explicitly investigated with regard to global and local processing, namely *acute mental fatigue*. Acute mental fatigue can be defined as a psychophysiological state resulting from sustained or previous mental effort. This state of fatigue is characterized by increased resistance against further effort and is accompanied by changes in information processing and by other mood states such as irritation (Hockey, 1997; Holding, 1983). When fatigued, a person generally experiences increased difficulties in maintaining attention focused on the task at hand. One gets more easily distracted by irrelevant stimuli in the environment or by distracting 'trains-of-thought'. These cognitive effects of mental fatigue are often assumed to be manifestations of compromised 'top-down' or executive control over ongoing behaviour and cognition (Lorist, Klein, Nieuwenhuis, De Jong, Mulder, & Meijman, 2000; Sanders, 1998; Van der Linden, Frese, & Meijman, 2003). On the other hand, more automatic information processing seems to be relatively unaffected by fatigue (Schellekens,

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Sijtsma, Vegter, & Meijman, 2000). Consequently, fatigue-related cognitive effects seem to resemble the cognitive deficits found in other research populations in which top-down or executive processing is compromised (Holding, 1983), for example healthy elderly or schizophrenic patients.

In line with this idea, van der Linden et al. (2003a) found that participants who were made mentally fatigued, showed an increased number of perseveration errors on the Wisconsin Card sorting Test and prolonged planning time in the Tower of London. Several other studies already showed that healthy elderly, as well as schizophrenia patients display similar patterns of results on these classical neuropsychological tasks (e.g., Braver, Barch, Keys, Carter, Cohen, Kaye, Janowsky, Taylor, Yesavage, Mumenthaler, Jagust, & Reed, 2001; Cohen & Servan-Schreiber, 1992). Regarding the current study, it is important to note that at least two previous studies found healthy elderly as well as schizophrenic patients to show specific impairments in local processing. For example, Roux and Ceccaldi (2001) found that, compared to young adults, healthy elderly generally reacted slower to both local and global targets. However, they also displayed an increased global advantage. Similarly, Bellgrove et al. (2003) found that besides, a general slowing in reaction time, particularly local processing was disturbed in early-onset schizophrenia. In the study of Roux and Ceccaldi (2001) as well as in the study of Bellgove et al. the deficits in attentional focusing were ascribed to disturbances in the control over attention. Based on such previous findings one can predict that mental fatigue also affects local-global processing.

A second reason to study this type of processing under fatigue is that during problem solving, fatigued people show a propensity towards a less analytic information processing style (Hockey, 1997; Kruglanski & Webster, 1996; Webster, Richter, & Kruglanski, 1996). Thus, at a conceptual level, fatigued people more often rely on 'the general picture' and are less likely to focus attention on details or on information that requires more elaborate processing. This specific effect of fatigue on attentional focusing mainly has been studied with relatively complex problem solving tasks (Webster et al. 1996). Hence, it would be informative to test whether this tendency to process information more globally under fatigue can also be found in a visual perception task.

To examine whether mental fatigue indeed affects attentional focusing, we used a local–global task based on the Derryberry and Reed (1998) study. In this task, participants are instructed to respond quickly and accurately to stimuli that contain either global or local targets, but never at the same time. With this kind of stimuli and task instructions, participants have to shift flexibly between searching the global and local level for targets (Navon, 2003). As global perception occurs relatively automatically under such conditions and takes place before local processing, it can be expected that global processing will not be affected strongly by fatigue. However, local processing is more strongly dependent of intentional search and of top–down control over attention (Miller & Navon, 2002). Hence, we expect that particularly local processing will be disturbed under fatigue.

Above, we argued that mental fatigue is a state that involves a wide range of cognitive and motivational effects. One of these effects entails that fatigued people often are less willing to engage in effortful tasks (Gaillard, 2001). This is an intrinsic aspect of fatigue and several decades of research has shown that this motivational aspect cannot clearly be differentiated from the 'pure' cognitive effects of fatigue (Hockey, 1997; Sanders, 1998). Nevertheless, fatigued people are more willing to engage in the task when it is challenging instead of boring (Sanders, 1998). Therefore, in order to increase probability of task engagement and to prevent boredom, we decided to embed the local-global task in a game. The Derryberry and Reed variant of the local–global task was particularly suited for this because it was constructed in such a way that participants could win or loose points depending on the accuracy and speed of their responses.

