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The same-object benefit is influenced by time-on-task

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Previous studies indicated that mental fatigue particularly compromises the control of attention. To our knowledge, the present study is the first to test this notion in a divided attention paradigm that involves comparing targets placed on one versus two background objects. In general, comparing targets on two objects is less efficient than on one object because it puts more demands on divided attention. This is the well-known same-object benefit. Based on the notion of lowered control of attention under fatigue, we hypothesised that this same-object benefit becomes more pronounced in fatigued participants. We tested this with an experiment in which participants performed a visual attention task (same/different task) for 2.5 hours without rest. As a function of time-on-task, participants showed a decline in performance that was significantly more pronounced in the two object condition versus the one-object condition. These findings suggest an increased same-object benefit with time-on-task, which is likely due to compromised divided attention under fatigue.

Keywords: Mental fatigue; Same-object benefit; Time-on-task.

Mental fatigue due to prolonged engagement in cognitively demanding activities is a common phenomenon. For example, it may occur after a hard day's work filled with mentally demanding tasks at the office. Yet, despite its mundane nature, fatigue is a complex state that involves changes in mood, motivation, and information processing (Van der Linden, 2011).The effects of fatigue on information processing seem rather difficult to "grasp" scientifically. That is, it is widely acknowledged that fatigue is accompanied with attentional difficulties (e.g., Lorist et al., 2000; Tops & Boksem, 2010, Van der Linden, Frese, & Meijman, 2003), but the exact nature of such difficulties is still unclear. Several studies have indicated that fatigue coincides with impairments in visual attention and changes in the ability to focus attention (Boksem, Meijman, & Lorist, 2005; Van der Linden, 2011). It has also been suggested that the common mechanism underlying these effects is a diminished top-down control over attention (Lorist, 2008; Lorist, Boksem, & Ridderinkhof, 2005; Lorist et al., 2000; Van der Linden et al., 2003). Here, top-down control refers to the set of higher order cognitive processes that oversee and regulate more basic perceptual and motor processes. Top-down control is often effortful and can be contrasted to more automatic processing that requires less effort (Miller & Cohen, 2001). The decreased control over basic functions has several behavioural consequences such as compromised task performance.

Based on the notion of diminished top-down control under fatigue, it can be expected that

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certain types of tasks are especially sensitive to the detrimental effects of fatigue. For example, tasks that require flexible shifts in attentional focus or tasks requiring sustained attention at the presence of task-irrelevant distractors. Several studies have confirmed that fatigue is accompanied with decreased performance on such types of tasks. For example, Van der Linden and Eling's (2006) study suggested that the processing of global object properties, which is assumed to be a more automatic process, stays relatively intact under fatigue, whereas the processing of local stimuli that is assumed to require more controlled processing is compromised. Also, Boksem et al. (2005) showed that with increasing fatigue, induced by time-on-task, participants experience more difficulties with inhibiting the detrimental effects of distractors.

One specific type of tasks that, to our knowledge, has not yet been systematically tested under fatigue is a visual divided attention task. Yet, testing such type of task may be relevant for refining knowledge about the specific cognitive deficits that occur under fatigue. Based on the presumed decreased top-down control under fatigue we hypothesised that such a diminished control might not only negatively affect the focusing of attention (Van der Linden & Eling, 2006) or the inhibition of distractors (Boksem et al., 2005), but may also weaken the ability to *divide* attention between targets.

From several clinical studies there are indications that more chronic forms of mental fatigue indeed compromise the ability to divide attention. Most of these studies have been conducted with Chronic Fatigue Syndrome patients (Ross, Fantie, Strauss, & Grafman, 2010), multiple sclerosis patients (Oken et al., 2006), and head injury patients (Stuss et al., 1989). So, all these previous studies involved chronic fatigue in patient groups and it is not clear whether such type of fatigue is similar to the more common and task-induced type of fatigue in healthy subjects.

