Perception, 2012, volume 41, pages 963–975

doi:10.1068/p7294

# Moderate movement, more vision: Effects of physical exercise on inattentional blindness

Stefanie Hüttermann, Daniel Memmert
Deutsche Sporthochschule Köln, Am Sportpark Müngersdorf 6, 50933 Cologne, Germany;
e-mail: s.huettermann@dshs-koeln.de
Received 20 May 2012, in revised form 24 August 2012

**Abstract.** Research on inattentional blindness shows that individuals fail to notice unexpected objects or events when attention is focused elsewhere. The majority of previous studies on inattentional blindness have been performed at rest, even though there are several real-life situations that require both physical exercise and focus of attention to accomplish a particular task. A number of different studies have demonstrated that physical exercise influences cognitive performance and attention processes in a variety of ways. Relatively little is known about the effects of physical load on inattentional blindness. The present study was the first attempt to investigate inattentional blindness effects as a function of physical load. Participants were randomly assigned to three groups where they performed two different inattentional blindness tasks: at rest (group 1) and on a bicycle ergometer under moderate (group 2) or high (group 3) physical exercise. The results showed a decrease of inattentional blindness effects from the resting to the moderate exercise condition, and then an increase for the high physical exercise condition, representing an inverted-U plot. Findings support the notion that physical exercise influences individuals' attention performance. We concluded that moderate physical exercise has a positive impact on inattentional blindness, given that people under moderate physical exercise more frequently notice an unexpected object when attention is diverted to another task, and that this evidence should be taken into account when considering certain real-life events.

**Keywords:** inverted-U curve, physical exercise, attention, perception

## 1 Introduction

Runners are oblivious to people walking past them while being focused on their course; bikers overlook stones and other obstacles on the path located within their field of view while, for example, paying attention to their speedometer mounted on the handlebar; and police officers might have to chase a burglar while attending to traffic and other people (Chabris et al 2011). Such situations illustrate that individuals under certain physical exercises might fail to notice unexpected, albeit fully visible objects and/or events when attending to other things. This phenomenon is called "inattentional blindness" (Mack and Rock 1998) and has been explored in several previous studies (eg Most et al 2005). However, most of these studies have examined the phenomenon at rest (ie with no physical exercise involved) and neglected the physical exercise intrinsic to many real-world events. Chabris et al were the first to show, for example, that the amount of physical exertion during a running activity might predict inattentional blindness. The aim of the present work was to compare inattentional blindness under different physical load intensities, in order to explore whether moderate or high physical load affects failure to detect an unexpected object more often than at rest.

The inattentional blindness approach of Mack and Rock indicates that conscious perception requires attentional processes. Without attention, individuals often do not detect unexpected objects, especially if those objects are not the centre of their interest, even though these become visible in the field of vision (Most et al 2005). They perceive only those objects that receive focused attention. Inattentional blindness studies have used both brief and static displays, as well as dynamic stimuli in more complex settings (eg Most et al 2000, 2005).

In a dynamic setting (see Neisser 1979; Simons and Chabris 1999), subjects had to count the number of passes made between three basketball players while simultaneously being distracted by three other basketball players dressed with black shirts. After 30 s, an individual carrying an umbrella (Neisser 1979) or dressed in a gorilla suit (Simons and Chabris 1999) walked across the display. A large proportion of participants failed to notice these unexpected events. Such inattentional blindness paradigms showed that subjects often do not perceive unexpected objects in dynamic settings, even though these are presented right in front of them.

Although there are several inattentional blindness studies regarding complex settings (Neisser 1979; Simons and Chabris 1999), until now it has not been taken into account that many real-life situations do not only take place in complex settings but also under physical strain. For instance, in football or basketball, athletes often do not pass the ball to a better positioned team mate, even when that team mate was located in the player's field of vision (Furley et al 2010; Memmert and Furley 2007). This is probably due to players' physical stress during the action while making decisions concerning the tactical behaviour. This potential moderator has not been addressed in inattentional blindness studies so far. Despite the fact that perhaps the most famous inattentional blindness paradigm represents an action basketball scene, it is surprising that, thus far, inattentional blindness studies have neglected the effects that exercise can have on this element. One recent study about inattentional blindness (Chabris et al 2011) was performed under physical exercise in a real-world situation. Yet, despite subjects' average heart rates having been taken as measure, the connection between heart rate and detection rate of the unexpected event has not been the focal point of this study.

It seems important to examine the effects of physical strain on inattentional blindness for two reasons: (i) Real-life situations requiring visual attention are common both at rest and under physical strain. One example for a rest situation might be driving a car and focusing attention on the road, and thus not perceiving unexpected objects at the roadside, or being on the phone while driving (Strayer et al 2003). Situations under physical exercise might occur in everyday life situations during jogging or cycling when subjects do not perceive what happens outside their route (Chabris et al 2011), or also during specific sport games when players overlook their team mates (Memmert and Furley 2007). (ii) Odds are that there is an optimal physical load intensity that might minimise subjects' inattentional blindness effects.