Another issue in mental fatigue research is that fatigue is often operationalized as effects of time on the (*same*) task (Lorist et al. 2000; Sanders, 1998). However, with such a design it is not directly obvious whether any detrimental effect on information processing is truly task-specific in the sense that such an effect might disappear after switching to a different task. In contrast, prolonged exertion of mental effort might lead to a more general disturbance, which transfers to subsequent tasks (Smit, Eling, & Coenen, 2004; Van der Linden, Frese, & Sonnentag, 2003). Therefore, in the current study, we do not operationalize fatigue as time on the same task, but instead use a design in which we induce mental fatigue by asking participants to exert cognitive or intellectual effort on tasks that are different than the main experimental (local–global) task.

Method

Participants

Thirty-nine undergraduate students (30 females) participated and were tested individually in sessions that lasted approximately 3 h and for which they were paid 20 Euro (about 25 US Dollar). All participants were right-handed and had normal or corrected to normal vision. Age of the participants ranged from 20 years to 26 years. Participants were randomly assigned to a fatigue ($n = 19$) or non-fatigue condition ($n = 20$).

Procedure

Fatigue was induced by a 2-h manipulation in which participants were asked to work on two types of tasks that required mental effort. The first hour of the manipulation consisted of working on tests of verbal reasoning and numerical aptitude. In the second hour, participants worked on a computer based scheduling task (Taatgen, 1999), in which they had to assign work hours to fictional employees. This task requires much mental effort as intermediate results have to be remembered while the participant simultaneously performs difficult cognitive operations. Previous studies have shown that working on this task for a prolonged period induces mental fatigue (Van der Linden, et al. 2003; Van der Linden, et al. 2003).

Testing was done in a light and sound attenuated room. Researchers could observe the participants through one-way windows in the experiment rooms. A session started by filling out questionnaires on mood, fatigue, and motivation. Subsequently, the fatigue manipulation followed for 2 h. Participants in the fatigue group worked on the effortful tasks. Participants in the non-fatigue group were instructed to 'wait' the following 2 h in the lab. During this time, they could read some magazines. However, care was taken that they did not engage in cognitively (or physically) demanding activities. Directly after the manipulation period, participants (in both groups) again filled out questionnaires on mood, fatigue and motivation. Subsequently, they worked on the local–global task. This task was presented on a 15in. Phillips monitor, controlled by a Compact Pentium I computer. The local–global task we used in our study, was developed by Derryberry and Reed and was programmed in Micro Experimental Laboratory (MEL) software (Schneider, 1988).

Participants were instructed to maintain focus on the fixation point at the centre of the screen and to detect targets (H's or L's) and respond as quickly and accurately as they could. They were informed that during each trial, targets could be present either at the global or at the local level. In addition, they were told that they could consider the task as a game in which they could win or loose points, depending on how quickly and accurately they responded. Details on the different type of trials and on how they exactly could win or loose points were also provided (see Task description). It was emphasized that there were no consequences of the scores that the participants obtained but that we were just interested in how many points they were able to gain.

Subjective fatigue and mood measures

Fatigue

Subjective fatigue was assessed with the rating scale mental effort (RSME; (Zijlstra, 1993), which consists of seven 150-point response scales, evaluating several aspects of fatigue, namely (1) difficulties with attention, (2) resistance against further effort, (3) difficulties with visual perception, (4) suppressing physical fatigue, (5) boredom, (6) level of physical fatigue, and (7) level of mental fatigue. The response scales in the questionnaire had verbal anchors ranging from "not at all" to "extremely much". Although some studies used the RSME as a single scale, we analysed the different aspects of fatigue separately (see also, Van der Linden, et al. 2003b).

Mood

We assessed several mood states with subscales from the short version of the profile of mood states (POMS). Specifically, we measured feelings of depression, anger, and tension before and after the manipulation. The short version of the POMS has been translated into Dutch and validated (Wald & Mellenbergh, 1990).

Motivation

Task specific motivation was measured with three questions (e.g., "I want do well on the forthcoming task", "I am willing to comply with instructions of the forthcoming task", "I will try to do my best"). Answers were given on a five-point Likert scale (reliability = 0.81).

Local–global task

In the local–global task, participants had to respond to either a global or a local 'L' by pressing a left-positioned button (the 'Z' on the computer keyboard). When a global or local 'H' was presented, they had to press a right-positioned button (the '/'). There were eight different types of stimuli, four of these contained global targets (two global L's consisting of either local T's or local F's and two global H's consisting of either local T's or F's) and four contained local targets (A global F or Global T consisting of local Ls, and a Global F or T consisting of local Hs).