In the present study we tested divided attention under fatigue in the context of same-object benefit. More specifically, there are now numerous studies that have shown that participants are generally faster and more accurate in comparing two targets that belong to the same object and are slower and/or less accurate when the targets belong to different objects (Lamy & Egeth, 2002; Lavie & Driver, 1996; Watson & Kramer, 1999). This effect has been labelled as "same-object benefit" and is generally ascribed to fewer demands on divided attention when targets belong to the same object.

Regarding the underlying neural circuit, neuroimaging studies revealed that dividing attention between two target stimuli always recruits activation in parietal and prefrontal regions that are considered to reflect the sources of attentional control (Hopfinger, Buonocore, & Mangun, 2000; Liu, Slotnick, Serences, & Yantis, 2003; Nobre et al., 1997). In contrast, it has been suggested that the possible neural basis of the same object benefit might come from the stronger additional activation of early cortical regions (V1–V4) in same-object comparisons relative to the different-object comparisons (Shomstein & Behrmann, 2006). More specifically, the comparison of two targets on the same object might rely more on automatic processes, whereas comparing targets on different objects put more demands on the controlled ability to divide attention. In addition, the time-on-task dependency of same-object benefit seems to be also supported by the observation that previous studies on same-object benefit frequently used relatively high number of experimental trials (approximately 300–1000 trials). This might suggest that the effect of long-duration performance can differentially affect same- and between-object comparisons.

In sum, in line with the general notion of diminished top-down in fatigue, we expect that the comparison of targets on two objects will be particularly impaired under fatigue, whereas this will be less so for targets on the same object. We investigated this prediction in an experiment in which fatigue was induced by time-on-task (ToT). For object cues, one-object and two-object conditions were created possessing symmetrical or random contours.

METHODS

Participants

Seventeen under- and postgraduate students (10 females, aged between 20 and 29 years with a mean of 22 years, $SD = 2.65$) from the University of Pécs participated in this study. All participants were right handed and had normal or corrected to normal visual acuity by self-report. They were naïve with regard to the purpose of the experiment and reported normal, medication-free health condition. All participants were paid and provided a written consent.

Apparatus and stimuli

A standard IBM-compatible computer with a 21-inch monitor using a 1280 × 1024 pixel resolution with 90 Hz refresh rate presented the stimuli. The participants viewed the stimuli at 90 cm, through a circular aperture. A keyboard was used to record their responses. Two main stimulus types were presented: object cues and target stimuli. The object cues appeared first and then two target stimuli were shown superimposed on them (see the Procedure section for more details).

To create *object cues*, we adopted the method used by van der Helm and Treder (2009). Object cues were black hard-edge shapes (1.5 cd/m^2) on a white background (88 cd/m^2), created by filling in a closed contour consisting of two vertical curves connected by horizontal straight lines. The curves were specified using the cubic Bézier function: $B(t) = (1-t)3\ P0 + 3\ t\ (1-t)2\ P1 + 3\ t2\ (1-t)\ P2 + t3\ P3$, $t \in [0,1]$ with control points of P1, P2, P3, and P4 (for further description, please see van der Helm & Treder, 2009). Object-related properties (e.g., visual regularities) have been found to be well detectable on stimuli created by this function. Each shape subtended 24.68° vertically and about 14.62° horizontally. We used two-object and one-object conditions. For the two-object condition, two shapes were displayed with a separation of 1.78°. For the one-object condition, first, two shapes were created and then these were connected at their closest curve points to form one object. In addition to the number of objects, object cues were also different in the visual regularity exhibited by their curves. We introduced this variation in objects because previous studies had indicated that the shape of the object may have an effect on the strength of the same-object benefit (Davis, 2004). More specifically, when different objects were symmetrical, the same-object benefit was found to be stronger. Although, the influence of symmetrical versus asymmetrical objects on the same-object benefit was not the focus of the present study, we used both symmetrical and asymmetrical objects to be able to control for any influence of object type on the fatigue effects. For the symmetrical objects, the corresponding curves were mirrored vertically. In the asymmetrical objects, the corresponding curves did not exhibit any visual regularity. Overall there were four types of stimuli, namely, one-object symmetrical, one-object asymmetrical, two-object symmetrical, and two-object asymmetrical. During the experiment, stimuli with one or two objects and with or without symmetry were presented randomly. Figure 1 shows example stimuli for each object.

