Attentional and perceptual capabilities are affected by high physical load in a simulated soccer decision-making task

Abstract

In a sport-specific decision-making task, we investigated whether different intensities of physical load have different effects on soccer players' decision making, visual attention, and perception. Under a rest condition as well as under physical exercise conditions of 70% (Moderate Load) and 90% (High Load) of their heart rate reserve, participants ($N = 30$) performed a soccer-related decision-making, a feature-recognition and an object-detection task in front of an immersive screen. Stimuli were displayed across a range of 0 to 180 degree visual angles. Results showed that decision-making performance decreased with increasing visual angles but was not negatively affected by physical demands. However, perceptual and attentional capabilities remained constant in the Moderate Load condition and deteriorated in the High Load condition compared to the rest condition. Furthermore, in the High Load condition, perceptual capabilities decreased more drastically with increasing visual angles compared to the other conditions. The findings show that high physical load affects attentional and perceptual capabilities more than moderate physical load, while decision-making performance does not differ in both conditions.

Keywords: object-detection; feature-recognition; physical load; sport expertise; training

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In order to be successful, athletes must rapidly perceive the positions and movements of teammates and opponents as well as the ball, attend to the most relevant features of the match, and make correct decisions (Hüttermann, Ford, Williams, Varga, & Smeeton, 2019; Klatt & Smeeton, 2020). In different sport situations, especially in most team sports, athletes are usually required to rapidly make these complex decisions under time pressure and high physical demands (Zurutuza, Castellano, Echeazarra, & Casamichana, 2017). In order to investigate this area of research, some studies have examined the effects of physical exercise on sport athletes' overall decision-making performance (e.g., Hepler, 2015). Others have investigated components of decision making such as the link between physical exercise and attentional performance in athletes (e.g., Pesce, Cereatti, Casella, Baldari, & Capranica, 2007) and the relationship between physical exercise and perceptual performance (e.g., Swart, Lindsay, Lambert, Brown, & Noakes, 2012). To date, however, there has been no examination of the effect of physical exercise on attentional and perceptual tasks underpinning decision making in sport—a decision that needs to be made rapidly in a complex environment. The aim of the current study, therefore, was to examine the effect of physical exercise on both athletes' attentional and perceptual capabilities in a single sport-specific decision-making task.

Over the last decades, several classes of theoretical models have been proposed to explain the effects of exercise on cognitive performance. One of the most dominant models suggests an inverted U-shape relationship to describe the change in cognitive performance as exercise intensity increases (cf. Yerkes-Dodson Law; Yerkes & Dodson, 1908). A moderate level of exercise usually results in increased physiological arousal and facilitated cognition compared to a rest condition. Furthermore, as soon as physiological arousal approaches a maximum level, cognitive performance often declines (e.g., Chmura, Nazar, & Kaciuba-Uscilko, 1994; McMorris & Graydon, 2000; McMorris, Sproule, Turner, & Hale, 2011). Alternatively, arousal-based models suggest that exercise increases arousal and when the physical load is too high, the demand for resources is beyond the amount available and performance declines as a result (Humphreys & Revelle, 1984; Lambourne & Tomporowski, 2010; Sanders, 1983). However, the inconsistent results from studies makes it difficult to rule out any one model.

Inconsistent results from studies examining the effect of exercise on cognition have been attributed to the type of task (for a review, see Tomporowski, 2003), exercise intensity (e.g., Labelle, Bosquet, Mekary, & Bherer, 2013), duration and mode (e.g., Lambourne & Tomporowski, 2010) as well as sport-specific effects (e.g., McMorris & Graydon, 1997) and expertise and fitness effects (e.g., Hüttermann & Memmert, 2014). Studies that have examined the task performed have shown effects for simple detection tasks (e.g., McMorris and Keen, 1994), visual search tasks (e.g., Aks, 1998; Allard, Brawley, Deakin, & Elliot, 1989), discriminative choice-response tasks (e.g., Arcelin, Brisswalter, & Delignières, 1997; Delignières, Brisswalter, & Legros, 1994), and complex problem-solving tasks (e.g., McMorris et al., 1999; Tenenbaum, Yuval, Elbaz, Gar-Eli, & Weinberg, 1993). For example, Lambourne, Audiffren, and Tomporowski (2010) showed that a sensory detection task performance was facilitated during 40 minutes of exercise at 90 % below ventilatory threshold compared to rest performance. No change was found for a cognitive task during exercise. These results suggest that steady state exercise at an intensity below ventilatory threshold influences sensory but not central executive task function. Whilst these experimental designs offer experimental control, they do not replicate the physical demands (i.e. intermittent exercise) of sports that require complex decisions to be made.