The task was given in ten blocks of trials. The first two blocks were practice blocks. The game in which we embedded the local–global task implied that we presented the stimuli alternately as only positive trials ($n = 52$) or only negative trials ($n = 48$). In blocks with positive trials, participants could win points if the reaction time (RT) was fast and correct, but no points were lost when the RT was (too) slow. In blocks with negative trials, participants lost points when the response was too slow, yet no points could be gained when the response was fast and correct. In both types of trials, points were lost when the response was incorrect. We assumed that by introducing the different blocks and letting participants win or loose points, the task would be perceived as more challenging than a standard reaction time task. In this way, we would increase participants' willingness to engage in the task.

The task was designed in such a way that the 'game-features' of the task did not interfere with our main measures of attentional focusing: firstly, whether a response was considered fast or slow was determined (by the computer) on the basis of a participant's median RT in the previous block. This procedure caused roughly half of the responses to be considered fast (accompanied with winning points or not loosing points) and half of the responses to be slow (losing points). In this way each individual participants roughly obtained the same score. Secondly, separate criteria for fast and slow responses were computed for local and global target trials. In this way, participants would not perceive either global or local targets as more difficult than the other.

The stimuli were presented in light grey on a black background and always consisted of a global letter about 2.1×2.1 cm in size (visual angle, $2.41 \times 2.41°$, at viewing distance of 50 cm), consisting of smaller, local letters, which were roughly 0.4×0.4 cm (visual angle, $0.45 \times 0.45°$). Stimuli were centred horizontally and vertically on the screen. The stimuli were arranged such that five local letters formed the horizontal and vertical components of the global letter. 250 ms after participants gave their response, the stimulus was replaced by a feedback sign (500 ms) which was a green '+' when the response was correct and fast, or a red "×" when a response was either correct but slow or was incorrect. Positive feedback was accompanied by a 250 ms tone of 1,000 Hz; negative feedback was accompanied by a 200 Hz tone. 250 ms after the feedback signal, the score was updated. Scores were visible on the screen throughout the task (4.5 cm below the centre of the screen in numbers of 0.8×0.8 cm). Inter-trial intervals lasted randomly 750 or 1,250 ms.

Statistical analyses

The main dependent variables in this study were RTs for correct responses only and the proportion of errors on local and global targets. Because participants may have 50% correct responses based on chance alone, we only included participants who at least had seventy percent correct responses (Derryberry & Reed, 1998). This criterion excluded one participant from further analyses. RTs and error rates were submitted to analyses of variance (ANOVAs) with stimulus type (local versus global) as within subject factor and Group (fatigue versus not) as between subject factor. To examine whether the 'game-features' of the task affected the primary local-global results, we confirmed RT and accuracy results with additional analyses in which we also included Block type (positive, negative) as within subject factor.

Fatigue aspects (RSME) before and after the manipulation were analysed with MANOVA's as well as with separate repeated measures analyses to test for differential increase in both groups. Motivation and Mood measures were analysed with ANOVAs with Time (before versus after the manipulation) as within-subject factor and Group (fatigue versus not) as between subject factor. Alpha of 0.05 was set for all analyses.

Results

Manipulation check

As a first step in testing the effects of our manipulation, we examined whether participants in the fatigue and non-fatigue condition differed before the manipulation on the fatigue aspects (RSME). We conducted a MANOVA with fatigue aspects as dependent variables and Group (fatigue versus not) as between-subject factor. This showed that there were no significant differences before the manipulation ($F(1, 28) = 0.39$, $P > 0.05$). Subsequently, we conducted separate repeated measures analyses on the fatigue aspects. These analyses showed that there were significant interaction effects of time (before versus after the manipulation) and Group (fatigue versus not) for difficulties with attention ($F(1, 34) = 4.68$, $P < 0.05$) and resistance against further effort ($F(1, 34) = 4.98$, $P < 0.05$). Post-hoc test showed that participants in the fatigue condition significantly increased on these two measures ($T_{\text{paired, attention}} = 2.09$, $P = 0.05$, $T_{\text{paired, effort}} = 2.39$, $P < 0.05$), whereas the participants in the control group did not ($T_{\text{paired, attention}} = 0.46$, $P > 0.05$, $T_{\text{paired, effort}} = 0.22$, $P > 0.05$) The interaction of Group and Time for mental fatigue showed a clear trend, indicating increased scores for fatigued participants, but this trend did not reach significance ($F(1, 34) = 3.62$, $P = 0.06$). There were no significant interactions for visual problems ($F(1, 34) = 0.30$, $P > 0.05$), boredom ($F(1, 34) = 1.05$, $P > 0.05$), resistance against physical fatigue ($F(1, 34) = 2.97$, $P > 0.05$), and physical fatigue ($F(1, 34) = 3.13$, $P > 0.05$). To fully test post-manipulation differences between the groups, we also conducted a MANOVA with the different fatigue aspects measured *after* the manipulation as dependent variables, and Group as between-subject factor. There was a significant multivariate effect ($F(1, 29) = 2.05$, $P < 0.05$), showing that after the manipulation, the groups significantly differed on attentional problems ($F(1, 35) = 7.39$, $P = 0.01$), resistance against further effort ($F(1, 35) = 10.38$, $P < 0.01$), and mental fatigue ($F(1, 35) = 4.47$, $P < 0.05$), but not on visual problems ($F(1, 35) = 0.08$, $P > 0.05$), boredom ($F(1, 35) = 0.35$, $P > 0.05$), and the questions related to physical fatigue (Respectively, $F(1, 35) = 1.97$, $P > 0.05$ and $F(1, 35) = 0.41$, $P > 0.05$). Thus, in general our manipulation proved successful as it strongly affected behavioural aspects associated with mental fatigue (e.g., attention, effort), but did not strongly affected other fatigue aspects.