A large amount of research has focused on the influence of physical exercise on the efficiency of cognitive processes. These studies have documented an inverted-U relationship (Duffy 1972; Easterbrook 1959; Schmidt 1988) between exercise and cognitive performance (eg Chmura et al 1994; Davey 1973; Kashihara et al 2000; McMorris et al 1999). Cognitive performance increases with physical exercise, however, only until a certain optimal point, which seems to be close to the anaerobic (lactate) threshold (Chmura et al 1994); additional high-intensity exercise beyond this point might decrease cognitive function. The anaerobic threshold is defined as the workload point generating the highest exercise intensity performed on the basis of oxidative phosphorylation without an extended utilisation of anaerobic energy mechanisms. This means that during exercise within the anaerobic threshold the pyruvate formation rate does not transcend the maximal rate of oxidative phosphorylation (Viru and Viru 2000). Kashihara et al (2009) provided several reasons for the improved effects of moderate physical exercise on cognitive performance, with an improvement in the cerebral circulation and an alteration of the neurotransmitters' action. Physical exercise modulates the cerebral blood flow (Ide and Secher 2000; Moraine et al 1993) which becomes faster during moderate exercise. Kashihara et al (2009) point out that the regional cerebral blood flow might improve the brain area to control cognition because mental (Hoshi and Tamura 1993) and motor tasks (Obrig et al 1996) modulate cerebral oxygenation in some areas of the brain. By changing the levels of specific neurotransmitters of the central nervous system (eg brain cortex or hippocampus) that activate cognitive function, acute physical exercise might improve cognitive performance (Gold and Zornetzer 1983). As soon as the anaerobic threshold is reached, the blood lactate concentration increases rapidly, and, additionally, human production of hormones and catecholamines is activated (Chmura et al 1998; Chwalbinska-Moneta et al 1998). Physical exercise leads to an increase of plasma catecholamines, such as adrenaline and noradrenaline (Brooks and Gregg 1988; Lehmann et al 1981; Mazzeo and Marshall 1989), and stimulates lactate production in skeletal muscles (Ivy et al 1987).

Among other things, authors provided evidence of positive effects of exercise on attention processes (Adam et al 1997; Paas and Adam 1991), creativity (Gondola 1987), simple reaction time (Davranche et al 2006), choice reaction time (Audiffren et al 2008; Davranche et al 2005), as well as stimulus detection and coincidence-timing (Fleury and Bard 1987). Relatively few studies have dealt with the effects of physical exercise on attention processes (eg Allard et al 1989; Castiello and Umiltà 1988). Studies have shown evidences for positive exercise effects on attention processes (eg Adam et al 1997). Other studies have assumed that an increase in arousal and activation level allows for higher involvement of attention resources in the performed cognitive task and results in facilitating effects of sub-maximal physical exercise on cognitive performance (Chmura et al 1998; Davranche and Audiffren 2004; Grego et al 2004).

To our best knowledge, there has been no study measuring the effects of physical exercise on inattentional blindness. However, given some of the reasons mentioned above, it seems plausible to examine inattentional blindness tasks under different physical load intensities. In two experiments, we combined standard inattentional blindness tasks described by Simons and Chabris (1999) and Most et al (2000) with a physical exercise task. We compared subjects performances at rest, as well as under moderate and high physical exercise on a cycle ergometer. Based on previous studies that explored the relationship between the intensity of exercise and the activation level of the central nervous system (for a review see Tomporowski and Ellis 1986), we hypothesised that subjects would show lower inattentional blindness effects under moderate workload compared to the other two examined conditions. We expected an inverted-U relationship between detection rate of the unexpected event and physical load intensity, with significant differences between rest condition and moderate load, as well as between moderate and high physical load.

## 2 Experiment 1

### 2.1 *Method*

2.1.1 *Participants.* Altogether, forty-five subjects (twenty-two female, twenty-three male) aged 18 to 62 years ($M_{age}$ = 25.80 years, SD = 9.19 years) took part in the study. Data from four additional subjects were excluded because of previous knowledge of inattentional blindness or related research. All participants reported normal vision without need for corrective lenses. Participants' maximum heart rates varied between 158 bpm and 212 bpm ($M$ = 200.16 bpm, SD = 10.56 bpm). At the time of the study, participants were taking part in different sports at least once a week up to a maximum of four times a week ($M$ = 2.38 h per week, SD = 1.17 h per week). Owing to their regular participation in sports, the study did not cause physical problems to any of the subjects. Written informed consent was obtained from each subject prior to participation in the study. The study was carried out in accordance with the Helsinki Declaration of 1975.

2.1.2 *Materials.* The experiment was conducted on a bicycle ergometer (Lode OEM®). Participants' heart rate frequencies were measured with a heart rate monitor (Polar S819®). We employed a 30 s video clip, created by Simons and Chabris (1999), which included two teams of three basketball players. Teams were distinguished by white and black shirts. Both teams moved around in an open area in front of three elevator doors, each passing an orange basketball among themselves in a regular order. After 15 s, a person in a gorilla costume entered the scene from the right side of the screen. Reaching the centre of the screen, the gorilla turned to face the camera and thumped his chest—visible for about 5 s at the centre of the action—before leaving the display from the left side. Overall, the gorilla was visible on the display for about 10 s.

2.1.3 *Procedure.* Participants were tested in a laboratory room, where they were required to sit on a bicycle ergometer at a distance of 60 cm from a PC-driven video screen with a visual angle of about 73° horizontal × 45° vertical direction. Furthermore, they had to wear a heart rate monitor. Individual heart rates were measured at a rest state before starting the experiment. During the experiment, participants' heart rates as well as pedal frequency were monitored at all times.

Participants were randomly allocated to one of three groups, each including fifteen subjects: Group 1 performed the monitoring task at rest, while sitting on the cycle ergometer; group 2 performed under a physical load intensity of 50% of the individual maximum heart rate. Group 3 performed the task under a physical load intensity of 70% of the individual maximum heart rate. Evaluation of the personal data revealed no significant difference regarding the number of practice hours per week in diverse sports activities between the three groups ($F_{2,42} = 0.833$, $p = 0.442$). Participants in the rest condition had an average rest heart rate of $M = 72.07$ bpm (SD = 9.25 bpm). Target heart rates of subjects participating in groups 2 or 3 were determined for physical load intensities of 50% and 70% of the individual maximum heart rates. The heart rate is considered to be a simple alternative index to measure exercise intensity during physical exercise (Yamaji et al 1978) instead of the $VO_{2\,max}$ and is often used as an indication of performance (Cereatti et al 2009). In order to assess the maximum heart rate, two formulae were employed based on participants' age and gender: 220 bpm minus participant's age for male, and 226 bpm minus participant's age for female subjects (Beashel et al 2001).