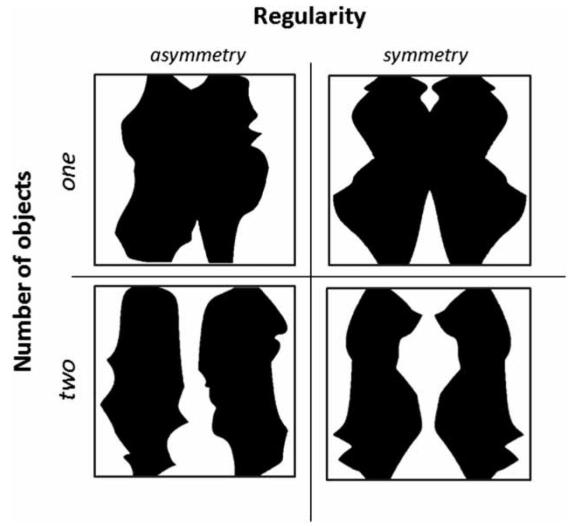

Figure 1. Examples of object stimuli from each stimulus condition. The conditions were one-object asymmetrical, one-object symmetrical, two-object asymmetrical, and two-object symmetrical.

Target stimuli were grey, simple geometric shapes, namely circle, square, and equilateral triangle with 82cd/m^2 luminance. Each target stimulus was created in a large (4.3° × 4.3°, height × width) and in a small size (2.52° × 2.52°). The two properties of the targets—shape and size—were varied to create three target stimulus conditions. (1) In the same-target stimulus condition, the targets were identical both in size and shape. (2) For the different-target stimulus condition, the targets were different in both shape and size (e.g., the right target was a large triangle, and the left target was a small circle). (3) Finally, a partially different target condition was created with targets different in one property only (e.g., the left target was a large triangle, and the right target was a large circle). The three target stimulus conditions were presented randomly but equally often. The participants were instructed to compare the shape and size of the targets, and they were asked to indicate whether the targets are the same or different in accordance with the three target stimulus conditions. The participants responded by pressing one of the three keys on a standard keyboard with their dominant hand (each key corresponded to one of the target conditions). The correspondence of the keys and target conditions was counterbalanced across participants. The importance of both speed and accuracy was emphasised.

Procedure

The experimental sessions started between 9:30 a.m. and 13:30 p.m. Participants were asked to abstain from alcohol and caffeine-containing substances at least 8 hours before the experiment. In addition, they were asked to have at least 7 hours of normal sleep during the night prior to the experiment. Each participant met these criteria by self-report. Participants were not informed about the exact duration of the experiment, and they were also asked to hand over their watches after their arrival at the laboratory. Both verbal and written instructions were used to inform the participants about the task.

In order to get an indication of the pretask subjective fatigue level, participants were asked to indicate their actual fatigue level on a Visual Analogue Scale (VAS; 100 mm long line, "No fatigue at all" was printed on the left side and "Very severe fatigue" on the right side). To measure the posttask subjective fatigue, this question was repeated right after the task ended. In addition, task-related motivation was also monitored before the experiment. On a 5-point Likert scale, participants had to indicate their agreement with the statement of "I will try to do my best on the forthcoming trials" (1 = "yes, that is true", 5 = "no, that is not true"). After the subjective measurements, the participants were given at least 60 practice trials. The practice session was followed by the task, which lasted 2.5 hours without a break. Reaction times and the participants' responses were recorded.