With regard to mood and motivation, we found a significant interaction effect of Time and Group on anger ($F(1, 35) = 5.4$, $P < 0.05$). Fatigued participants reported more feelings of anger after the manipulation than before ($t_{\text{paired}} = 3.0$, $P < 0.01$). For the non-fatigued participants, this was not the case ($t_{\text{paired}} = 0.3$, $P > 0.5$, see Table 1 for means). There were no significant main or interaction effects for feelings of tension,

Table 1 Means (and SD) of fatigue and mood measures before and after the fatigue manipulation.

	Pre-manipulation		Post-manipulation	
	Non-fatigue	Fatigue	Non-fatigue	Fatigue
	Fatigue aspects			
Attentional problems	34.58 (*22.8*)	34.41 (*23.7*)	32.36 (*24.4*)	58.83 (*34.2*)
Effort resistance	27.38 (*18.5*)	30.47 (*24.1*)	27.47 (*25.0*)	55.44 (*27.8*)
Visual difficulties	24.26 (*25.4*)	17.18 (*15.6*)	28.79 (*27.5*)	29.61 (*29.9*)
Resistance physical fatigue	34.47 (*30.3*)	28.0 (*24.2*)	38.05 (*30.6*)	44.11 (*31.7*)
Boredom	37.84 (*33.4*)	31.11 (*26.8*)	31.78 (*24.2*)	45.66 (*35.0*)
Level of physical fatigue	49.0 (*29.6*)	44.35 (*27.8*)	46.63 (*27.9*)	53.11 (*33.2*)
Level of mental fatigue	31.16 (*22.0*)	38.05 (*31.7*)	35.05 (*24.0*)	55.50 (*34.2*)
	Other Mood States			
Depression	10.88 (*2.7*)	11.85 (*3.8*)	10.43 (*2.6*)	12.99 (*6.2*)
Tension	7.78 (*3.7*)	9.0 (*2.6*)	7.26 (*.9*)	8.58 (*3.7*)
Anger	9.59 (*2.5*)	9.55 (*3.5*)	8.34 (*1.7*)	13.01 (*6.7*)

$n_{\text{fatigue}} = 19$, $n_{\text{non-fatigue}} = 19$

depression, or task specific motivation (lowest $P > 0.1$). There was no significant interaction effect of Time and Group for task motivation ($F(1, 34) = 2.56$, $P > 0.05$). Thus, fatigued and non-fatigued participants did not differ in their self-reported willingness to do well on the forthcoming tasks.

Local-global task

Analyses of RT in the local-global task revealed a significant main effect of stimulus type (global versus local, $F(1, 36) = 46.1$, $P < 0.001$). In accordance with previous studies, we found RTs on global targets to be faster than RTs on local targets (respectively, M = 407.1, SD = 55.1, M = 428.4, SD = 55.9). The advantage of global processing over local processing was significant in both the fatigue ($t_{\text{paired}} = 6.61$, $P < 0.001$) and the non-fatigue group ($t_{\text{paired}} = 3.33$, $P = 0.01$). In accordance with our main expectation, the interaction between Stimulus type and Group was also significant ($F(1, 36) = 6.1$, $P < 0.05$), showing that the negative effect of fatigue was stronger for local information processing than for global processing (see Table 2 for Means). Post-hoc tests showed that the fatigue and non-fatigue groups significantly differed in RTs on local targets ($F(1, 36) = 9.9$, $P < 0.01$) whereas the RT difference on global targets also showed a trend but did not reach significance level ($F(1, 36) = 3.73$, $P = 0.06$).