The physical load intensities were increased by increments in resistance strength. 50% physical load intensity of the maximum heart rate corresponded to $M = 106.50$ bpm (SD = 16.53 bpm) and 70% to $M = 142.99$ bpm (SD = 3.09 bpm) across all subjects. Participants first warmed up, starting with a 50 W load, for a period of 5 min until they had reached their individual target heart rates. An experimenter altered the wattage depending on the required target heart rate. If the actual heart rate deviated from the required target heart rate more than ±5 bpm, adjustments would be made to the individual physical load by altering the wattage. Participants had to pedal on the bicycle ergometer at approximately 60 rpm to be in accordance with reported physiological optimal rates (eg Gregor et al 1991); they were rigorously instructed to maintain the imposed pedal rate.

Before viewing the gorilla video of Simons and Chabris (1999), participants were told that they would see two teams in white and black shirts playing basketball. Furthermore, they were instructed to count the number of passes within the white team, independent of bounce and aerial passes, while entirely ignoring the black team. Once the videotape and exercise started, heart rate was continuously monitored.

Participants were not forewarned about the gorilla, so that its appearance was unexpected for them. After completing the monitoring task, participants were asked to write down their count totals on a separate page of paper and reply to the following questions, following

Simons and Chabris's (1999) procedure: (1) While you were doing the counting, did you notice anything unusual on the video? (2) Did you notice anything other than the six players? (3) Did you see a gorilla walking across the screen? If participants answered "yes" to any of these questions, they had to describe details of what they had noticed. The questions were skipped whenever a subject mentioned the gorilla. After replying to the questions, subjects were asked whether they had ever previously participated in or heard of this or a similar experiment. In the end, the videotape was replayed to verify that subjects saw the gorilla with full attention to the whole display scenario. In total, each testing session lasted between 5 and 10 min.

2.2 *Results*

Across all conditions, 20% of the remaining subjects noticed the gorilla while 80% failed to notice it. Figure 1 shows that the rates of noticing the unexpected object were highest under moderate exercise (50% of maximum heart rate) compared to high exercise (70% of maximum heart rate) or at rest ($\chi_2^2 = 7.500$, $p < 0.05$, $\phi = 0.408$). The differences in the detection rate were significant between 50% and 70% physical load of maximum heart rate ($\chi_1^2 = 7.500$, $p = 0.006$, $\phi = 0.500$), but not between rest condition and 50% physical load of maximum heart rate ($\chi_1^2 = 1.429$, $p = 0.232$), or rest condition and 70% physical load of maximum heart rate ($\chi_1^2 = 3.333$, $p = 0.068$), with Bonferroni adjusted $\alpha$ levels of 0.017. No significant differences were evident for the accuracy of counted passes between subjects who noticed the unexpected object and those who failed to see it ($F_{1,43} = 1.162$, $p = 0.287$). Accuracy did not vary across conditions ($F_{2,42} = 3.094$, $p = 0.056$), and there was also no condition × noticing interaction effect ($F_{1,40} = 2.321$, $p = 0.135$).

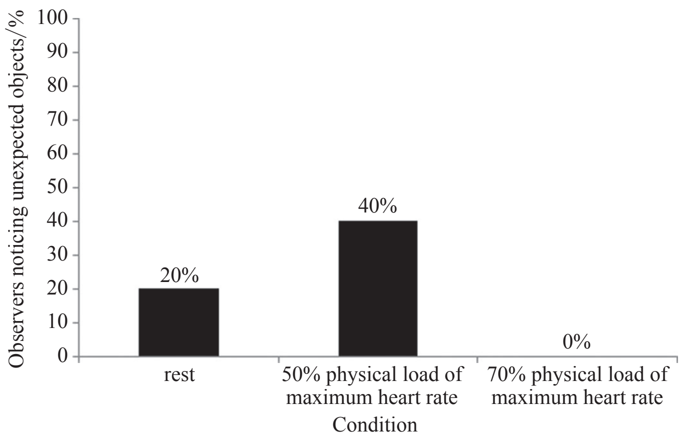


**Figure 1.** Percentage of observers in the critical trial who reported seeing the unexpected object.

2.3 *Discussion*

In this experiment, we aimed to examine for the first time how far physical exercise of moderate and high physical load intensity, in contrast to a rest condition, affects subjects' visual attention for unexpected events presented centrally within their visual field of view. In line with findings on the effect of arousal on cognitive performance (for a review see Tomporowski and Ellis 1986), our prediction was that the performance graph would show an inverted-U shape including resting condition, moderate, and high physical load. In total, 80% of participants failed to notice the unexpected object (ie the gorilla), which exceeds the findings of Neisser and Becklen (1975) and Simons and Chabris (1999) who found that approximately 50% of participants noticed the unexpected event when examining inattentional blindness phenomena without physical exercise. One possible explanation of the higher rate of inattentional blindness in our study, compared to Simons and Chabris's (1999) original study, might be the fact that participants were more distracted since they were sitting on a bicycle ergometer. Subjects detected the gorilla more often under moderate than under high physical load intensity or at rest. However, differences in the detection rate were only significant between moderate and high physical load intensity, with no differences being apparent between the other comparisons of physical load stages. This means that our hypothesis could only be confirmed in part, not showing a completely inverted-U shape with significant differences between the workloads. Yet, in total, participants appear to be able to access highest attention performance under moderate physical load. The observed effect of moderate physical exercise on inattentional blindness is consistent with previous results reported in different research works during basic cognitive tasks (for a review see Tomporowski and Ellis 1986), showing a cognitive performance improvement with exercise-induced activation of the central nervous system. However, in accordance with previous studies (eg Chmura et al 1994), our findings show an increase of inattentional blindness with higher physical load, probably due to the concomitant production of lactate. High-intensity physical load is associated with a very high plasma catecholamine concentration and lactic acidosis leading to a release of stress hormones, an increase of blood glucose and osmolality levels (Soya et al 2007), thus restricting cognitive functions (Kashihara et al 2009), such as visual attention performance. This process is influenced in the way that physical load of high intensity restricts subjects' attention more than during moderate exercise and at rest.