On each trial, before the stimuli appeared, a fixation cross was presented (700 ms) centred on the screen. Then, the object display followed and remained on the screen for 500–700 ms. A previous study indicated that this range of SOA is optimal to induce same-object benefit (Feldman, 2007). The object was followed by two target stimuli superimposed on the object cues. The position of the targets randomly varied between three positions along imaginary vertical lines (one line for the left target, and one for the right target). After 200 ms, a mask (a number of lines with random orientation) was briefly presented (10 ms) to obliterate afterimages. After response or when 2500 ms elapsed, participants were always given a feedback about the correctness of their responses. The word of "correct", "wrong", or "no response" (in the case of no keypress) was displayed for 500 ms on the centre of the screen. The appearance of the visual feedback was always accompanied by an auditory signal (a beep) with a high pitch tone for a correct response and with a lower pitch tone for an incorrect or a late response. Intertrial interval was varied randomly between 100 and 800 ms. Figure 2 schematises a typical sequence of displays in a trial.

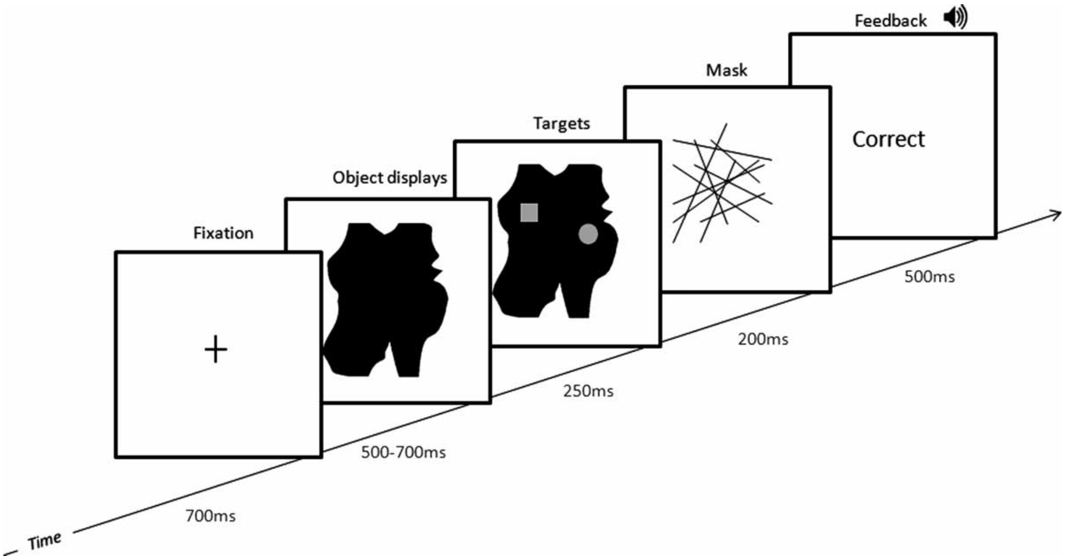

Figure 2. A typical sequence of displays in a trial. On each trial, before the stimulus, a fixation cross was presented centred on the screen. Then, the object cue followed and remained on the screen with an SOA randomly varied between 500 and 700 ms. It was followed by two target stimuli superimposed on the object cues. Finally, after response, participants were given a feedback about the correctness of their responses.

Data analysis

In order to examine the effect of time-on-task, the data were divided into four time intervals of 2250 s each (37.5 min). Such intervals contain many trials; therefore, we expected the results to be quite reliable.

Reaction times for correct responses (RT) and accuracy data were analysed. RT and accuracy data were subjected to repeated measures of ANOVA. The main factors of interest were time-on-task (fatigue) and number of objects (divided attention). In addition, we also took object regularity (symmetrical vs. asymmetrical) and target conditions (same, different, partially different) into account in order to test for any interactions with fatigue. For the follow-up analysis of the significant main effects and interactions, contrast analyses were performed with Bonferroni adjustment. A corrected *p*-value of $<.05$ was considered statistically significant. Participants' indications of their subjective fatigue levels before and after the task were also analysed.