Table 2 Mean (and SD) of RTs and errors (percentages) for the fatigue and non-fatigue group.

	Non-fatigue group	Fatigue group
Global targets		
RT	390 (*46.1*)	424 (*61.6*)
Errors	0.11% (*5*)	0.12% (*6*)
Local targets		
RT	403 (*42.4*)	455 (*56.7*)
Errors	0.15% (*9*)	0.20% (*7*)

$N_{\text{fatigue}} = 19$, $N_{\text{non-fatigue}} = 19$

Analyses of accuracy showed that for participants in both groups the percentages of errors on global and local targets were significantly negatively correlated with RT (resp., $r = -0.36$, $P < 0.05$, and $r = -0.59$, $P < 0.001$). However, errors-RT correlations did not differ significantly between the two groups (Fischer r-to-Z test). We therefore analysed error rates with covariance analyses in which we controlled for RT (with Stimulus type as within-subject factor and Group as between-subject factor). In this analysis, we found a significant main effect of Stimulus type on error rate ($F(1, 35) = 16.2$, $P < 0.0005$, $M_{\text{global}} = 11\%$, SD = 6, $M_{\text{local}} = 18\%$, SD = 8). In general, participants made more errors on local than on global targets. The interaction effect of Stimulus type and Group did not reach significance, but there was a trend ($F(1, 35) = 3.69$, $P = 0.06$), indicating that, compared to the non-fatigue group, fatigued participants made more errors on local targets (for fatigued and non-fatigued participants respectively, $M = 20\%$ and $M = 15\%$, $P = 0.08$) but not on global targets (for fatigued and non-fatigued participants respectively, $M = 12\%$ and $M = 11\%$, $P > 0.8$).

There was no significant main effect of Block type (positive vs. negative trials) on RT (F(1, 35) = 0.69, $P > 0.05$), or errors ($F(1.35) = 2.8$, $P > 0.05$). Nor were there any significant interaction effects of Block type with Group or Stimulus Type on RT or errors (Smallest $P > 0.6$). Thus, this showed that the game-format of the task did not interfere with our main results regarding global and local processing.

Above described manipulation checks showed that the manipulation also led to significant differences between the groups on anger. This measure may reflect the feelings of irritation that are generally observed when demands are placed on fatigued people (Holding, 1983). Nevertheless, to gain insight into the effects of anger we conducted some additional analyses in which we, again, tested RT and error rates but this time controlled for anger. We conducted ANCOVAs on RT and errors with group as dependent variable and anger as covariate.

These analyses showed that anger did not influence our results. The Stimulus type (local versus global) and group interaction as well as the main effect of stimulus Type remained significant for RT (respectively, $F(1, 35) = 4.90$, $P < 0.05$ and $F(1, 35) = 7.73$, $P < 0.01$). The significant interaction effect on error rate and main effect of Stimulus type did not change substantially (respectively, $F(1, 35) = 2.74$, $P = 0.1$, and $F(1, 35) = 16.31$, $P < 0.0005$).

Discussion

Mental fatigue elicits a diversity of behavioural and cognitive effects. In the current study, we examined whether fatigue also affects performance on a visual perception task with local and global targets. Based on previous studies, indicating that fatigue negatively affects attentional control (cf. Lorist et al. 2000; Sanders, 1998; van der Linden, et al. 2003) and leads to global, less analytic analyses of conceptual information (Webster et al. 1996), we expected fatigue to differentially affect local and global processing.

The results of our study confirmed our expectations because, compared to global processing, local processing was more strongly affected under fatigue. Although fatigued participants displayed a general slowing of reaction times compared to non-fatigued participants, the negative effect on local processing was roughly thirty percent larger than on global processing. Moreover, there was a trend in the data indicating that fatigued participants made more errors than non-fatigued participants on local targets, but not on global targets. In accordance with previous studies, we also found a general advantage of global processing over local processing (Derryberry & Reed, 1998; Ivry& Robertson, 1998; Navon, 1991); compared to local targets, responses to global targets were faster and less error-prone. The overall results showed that, compared to the non-fatigued control group, the global advantage was more pronounced in fatigued participants.