## 3 Experiment 2

In a second experiment we tried to replicate our findings as it is stressed by Fiedler (2011) and Simmons et al (2011) by measuring the effects of physical load on inattentional blindness using a different paradigm (eg Most 2010 suggested that different paradigms may induce distinct types of inattentional blindness; see also Memmert and Furley 2010) including other requirements (eg stimuli) and challenges compared to the experiment 1.

In the first experiment, we found only significant differences for the rates of noticing the unexpected object between moderate and high load exercise, although differences were evident between moderate physical load and high load exercise, or the rest condition. Based on previous research, cognitive performance of humans is highest under physical load close to the anaerobic threshold (eg Chmura et al 1994). According to Kashihara et al (2009) and Chmura et al (1994), the optimal intensity of physical exercise for cognitive function seems to be closely related to the anaerobic threshold, with average heart rates between 115 and 135 bpm in young subjects (Yamaji et al 1978). Since participants' heart rate values were of approximately 107 bpm during moderate physical load, which is somewhat lower than the aforementioned values, one might speculate that participants' anaerobic threshold was not reached in the first experiment and that this was the reason for some non-significant differences of noticing rates between workload stages. Therefore we raised the moderate workload to 60% of maximum heart rate in this experiment. In the first experiment, the unexpected object was presented so that it was clearly visible in the observer's zone of attention and its presentation size took up more than half of the screen height, similar to the objects or the players who should be observed. However, many real-world events require human attention to unexpected objects of different sizes at different locations. For example, the best soccer players should be able to perceive an unexpected free-standing team mate on the other side of the playing field during physical exercise, or a runner should perceive unexpected stones or other obstacles on the path located at the edge of his visual field. This means that the examination of inattentional blindness effects under physical exercise on stimulus size as well as stimulus location seems to be of interest for real-world events.

In experiment 2, we examined two different effects: the entry of a much smaller unexpected object (which again had the same size as the observed objects) into the zone of attention and, second, the entry of the same object outside the zone of attention (cf Mack and Rock 1998). Following location-based models (see eg Newby and Rock 1998) and previous inattentional blindness studies (Most et al 2000), the probability to detect an unexpected object is affected by the distance of the object from the focus of attention. An unexpected object that appears near the focus of attention will be noticed more frequently than if it appears further away (Newby and Rock 1998). Subjects performed the dynamic monitoring task by Most et al (2000) with either using a near or very far distance of the unexpected object to the focus of attention and under moderate or high physical load, or at rest. According to location-based models and the approach of an inverted-U relationship between exercise and cognitive performance, we hypothesised that subjects would detect the unexpected event entering into or outside the zone of attention more often under moderate than under high physical load intensity or at rest. In addition, we assumed that subjects would achieve higher detection rates when the unexpected object was presented inside as opposed to outside the zone of attention.

### 3.1 *Method*

3.1.1 *Participants.* A total of sixty subjects (twenty-five female and thirty-five male) between the ages of 18 and 32 years ($M_{\text{age}} = 23.22$ years, SD = 3.24 years) took part in the study. Data from two additional subjects were excluded because of their previous knowledge of inattentional blindness or related research. All participants reported normal vision without need for use of corrective lenses. Participants' maximum determined heart rates varied between 189 bpm and 207 bpm ($M = 200.78$ bpm, SD = 3.87 bpm). At the time of the study, participants were taking part in different sports at least once a week to a maximum of 5 times a week ($M = 2.33$ h per week, SD = 1.08 h per week). Owing to their regular participation in sports, participation in the study did not cause any physical problems to subjects. Written informed consent was obtained from each subject prior to participation. The study was carried out in accordance with the Helsinki Declaration of 1975.

3.1.2 *Materials.* As in experiment 1, the monitoring task was conducted on a bicycle ergometer (Lode OEM®). Participants had a visual angle of about 73° in the horizontal and 45° in the vertical direction from the 60 cm wide PC video screen. Participants' heart rate frequencies were measured with a heart rate monitor (Polar S819®). We used three video trials created by Most et al (2000). The events of each trial were shown within a grey display window divided into halves by a blue horizontal line. 4 black and 4 white Ls and Ts, presented as block letters of 1 cm × 1 cm size, moved independently on random paths within the display window. The first trial contained no unexpected object. 5 s after starting the second trial (the "critical trial"), a light grey cross (unexpected object) with the same horizontal and vertical alignment as the Ls and Ts moved through the display horizontally and in a linear path. It entered from the right side of the display at different distances from the centre line, either 2.4 cm above the horizontal line which corresponded to the "near" condition (visual angle of about 17° in the vertical direction) or 5.9 cm above the horizontal line, corresponding to the "very far" condition (visual angle of about 42° in the vertical direction). As opposed to the near condition, in the very far condition, the path of the cross did not overlap with other moving letters in the display because these were constrained closer to the centre of the display.