RESULTS

Fatigue manipulation and subjective states

First, we examined whether the fatigue manipulation affected the participants' subjective states. Participants reported lower fatigue at the start of the task than after the task ($M_{\text{before}} = 31.41$ mm, $M_{\text{after}} = 62.44$ mm), $F(1, 16) = 43.81, p < .001$. So, in terms of subjective feelings, the time-on-task manipulation successfully induced mental fatigue. Task-specific motivation before the task was high as indicated by the high absolute score on the pretask motivation scale ($M = 4.82$, $SD = 0.39$): Only three of the participants gave less than the maximum score (i.e., a 4) on the 5-point scale.

Analysis of task performance

Participants performed 2543 trials on average (first interval: 632, second interval: 639, third interval: 638, fourth interval: 637) during the experimental session (2.5 hrs). RT on correct responses, and accuracy data were subjected to repeated measures of ANOVAs. More specifically, we conducted an ANOVA including all the experimental factors, namely time-on-task interval (four equal intervals), number of objects (one-object, two-object), object regularity (symmetrical, asymmetrical), and target condition (same, different, partially different). In this analysis, time-on-task and number of objects were the main variables of interest in order to test our main hypotheses. Object regularity and target condition were included in order to test the potential effects of these stimulus characteristics on the main outcomes.

For accuracy data, we found that the main effect of time-on-task was marginally significant for accuracy: RT, $F(3, 14) = 1.67$, *ns*; accuracy, $F(3, 14) = 3.95$, $p = .06$, $\eta_p^2 = .39$. However, a significant interaction between time-on-task and number of objects was found, $F(3, 14) = 6.2$, $p = .007$, $\eta_p^2 = .57$. Further analyses revealed that the main source of this interaction was the difference in the temporal pattern of accuracy of the one- and two-object condition (see Figure 3). Specifically, additional ANOVAs showed that within the one-object condition, time-on-task did not have a significant effect, $F(3, 14) < 1$, suggesting that accuracy of performance on one-object trials were not sensitive to the effects of fatigue. For the two-object condition, however, we did find a significant time-on-task effect, $F(3, 14) = 4.69$, $p = .01$, $\eta_p^2 = .5$. The post hoc analysis did not reveal significant change from the first to the second interval, but it yielded a significant decline from the second to fourth interval: second vs. fourth interval, $t(16) = 2.92$, $p = .04$, $d = 0.75$; third vs. fourth interval, $t(16) = 2.61$, $p = .07$, $d = 0.74$, Bonferroni corrected. These findings confirm our expectation that particularly the two-object trials are more vulnerable to the detrimental effect of time-on-task (i.e., fatigue).

The pattern of results for RT showed the same tendencies as for accuracy (see Table 1), the main effect of time-on-task, $F(3, 14) = 1.67$, *ns*, and the interactions with the number of objects, however, did not reach significance. Nevertheless, the fact that accuracy significantly decreased and RT tended to increase indicates that the effects of time-on-task were not due to speed–accuracy tradeoffs adopted by the participants, but instead reflect a true decline in performance.

In addition to these effects that were the focus of our study, the overall analysis that we have reported here also showed that object regularity had no significant effect: RT, $F < 1$; accuracy, $F(1, 16) = 1.09$, *ns*. Regarding the target conditions, participants generally responded slower and less accurately when targets were partially different: RT, $F(1, 16) = 57.58$, $p < .001$, $\eta_p^2 = .88$; accuracy,