Besides these main findings, the current study provides some additional information that may be of interest for fatigue research, namely that the effects of mental fatigue may transfer to other tasks. The manipulation tasks were different from the main experimental tasks, and taxed more general cognitive processes such as attentional regulation, working memory, and reasoning. Nevertheless, working on these tasks for 2 h led to significant effects on performance on a visual perception task involving local and global targets.

In general, current results contribute to fatigue literature because they provide a first indication that the negative effects of fatigue on behaviour also include disturbances in local–global processing. Moreover, our findings fit with current ideas about the nature of fatigue-related cognitive deficits. Such deficits imply compromised top-down or executive control over attention whereas automatic tasks are less affected (Hockey, 1997; Van der Linden, et al. 2003). In local–global research it is assumed that global processing occurs relatively automatically and is a '...is a necessary step in perception'' (Navon, 1977, p. 381). Perceptual analysis of local features, however, often requires top-down initiated shifts of attention from global to local perception—especially in stimuli in which local features do not automatically attract attention (Miller & Navon, 2002). As initiating flexible, top–down control over ongoing processing seems to be one of the most prominent difficulties associated with fatigue, a pronounced effect on local processing is in line with expectations.

In addition, the specific disturbances in local processing we found, are in accordance with insights on the neuropsychological underpinnings of fatigue: Derryberry and Tucker (1994) argued that the efficiency of local processing strongly depends on the level of energetic or tonic activation, which is mediated by dopaminergic activity in, mainly the left hemisphere of, the brain. Interestingly, mental fatigue has also been linked to lowering of dopaminergic mediated activation (Ishiwari, Weber, Mingote, Correa, & Salamone, 2004; Lorist & Tops, 2003) as well as with reduced activation of the left-hemisphere (Dimond & Beaumont, 1972). Thus, future studies might want to test more directly the potential relationship between (dopaminergic) energetic activation under fatigue and attentional focus. Using global–local paradigms may be useful in such type of research.

It is important to note that we consider it unlikely that the pronounced effects on local processing are simply the result of a visual acuity deficit; compared to the control group, fatigued participants did not report significantly more difficulties with visual perception. However, they did report significantly more attentional problems. In addition, fatigued participants also tended to react slower to the larger global letters. Thus, ascribing our results to peripheral (visual) effects seems implausible.

It is also unlikely that our findings were caused by deliberate non-compliance or intentional disengagement from the task. Firstly, the subjective measures after the manipulation suggest that participants in the control and fatigue group did not differ from their willingness to do their best on the task. Secondly, observations during the task confirmed this finding: it appeared that participants in both groups were strongly engaged in the task/game. Thirdly, such subjective measures and observations in our study are in accordance with general observations in many fatigue studies, which indicate that in laboratory studies, participants still try to do their best despite their fatigue because they ''... are aware that their performance is continually monitored'' (Sanders, 1998, p. 407).

Obviously, the current study is a first attempt to evaluate the effects of mental fatigue on local-global processing. As such, some limitations need to be considered when interpreting the results. Firstly, in this study we used the more traditional compound stimuli in which a large letter consists of a specific configuration of smaller letters of limited visual angle (< 0.50°). Previous studies, however, have shown that stimuli characteristics such as stimuli density and relative size of global and local stimuli can affect the nature and strength of the local-global processing difference (e.g., Enns, & Kingstone, 2002; Kimchi, Hadad, Berhmann, & Palmer, 2005). For example, Kimchi (1998) showed that with a specific set of hierarchical stimuli, attentional demands were stronger for global than for local targets. Consequently, it is not yet clear how fatigue might affect other types of compound stimuli.

An additional limitation is that mental fatigue is a complex multi-faceted state that involves changes in motivation, mood, and cognition. Such changes may interact with local and global processing trough several mechanisms. The attentional effect of fatigue, as we described above, is a likely candidate for such mechanism. However, other possibilities still exist. More specific, research on local and global processing has come up with a range of different explanations for the distinction between local and global processing (e.g., grouping requirement [Enns & Kingstone, 1995], response activation differences [Miller & Navon, 2002], attentional shifting or interference [Lamb, Robertson, & Knight, 1989; Yamaguchi, Yamagata, & Kobayashi, 2000], spatial analysis [Ivry & Robertson, 1998]) and it is currently not clear how the effects of fatigue fit within those different theoretical points of view. It will probably require many future studies to address these issues and to disentangle the different mechanisms involved. Yet, current results provide an important first step in such research by showing that there are differential effects of fatigue on local and global processing in the first place.

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