3.1.3 *Procedure.* The test setup was the same as in experiment 1. Again, participants were randomly allocated into three groups performing the monitoring task at rest, under a physical load intensity of 60% of individual maximum heart rate, or under a physical load intensity of 70% of individual maximum heart rate. Evaluation of the personal data revealed no significant difference regarding the number of practice hours per week in diverse sports activities between the three groups ($F_{2,57} = 2.423$, $p = 0.098$). Heart rate frequencies were measured as in experiment 1 and deviations were handled in the same way. Participants in the rest condition had an average rest heart rate of $M = 74.50$ bpm (SD = 5.71 bpm). 60% physical load intensity of the maximum heart rate corresponded to $M = 119.37$ bpm (SD = 2.44 bpm) and 70% to $M = 166.04$ bpm (SD = 4.63 bpm). Participants pedaled on the bicycle ergometer at approximately 60 rpm.

Before performing the dynamic monitoring task by Most et al (2000), subjects were instructed to fixate gaze on a central point located on the centre of the blue horizontal line. They had to silently keep track of the total number of times that the black letters touched the horizontal line during each trial. A touch was defined as every single contact of an L or T letter with the line (whether the letter crossed the line or not) and regardless of how long it remained in contact with the line. Each trial lasted approximately 15 s. All subjects completed two trials. The first trial contained no unexpected object. In the second trial (critical trial) a cross (unexpected object) moved horizontally through the display at two different distances from the centre line depending on the condition type (ie near vs very far).

Participants were not forewarned about the cross, so that its appearance was unexpected for them. After the first trial, participants were asked to report the number of touches of the black letters with the horizontal line. After the second critical trial, they were asked to report (1) the number of touches, and (2) whether or not they had seen anything else than the black and white L and T letters (see Most et al 2000). If participants answered "yes" to the second question, they were asked to describe details of what they had noticed.

After completing both trials, subjects were shown the second trial (critical trial) again. This time, they were only instructed to fixate the display without counting how often the black letters touched the line. The moderate and high exercise load groups conducted this trial while cycling on the ergometer. Although participants were not explicitly informed that another object would appear, the previous questions had alerted them to the possibility that a further object might appear. While attention was not engaged otherwise, this trial tested perception under a "full attention" condition (see Most et al 2000) and was used as control to ensure that subjects had understood and could follow the task instructions.

Following the procedure of Most et al (2000), subjects were then asked whether they were familiar with this or other related experiments prior to participation. This way, we ensured that participants had no reason to expect another object to appear in the display during the critical trial and did not have any prior experiences with other studies of inattentional blindness. In total, the experiment was completed in 5 to 10 min.

### 3.2 *Results*

A 3 × 2 [physical load intensity (rest, 60%, 70% of maximum heart rate) × distance to an unexpected object (near, very far)] ANOVA with the detection rate of an unexpected object as categorical dependent variable (noticed, not noticed) revealed significant differences for the factor physical load intensity ($F_{2,54} = 5.188, p < 0.01, \eta_p^2 = 0.161$) and for the factor distance to the unexpected object ($F_{1,54} = 8.576$, $p < 0.01$, $\eta_p^2 = 0.137$). No significant interaction between physical load intensity and distance to an unexpected object ($F_{2,54} = 2.224, p = 0.118$) was detected (for details on an ANOVA with a dichotomous dependent variable, see Lunney 1970). Across both conditions (near, very far) and physical load intensities (rest, 60%, 70%), 28.33%, that is, seventeen subjects noticed the unexpected object (ie cross) while 71.67% (forty-three subjects) failed to notice it. Figure 2 shows that observers noticed the unexpected object more frequently in the condition near than in the condition very far. The follow-up Bonferroni-corrected pairwise comparison revealed only significant differences between

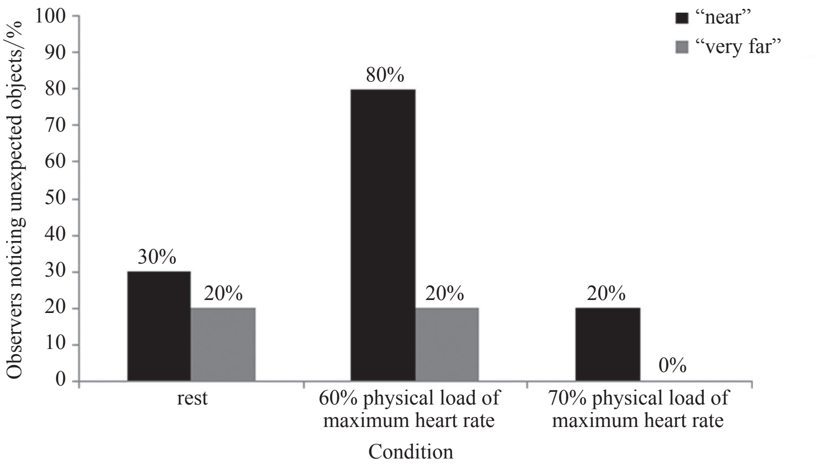


**Figure 2.** Percentage of observers in the critical trial who reported seeing the unexpected object in the "near" and "very far" condition.

60% and 70% physical load of maximum heart rate ($p < 0.01$), but not between rest and 60% physical load ($p = 0.154$), and between rest and 70% physical load ($p = 0.711$) across both conditions.

The results of the near condition indicated a significant main effect for physical exercise conditions ($\chi^2_2 = 8.416$, $p < 0.05$, $\phi = 0.530$). The difference in the detection rate in the near condition was significant between 60% and 70% physical load of maximum heart rate ($\chi^2_1 = 7.200$, $p = 0.007$, $\phi = 0.600$), but not between the rest condition and 60% physical load of maximum heart rate ($\chi^2_1 = 5.051$, $p = 0.025$), and between rest condition and 70% physical load of maximum heart rate ($\chi^2_1 = 0.267$, $p = 0.606$), with Bonferroni adjusted $\alpha$ levels of 0.017. In the very far condition, there were no significant differences between physical exercise conditions ($\chi^2_2 = 2.308$, $p = 0.315$).