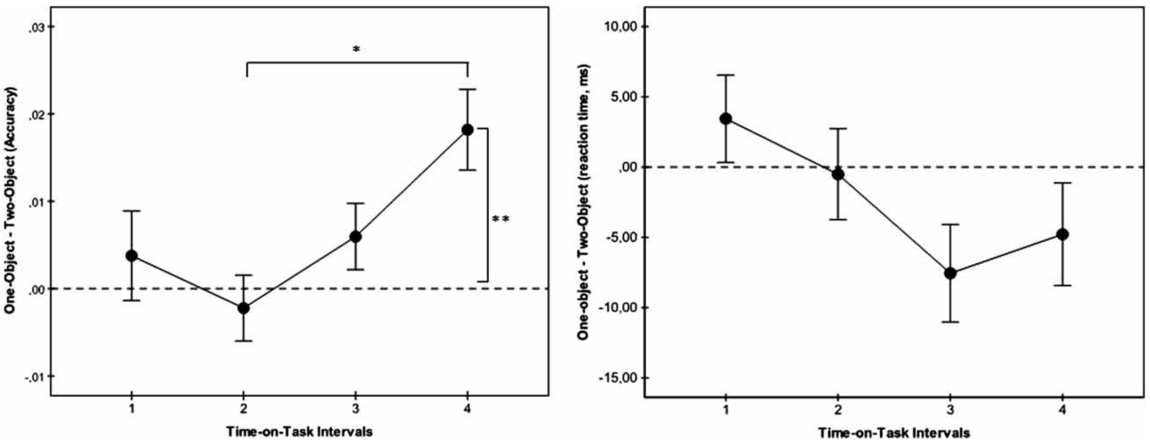

Figure 3. Same-object benefit calculated by as difference between the one-object and two-object conditions for each time-on-task interval. (A) Difference in reaction times (RT) of correct responses. (B) Difference in accuracy rates. For RT the negative values indicate same-object benefit; for accuracy it is reversed, that is, the more positive values indicate an increased same-object benefit. Error bars represent the standard errors of mean.

$F(1, 16) = 13.85$, $p < .001$, $\eta_p^2 = .65$. We also found a significant main effect of the number of objects for accuracy showing that overall performance was worse in the two-object condition as compared to the one-object condition, $F(1, 16) = 7.4$, $p = .01$, $\eta_p^2 = .31$. This main effect reflects the typical outcome of the well-known same-object benefit. In addition, the Target condition × Number of objects interaction was found to be significant both for RT and accuracy: RT, $F(2, 15) = 8.31$, $p = .004$, $\eta_p^2 = .52$; accuracy: $F(2, 15) = 5.99$, $p = .01$, $\eta_p^2 = .44$. Separate ANOVAs for each target condition revealed that the overall advantage of the one-object over the two-object condition was particularly strong in the trials with different targets: RT, $F(2, 15) = 8.31$, $p = .004$, $\eta_p^2 = .52$; accuracy, $F(2, 15) = 5.99$, $p = .01$, $\eta_p^2 = .44$. This finding is in line with previous observations that perceptual characteristics of targets and objects affect the magnitude of same-object benefit yet often do not fundamentally change the nature of the effect (Davis, 2004). Finally, the Time-on-task × Target condition interaction was found to be significant: RT, $F(6, 11) = 3.25$, $p = .04$, $\eta_p^2 = .64$; accuracy, $F(6, 11) = 3.66$, $p = .03$, $\eta_p^2 = .66$, showing that time-on-task had a particularly detrimental effect on performance in the different target condition. Yet regarding target condition, there was no significant three-way interaction of target condition with time-on-task and number of objects. So, based on the earlier analyses, we could conclude that neither object regularity nor target condition influenced our main effect of interest (Time-on-task × Object condition) in this study.

Relationship between performance and subjective fatigue rating

It is widely acknowledged that subjective fatigue is a complex mental state that rarely shows direct correlations with the objective performance measures (see, e.g., Hockey, 1997). Nevertheless in

TABLE 1

Means (and standard deviations) of performance measures in the object conditions in each time-on-task interval

	Number of objects			
	1-object		*2-object*	
Time-on-task intervals	*RT (ms)*	*Accuracy*	*RT (ms)*	*Accuracy*
1	760.7 (77.7)	0.905 (0.07)	757.8 (81.8)	0.901 (0.07)
2	737.2 (70.5)	0.913 (0.08)	737.7 (70.1)	0.915 (0.04)
3	741.9 (68.8)	0.909 (0.07)	749.5 (68.1)	0.903 (0.07)
4	746.5 (59.8)	0.903 (0.09)	751.4 (59.5)	0.885 (0.09)

$N = 17$.

order to get a complete picture of the study effects, we tested the direct relationships between task performance and the subjective fatigue ratings.