There are some studies that have investigated physical exercise effects on cognition in sport-specific situations. McMorris and Graydon (1996) investigated the impact of physical exercise on a visual information processing and searching in a decision-making task in soccer. Experienced soccer players exercised at 70 % or 100 % of their maximum power output and made decisions in comparison to rest. They found that maximal exercise facilitated visual search and speed of ball detection was faster during exercise. Additionally, Royal et al. (2006) found that sport-specific tests of decision making during a very high fatigue (high exercise intensity) condition facilitate decision making, but not motor performance, in water polo. Especially in fast-paced team sports, such as water polo and soccer, well-developed visual and attentional skills are required to enable players to make the right decisions under time pressure. In a recently published study by Hüttermann, Smeeton, Ford, and Williams (2019), these visual and attentional skills were examined in one sport-specific test. The authors developed a soccer-specific task to examine decision making as a function of attentional and perceptual capabilities. Stimuli in the form of pairs of soccer players were briefly presented across a range of visual angles on a large immersive screen (radius of 3m). Participants were required to decide to whom to pass the ball to while their perceptual and attentional skills on this task were assessed. Results showed attentional performance was poorer than perceptual performance when stimuli were presented across wider viewing angles (cf. Hüttermann, Ford et al., 2019 for similar results concerning the same soccer-specific task as well as Hüttermann and Memmert, 2017 for a general distinction between attentional and perceptual skills). What is unclear is how perceptual and cognitive processes involved in sport-specific decision making are influenced by high physical loads often experienced when playing sports.

The physical load of elite soccer players during games has been well-described (e.g., Sarmento et al., 2014). Various studies included both acceleration and metabolic variables (e.g., Dalen, Ingebrigtsen, Ettema, Havard, & Wisløff, 2016; Osgnach, Poser, Bernardini, Rinaldo, & Di Prampero, 2010; Russell et al., 2014). Soccer involves intermittent sprinting activity and, whilst there are positional and time-of-game-specific differences, there are periods of high, medium, and low intensity activity separated by active and passive recovery periods (Bradley et al., 2009). The effect of subjecting athletes to physical loads with short duration periods on decision making has not yet been examined in detail. The aim of the current study, therefore, was to explore the effect of short duration periods of moderate and high physical loads on soccer players' performance in the sport-specific decision-making task validated by Hüttermann, Smeeton, and colleagues (2019). In this task, participants are required to judge two stimuli equidistant to the centre of an immersive screen at their left and right body side with varying visual angles between the stimuli. Each stimulus consists of a player configuration of one teammate and a maximum of three opponent players. Participants then have to decide on whether and where to pass the ball (decision-making task), they also have to perceive the movement direction of their teammates (feature-recognition task), and they have to recognize the number of opponent players surrounding their teammates (object-detection task). While the object-detection task requires the differentiation between jersey colours (recognition of number of players wearing white jerseys), the feature-recognition task requires the differentiation between colour and shape of stimuli (recognition of players wearing black jerseys and assessment of their running direction) thereby, demanding more visual attention (cf. Hüttermann, Ford et al., 2019). In order to present the game situations in a realistic size in foveal and peripheral vision a 210° immersive dome with a radius of 3m was used (cf. Klatt & Smeeton, 2019). Participants performed the decision-making task at rest, at a moderate, and at a high physical load condition. Based on previous findings showing a link between physical exercise, visual (e.g., McMorris & Graydon, 1997) and attentional performance (e.g., Hüttermann & Memmert, 2014) as well as decision making (e.g., Hepler, 2015; Paradis, Larkin, & O'Connor, 2016), we assumed that athletes' perception (Lambourne et al., 2010), visual attention (Hüttermann & Memmert, 2014), and decision making (Royal et al., 2006) in the soccer-specific task would be affected by changes in the physical load. More precisely, we expected changes to task performance to be seen between moderate exercise load (70% of heart rate reserve) and high exercise load (90% of heart rate reserve), and compared to the rest condition.

Method

Sample size estimation

Based on previous research examining the attentional window and decision making in sport (Hüttermann, Ford et al., 2019; Hüttermann, Smeeton et al., 2019; Klatt & Smeeton, 2020), a minimum sample size of 28 was calculated using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009). This calculation was based on the main effect of visual angle in these previous studies having a median effect size (η^2) of .623 and a 50% attenuation of this variable under different exercise loads being predicted.