There were no differences in performance comparing the accuracy of counted touches between participants who noticed the unexpected object and those who failed to see it, for both conditions—near condition: ($F_{1,28} = 0.073$, $p = 0.789$), very far condition ($F_{1,28} = 0.326$, $p = 0.573$). Accuracy did not vary across physical load conditions—near condition ($F_{1,28} = 0.073$, $p = 0.789$), very far condition ($F_{1,28} = 0.326$, $p = 0.573$); and there was also no condition × noticing interaction in accuracy—near condition ($F_{1,25} = 0.365$, $p = 0.698$), very far condition ($F_{1,25} = 0.565$, $p = 0.459$).

### 3.3 *Discussion*

In addition to experiment 1, which examined the influence of physical exercise on inattentional blindness effects, this second experiment investigated whether there is also an effect concerning the distance of the unexpected object from the spatial focus of attention. Consistent with previous studies on inattentional blindness that did not involved physical exercise (Mack and Rock 1998; Most et al 2000; Newby and Rock 1998), and in line with our hypothesis, the results showed an influence of distance from the focus of attention at rest as well as under moderate and high physical exercise. When the unexpected object moved further away from the fixated horizontal line in the middle of the display (very far condition), fewer participants noticed its appearance compared to when it was closer to the line (near condition). In total, more than half of the observers (72%) failed to notice the unexpected object in the critical trial, but all of them were able to see it when not being engaged in the attention-demanding task. In the near condition, results presented an inverted-U relationship between physical exercise and detection rate, confirming our hypothesis. Results indicate that moderate physical exercise improves attention and decreases the failure of detecting unexpected objects inside the zone of attention, while focusing attention on other objects or events of interest; on the other hand, high physical exercise decreases attention performance, thus increasing inattentional blindness effects. In contrast to the first experiment, the results demonstrate that 60% load intensity of maximum heart rate rather corresponds to a moderate workload than 50% load intensity of maximum heart rate. In accordance with previous findings (eg Tomporowski and Ellis 1986) the results of the near condition support the approach of an inverted-U relationship showing that aerobic exercise of moderate intensity facilitates cognitive performance, as opposed to high intensities. However, in the very far condition no significant effects between detection rate and physical load were apparent, and as a result no inverted-U relationship could be found. Our results show that moderate physical exercise reduces inattentional blindness effects when the unexpected object is presented closely to the fixation point but does not have an effect when the object is presented far away from fixation. This particular finding, showing that subjects become less likely to detect an unexpected object as its path is moved further from fixation, is consistent with the models that point out that detection rate decreases with distance from fixation (Newby and Rock 1998).This might be attributed to a greater impact of the location effect, being responsible for the probability to detect an unexpected object more frequently as it becomes closer to the focus of attention (eg Newby and Rock 1998) compared to the inattentional blindness effect (Mack and Rock 1998). That means that location-based effects exceed inattentional blindness effects independently of physical exercise influences. This second experiment highlighted the fact that both physical exercise and the spatial location of an unexpected event can influence inattentional blindness effects.

## 4 General discussion

In two experiments, using different inattentional blindness tasks, we attempted to examine how far physical exercise of different physical load intensities (moderate load with 50% or 60% physical load of maximum heart rate, and high load with 70% physical load of maximum heart rate) affect visual attention capacity in contrast to a resting condition. Results confirm findings of previous research on inattentional blindness for the resting condition in which subjects mostly failed to notice an unexpected object or event when performing another attention demanding task (Most et al 2000; Simons and Chabris 1999). For both inattentional blindness paradigms, we demonstrated an effect of physical exercise on attention performance, even if this does not hold true for all workload stages. The effect was greater when the moderate workload was to some extent higher. This observed effect of physical exercise on visual attention is consistent with previous results reported in different areas of cognitive research (eg Tomporowski 2003). Several researchers were able to show that cognitive performance improves with exercise-induced activation of the central nervous system and deteriorates after exceeding certain work intensities around the anaerobic threshold (eg Chmura et al 1994; Davranche et al 2009).

Kashihara et al (2009) analysed features, in particular those related to physiological factors, being responsible for the improved effects of moderate physical exercise close to the anaerobic threshold in cognitive performance, and showed that cognitive effort modulates arousal and activation; these in turn enhance the amount of available resources. During physical exercise around the anaerobic threshold, the modulated central nervous system with a facilitated regional cerebral blood flow and its neurotransmitters seem to positively affect cognitive task performance, for example the attention performance. Various studies dealing with the relationship between the intensity of exercise and the activation level of the central nervous system illustrate their results as an inverted-U relationship (eg Duffy 1972;

Easterbrook 1959; Schmidt 1988). The course of the curve demonstrates that performance increases until a certain workload and from then on decreases, as based on the reasons mentioned before. The results of our study partially support the approach of an inverted-U relationship (Tomporowski and Ellis 1986) showing that aerobic exercise of moderate intensity facilitates cognitive performance, as opposed to high intensities. However, it should be noted, and this might also be a reason why we did find only significant effects for some load stages, that we only examined two different physical load intensities including a rest condition, so that we can only assume an inverted-U course. Further studies with more physical load intensities and greater differences between the load intensities could generate additional results and verify an optimal workload for cognitively challenging physical activity at different skill levels, ages, and genders. For example, it has been shown that it makes some difference whether or not participants are athletes. Non-athletes generally show a lower exercise workload at the optimal load point than athletes with enhanced cardio pulmonary function (Kashihara et al 2009). Physiological constraints as well as attention demands of the physical tasks are reduced at higher physical fitness levels (Brisswalter et al 2002). One further obvious explanation for the lack of some expected significant differences in the studies might be associated with the relatively small sample sizes used, so that future research should attempt to include a greater number of participants.