A first step herein was to calculate the difference between subjective fatigue at the beginning of the task and at the end of the task (henceforth subjective fatigue change). This measure was positive for all participants indicating their increase in fatigue over time. First, we performed a linear regression between subjective fatigue change for each time-on-task interval and the same-object benefit index (*difference* between the one-object and two-object conditions; see, e.g., Davis & Holmes, 2005b; Watson & Kramer, 1999). This analysis yielded marginally significant result between subjective fatigue change and same-object benefit for accuracy in the last interval, suggesting that those participants who reported a higher increase in subjective fatigue also had a larger deterioration in performance on the two-object trials relative to the one-object trials in the last time-on-task interval, $F(1, 15) = 3.16$, $p = .09$, $R^2 = .17$, $b = 0.41$. In addition, when this regression analysis was performed separately for each target condition then the relationship between same-object benefit and subjective fatigue change was found to be significant for the different target condition, $F(1, 15) = 5.64$, $p = .03$, $R^2 = .27$, $b = 0.52$.

In addition, we reran the original analyses with all experimental factors as reported earlier, but this time also entered the increase in subjective fatigue change as a covariate. The reason for this is that if the experimental effects become nonsignificant in this analysis, then this would indicate that subjective fatigue indeed played a role in the decline of performance. As expected, in the analysis the main effects and interactions involving time-on-tasks that were significant in the original analysis, were no longer significant in the present analysis (main effect of time-on-task: RT, $F(3, 13) < 1$, accuracy, $F(3, 13) < 1$; interaction Time-on-task × Number of objects: RT, $F(3, 13) < 1$, accuracy, $F(3, 13) = 1.29$, *ns*).

DISCUSSION

Compromised top-down control over attention has been mentioned as one of the major cognitive effects occurring under mental fatigue (Lorist et al., 2000; Van der Linden et al., 2003). Because control mechanisms have an essential role in maximising the allocation of attention to the task at hand, fatigue-related decrements in control might ultimately lead to decreased performance. In the current study, we examined divided attention under fatigue. The ability to divide attention is often considered one of the major aspects of attentional control. However, to our knowledge the relationship between fatigue and this specific aspect of control has before now not been explicitly tested.

In the present study we examined divided attention in the context of the well-known same-object benefit paradigm (e.g., Davis, 2005b; Feldman, 2007). Regarding this, the performance measures confirmed that, compared to targets on the same object, fatigue indeed had a stronger negative impact on identifying targets on two objects. Overall, the present results were in line with the hypothesised changes in performance under fatigue. In fact, the results with regard to the present divided attention task seem to mimic the results that were reported in a previous study on fatigue and focused attention. That is, Van der Linden and Eling (2006) reported that global identification of targets, which relies more strongly on automatic attentional processes, was less strongly affected by fatigue than local identification, which requires more controlled focus of attention. In the present study we found that one-object targets comparisons, which are assumed to put relatively low demands on divided attention, are less strongly affected by fatigue than two-objective targets comparisons, which are often assumed to require controlled divided attention (Lavie & Driver, 1996).

Although the results may contribute to insight into the nature of cognitive decline under fatigue, we need to address several topics that have to be taken into account when interpreting these results. First, the same-object benefit was not indicated during the first half of the experiment. Regarding this, it has been shown that the effects of the same-object benefit range from 5 ms (Shommstein & Berhmann, 2006) to about 60 ms (Watson & Kramer, 1999), depending on stimulus and procedure details. Subsequently, previous studies have indicated that in some experiments, the same-object benefit tends to become visible only after the participants executed a relatively large number of trials (e.g., Feldman, 2007). In line with this, in the present study the same-object benefit was relatively small at baseline, but was nevertheless clearly visible over the entire course of the experiment. The same-object benefit increased significantly over time too, indicating that fatigue might have played a role in increasing the gap between object and two-object target comparisons. In other words, the same-object benefit became well pronounced by the final interval when participants' fatigue likely reached the maximum level during the experiment.