As mentioned before, a facilitated regional cerebral blood flow as well as neurotransmitters in the central nervous system seem to be responsible for improved attention performance during exercise around the anaerobic threshold. Further reasons, for example those associated with psycho-physiological mechanisms to explain the inverted-U relationship, require advanced research. In addition, future research should investigate whether the advantage of moderate physical exercise over high physical exercise and rest can be generalised for further exhausting situations. Among other things, it would be conceivable that the safety at work for physically exhausting professions (such as scaffold building, painting and varnishing, or manufacturing) could be at risk in consequence of restricted attention performance capability.

**References**


Adam J J, Teeken J C, Ypelaar P, Verstappen F T J, Paas F, 1997 "Exercise-induced arousal and information processing" *International Journal of Sport Psychology* **28** 217–226

Allard F, Brawley L R, Deakin J, Elliot F, 1989 "The effect of exercise on visual attention performance" *Human Performance* **2** 131–145

Audiffren M, Tomporowski P D, Zagrodnik J, 2008 "Acute aerobic exercise and information processing: Energizing motor processes during a choice–reaction time task" *Acta Psychologica* **129** 410–419

Beashel P, Sibson A, Taylor J, 2001 *The World of Sport Examined* 2nd edition (Cheltenham, Glos: Nelson Thornes)

Brisswalter J, Collardeau M, Arcelin R, 2002 "Effects of acute physical exercise on cognitive performance" *Sports Medicine* **32** 555–566

Brooks G A, Gregg S G, 1988 "Catecholamine stimulation during acute anemia increases exercise lactate production and decreases clearance" *Medicine and Science in Sports and Exercise* **20** S46

Castiello U, Umiltà C, 1988 "Temporal dimensions of mental effort in different sports" *International Journal of Sport Psychology* **19** 199–210

Cereatti L, Casella R, Manganelli M, Pesce P, 2009 "Visual attention in adolescents: Facilitating effects of sport expertise and acute physical exercise" *Psychology of Sport & Exercise* **10** 136–145

Chabris C F, Weinberger A, Fontaine M, Simons D J, 2011 "You do not talk about fight club if you do not notice fight club: Inattentional blindness for a simulated real-world assault" *i-Perception* **2** 150–153

Chmura J, Krysztofiak H, Ziemba A W, Nazar K, Kaciuba-Uscilko H, 1998 "Psychomotor performance during prolonged exercise above and below the blood lactate threshold" *European Journal of Applied Physiology and Occupational Physiology* **77** 77–80

Chmura J, Nazar K, Kaciuba-Uscilko H, 1994 “Choice reaction time during graded exercise in relation to blood lactate and plasma catecholamine thresholds” *International Journal of Sports Medicine* **15** 172–176

Chwalbinska-Moneta J, Kaciuba-Uscilko H, Kryszofiak H, Ziemba A, Krzeminski B, Kruk B, Nazar K, 1998 “Relationship between EMG blood lactate and plasma catecholamine threshold during incremental exercise” *Journal of Physiology and Pharmacology* **49** 433–441

Davey C P, 1973 “Physical exertion and mental performance” *Ergonomics* **16** 595–599

Davranche K, Audiffren M, 2004 “Facilitating effects of exercise on information processing” *Journal of Sports Sciences* **22** 419–428

Davranche K, Burle B, Audiffren M, Hasbroucq T, 2005 “Information processing during physical exercise: A chronometric and electromyographic study” *Experimental Brain Research* **165** 532–540

Davranche K, Burle B, Audiffren M, Hasbroucq T, 2006 “Physical exercise facilitates motor processes in simple reaction time performance: An electromyographic analysis” *Neuroscience Letters* **396** 54–56

Davranche K, Hall B, McMorris T, 2009 “Effect of acute exercise on cognitive control required during an Eriksen flanker task” *Journal of Sport and Exercise Psychology* **31** 628–639

Duffy E, 1972 “Activation”, in *Handbook of Psychophysiology* volume 5, Eds N S Greenfield, R A Sternbach (New York: Holt, Rinehart, & Winston) pp 577–595

Easterbrook J A, 1959 “The effect of emotion on cue utilization and the organization of behavior” *Psychological Review* **66** 183–201

Fiedler K, 2011 “Voodoo correlations are everywhere—not only in neuroscience” *Perspectives on Psychological Science* **6** 163–171

Fleury M, Bard C, 1987 “Effects of different types of physical activity on the performance of a perceptual task in peripheral and central vision and coincidence timing” *Ergonomics* **30** 945–958

Furley P, Memmert D, Heller C, 2010 “The dark side of visual awareness in sport—Inattentional blindness in a real-world basketball task” *Attention, Perception, & Psychophysics* **72** 1327–1337

Gold P E, Zornetzer S F, 1983 “The mnemon and its juices: Neuromodulation of memory processes” *Behavioral and Neural Biology* **38** 151–189

Gondola J C, 1987 “The effects of a single bout of aerobic dancing on selected tests of creativity” *Journal of Social Behaviour and Personality* **2** 275–278

Grego F, Vallier J-M, Collardeau M, Bermon S, Ferrari P, Candito M, Bayer P, Magnie M-N, Brisswalter J, 2004 “Effects of long duration exercise on cognitive function, blood glucose and counterregulatory hormones in male cyclists” *Neuroscience Letters* **364** 76–80