A second topic we should mention is learning or practice effects. Although in the current results, there is no significant indication of learning effect, still from the first to the second interval the data suggests a modest improvement in performance (see Table 1). In general, participants working on an RT task often become more effective or more efficient over time due to task familiarity or to the development of response strategies. It is well known in fatigue research that learning curves tend to be confounded with fatigue curves (e.g., Boksem et al., 2005; Lorist et al., 2000, 2005). Often, participants become somewhat more efficient in a task, which might mask initial fatigue effects, but after a prolonged time on task, the fatigue effects become more pronounced and lead to an actual decline in performance. Regarding the same-object benefit, Shomstein and Yantis (2004) argued that, during a task, participants might learn to assign higher attentional priority to locations with higher task relevance. Such learning effects might have strengthened the same-object benefit. On the other hand, learning or practice effects generally lead to *more efficient* performance. In the present study, however, overall performance *declined* in the last interval, which is in contrast to typical learning effects. The decline was also less pronounced in same-object comparisons than in two-object comparisons. So, we consider it more likely that the increased same-object benefit was caused by fatigue than by learning effects.

The results of the present study are in accordance with the idea that fatigue mainly compromised the top-down control over attention and that more automatic processing is less strongly affected. The fact that findings on same-object target comparisons were different from different-object target comparisons indicates that the effects of fatigue cannot solely be ascribed to disturbances in basic perceptual processes, caused for example, by visual fatigue (e.g., difficulties in identifying the targets). In contrast, it is more likely that fatigue particularly affected different-object processing, because this type of trials puts more demands on the ability to divide attention. In future research it may also be important to examine the possible neuropsychological mechanisms that may mediate the effects of fatigue on the same-object benefit. Previous findings from neuroimaging studies provide some clear predictions. These studies suggested that the advantage of one-object over two-object comparisons might come from additional activation of early visual areas in the same-object comparisons relative to the different-object comparisons (Shomstein & Behrmann, 2006). This differential activation indicates that more automatic perceptual processes are responsible for comparison of targets belonging to the one-object category. We expect that this finding can possible also explain why fatigue has a differential effect on same-object versus different object comparisons. That is, with the declined attentional control under fatigue, the more automatic, same-object comparisons will likely be less disturbed by fatigue leading to an increasing same-object benefit under fatigue. Presently, these ideas remain expectations based on what is currently known about the neuropsychological substrate of the same-object benefit under fatigue.

In sum, the findings of the present study provide more insight into how mental fatigue (due to time-on-task) affects divided attention. To our knowledge, this is the first study showing that fatigue might differentially affect same and different object processing. In addition, since previous research focused mostly on various patient groups to investigate fatigue-related changes in divided attention, the current study might also provide valuable information about such changes in healthy, normal observers.

The fatigue-related results in our study were obtained with experimental settings (e.g., SOA, stimuli types) that are in accordance with several other basic studies on the same-object benefit. Nevertheless, it is important to note that Davis and Holmes (2005a, 2005b) argued that the characteristics of the same-object benefit may change depending on the experimental settings. For example, very short presentation times (less than 200 ms) have been found to reverse the effect (Feldman, 2007). So, in such extreme cases, the effects of fatigue may possibly be different. We did not test this in the present study but the effect of fatigue on the same-object benefit with other experimental settings can be the focus for future studies on this topic.

Research on object-based attention may provide important practical implications for a high variety of visual display technologies (Davis, 2004). Visual display terminals, everyday road traffic situations, or the range of complex displays in a cockpit are a couple of examples for places and situations where observers are required to process diverse object-related information simultaneously. In order to minimise observers' errors in such situations, it is highly valuable to understand the attentional strategies adopted in viewing a particular display. However, considering the fact that in everyday life mental fatigue has a well-known and pronounced impact on attentional performance, it is also crucial to understand how fatigue modifies basic object-related attentional processing. Therefore, the results in the current study might also provide information for better optimisation of visual displays to prevent fatigue-related errors.

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