Gregor R J, Broker J P, Ryan M M, 1991 “The biomechanics of cycling” *Exercise & Sport Sciences Reviews* **19** 127–169

Hoshi Y, Tamura M, 1993 “Dynamic multichannel near infrared optical imaging of human brain activity” *Journal of Applied Physiology* **75** 1842–1846

Ide K, Secher N H, 2000 “Cerebral blood flow and metabolism during exercise” *Progress in Neurobiology* **61** 397–414

Ivy J L, Chi M-Y, Hintz C S, Sherman W M, Hellendall R P, Lowry O H, 1987 “Progressive metabolic changes in individual human muscle fibres with increasing work rates” *American Journal of Physiology* **252** 630–639

Kashihara A, Kinshuk, Oppermann R, Rashev R, Simm H, 2000 “A cognitive load reduction approach to exploratory learning and its application to an interactive simulation-based learning system” *Journal of Educational Multimedia and Hypermedia* **9** 253–276

Kashihara K, Maruyama T, Murota M, Nakahara Y, 2009 “Positive effects of acute and moderate physical exercise on cognitive function” *Journal of Physiological Anthropology* **28** 155–164

Lehmann M, Keul J, Huber G, Da Prada M, 1981 “Plasma catecholamines in trained and untrained volunteers during graduated exercise” *International Journal of Sports Medicine* **2** 143–147

Lunney G H, 1970 “Using analysis of variance with a dichotomous dependent variable: An empirical study” *Journal of Educational Measurement* **7** 263–269

Mack A, Rock I, 1998 *Inattentional Blindness* (Cambridge, MA: MIT Press)

McMorris T, Myers S, MacGillivary W W, Sexsmith J R, Fallowfield J, Graydon J, Forster D, 1999 “Exercise, plasma catecholamine concentrations and decision-making performance of soccer players on a soccer-specific test” *Journal of Sports Sciences* **17** 667–676

Mazzeo R S, Marshall P, 1989 "Influence of plasma catecholamines on the lactate threshold during graded exercise" *Journal of Applied Physiology* **67** 1319–1322

Memmert D, Furley P, 2007 "I spy with my little eye!—Breadth of attention, inattentional blindness, and tactical decision making in team sports" *Journal of Sport & Exercise Psychology* **29** 365–347

Memmert D, Furley P, 2010 "Beyond inattentional blindness and attentional misdirection: From attentional paradigms to attentional mechanisms" *Consciousness and Cognition* **19** 1107–1109

Moraine J J, Lamotte M, Berré J, Niset G, Leduc A, Naeije R, 1993 "Relationship of middle cerebral artery blood flow velocity to intensity during dynamic exercise in normal subjects" *European Journal of Applied Physiology and Occupational Physiology* **67** 35–38

Most S B, 2010 "What's inattentional about inattentional blindness?" *Consciousness and Cognition* **97** 1102–1104

Most S B, Scholl B J, Clifford E R, Simons D J, 2005 "What you see is what you set: Sustained inattentional blindness and the capture of awareness" *Psychological Review* **112** 217–242

Most S B, Simons D J, Scholl B J, Chabris C F, 2000 "Sustained inattentional blindness: The role of location in the detection of unexpected dynamic events" *Psyche* **6**(14), http://www.theassc.org/files/assc/2472.pdf

Neisser U, 1979 "The control of information pickup in selective looking", in *Perception and Its Development: A Tribute to Eleanor J Gibson* Ed. A D Pick (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 201–219

Neisser U, Becklen R, 1975 "Selective looking: Attending to visually specified events" *Cognitive Psychology* **7** 480–494

Newby E, Rock I, 1998 "Inattentional blindness as a function of proximity to the focus of attention" *Perception* **27** 1025–1040

Obrig H, Hirth C, Junge-Hülsing J G, Döge C, Wolf T, Dirnagl U, Villringer A, 1996 "Cerebral oxygenation changes in response to motor stimulation" *Journal of Applied Physiology* **81** 1174–1183

Paas F G W C, Adam J J, 1991 "Human information processing during physical exercise" *Ergonomics* **34** 1385–1397

Schmidt R A, 1988 *Motor Control and Learning. A Behavioral Emphasis* 2nd edition (Champaign, IL: Human Kinetics)

Simmons J P, Nelson L D, Simonsohn U, 2011 "False-positive psychology: Undisclosed flexibility in data collection and analysis allows presenting anything as significant" *Psychological Science* **22** 1359–1366

Simons D J, Chabris C F, 1999 "Gorillas in our midst: Sustained inattentional blindness for dynamic events" *Perception* **28** 1059–1074

Soya H, Mukai A, Deocaris C C, Ohiwa N, Chang H, Nishijima T, Fujikawa T, Togashi K, Saito T, 2007 "Threshold-like pattern of neuronal activation in the hypothalamus during treadmill running: establishment of a minimum running stress (MRS) rat model" *Neuroscience Research* **58** 341–348

Strayer D L, Drews F A, Johnston W A, 2003 "Cell phone induced failures of visual attention during simulated driving" *Journal of Experimental Psychology: Applied* **9** 23–32

Tomporowski P D, 2003 "Effects of acute bouts of exercise on cognition" *Acta Psychologica* **112** 297–324

Tomporowski P D, Ellis N R, 1986 "The effects of exercise on cognitive processes: A review" *Psychological Bulletin* **99** 338–346

Viru A, Viru M, 2000 "Nature of training effects", in *Exercise and Sport Science* Eds W E Garett, D T Kirkundall (Philadelphia, PA: Lippincott Williams & Wilkins) pp 67–95

Yamaji K, Miyashita M, Shephard R J, 1978 "Relationship between heart rate and relative oxygen intake in male subjects aged 10 to 27 years" *Journal of Human Ergology* **7** 29–39