Participants

Altogether, 30 participants (6 female) aged 19 to 28 years (M_{age} = 23.97 years, *SD* = 2.34 years) took part in the experiment. Data from three additional participants had to be excluded because one had muscular problems restricting the exercise performance during the task, one had circulatory problems, and one did not reach the chance level threshold for performance in any of the tasks. According to self-reports, all other participants were healthy, and physically active. Twenty-six participants were active soccer players and reportedly participated in competitions regularly (e.g., in the English national league, national league south, southern league), the other four also had previous experience in playing soccer for at least ten years. (Experiences in soccer for at least ten years were provided in order to take part at the study.) Overall, participants had played soccer for 12.00 years (*SD* = 1.76 years). At the time of the data collection, they trained for an average of 9.87 hours (*SD* = 2.08 hours) on the soccer field per week. Twenty-three players reported to usually prefer kicking with their right leg/foot and seven players with their left leg/foot. Furthermore, participants reported normal or corrected-to-normal (with contact lenses) vision—this was another prerequisite in order to take part. The study was carried out in accordance with the Helsinki Declaration of 1975, and written informed consent was obtained from each participant prior to testing. Approval was obtained from the lead institution's ethics board.

Materials and Procedure

Participants were tested individually in a laboratory room. They sat on a cycle ergometer (Wattbike Pro Indoor Trainer®) at a distance of 3m from the centre of a 210° curved projection screen (IGLOO, radius of 3m, height: 2.20m; see Figure 1). They wore a heart rate monitor (Polar A300®), and their heart rate as well as cadence were continuously monitored during the whole testing period. Participants carried out the soccer-specific decision-making task developed by Hüttermann, Smeeton et al. (2019) at three different exercise loads in a randomized order: rest, moderate, and high—i.e. one third started with the rest condition, one third with the moderate, and one third with the high load condition. Instructions were delivered on the screen, and participants were given the opportunity to ask questions prior to starting the experiment.

Physical load. Previous research has reported that the mean duration of each 'purposeful' movement in soccer lasts about 13s, while the mean time between 'purposeful' movements is 20s (all spent on a low intensity level). This finding demonstrated a mean ratio of 1:1.6. (Note though that this ratio is not to be confused with the 'physiological work: rest' - ratio, because some purposeful movements also included low intensity movements (Bloomfield, Polman, & O'Donoghue, 2007)). In accordance with previous research examining the effects of moderate-and high-intensity exercise on cognitive performance (e.g., Smith et al., 2016), we determined the resting heart rate (HR_{rest}) as well as the maximum heart rate (HR_{max}) for each participant to calculate 70 % and 90 % of the individual heart rate reserve (HRR) before the implementation of the soccer task. HR_{rest} was obtained while the participant was lying down in a supine position and wearing the heart rate monitor in a quiet room for 3 minutes. For male participants the HR_{max} was estimated as 220 minus their age; for female participants the HR_{max} was estimated as 226 minus their age (Beashel, Sibson, & Taylor, 2001). Afterwards, we calculated HRR as the difference between HR_{max} and HR_{rest}. Using the Karvonen formula (cf. Karvonen, Kentala, & Mustala, 1957), we calculated the exercise heart rates at 70 % and 90 % target load (e.g., Exercise HR = 70 (HR_{max} - HR_{rest}) + HR_{rest}). Previous research has shown that this calculation gives an exercise intensity that is equivalent to the desired percentage of VO_2R (maximal oxygen uptake reserve, i.e. the difference between resting and maximal VO_2; Swain & Leutholtz, 1997).

The Borg's (1970) scale was used as an additional rating of perceived (subjective) exertion (RPE) and was indicated by each participant after each of the three test conditions. It is a scientifically validated method for estimating feelings of exertion. On this scale physical exertion can be rated on a range that varies from 6 (no exertion at all) to 20 (maximal exertion). Participants were asked to rate their perceived exertion based on the strain on and the fatigue of their musculature as well as their breathlessness (or shortness of breath). In order to familiarise the participants with the magnitude of the values on the RPE scale, they were given the following verbal 'anchors' - number 9 corresponds with very light effort/exertion, for example, normal walking at one's preferred pace - 13 on the scale indicates that the task is somewhat exhausting, but one could continue the task at the current level of load rather easily - 15 is strenuous and difficult, but one could still continue - 17 signifies that the level of physical load is very exhausting and that continuation is still possible, but one would have to exert great effort and would be fatigued within a short time. Participants were asked to indicate their RPE as honest as possible and without pondering.

The increasing HR (70% and 90% of individual HRR) were achieved by incrementally increasing the resistance of the cycle ergometer until participants reached their individually required target heart rates. Participants warmed up for a period of 5min. After the respective target heart rates were reached, the soccer task started while participants continued their exercise. The experimenter constantly ensured that participants stayed at their predetermined target heart rates during the presentation of the trials (+/- 3 bpm). In between the trials participants were allowed to reduce the level of physical load, and therefore their heart rate, for a few seconds (while ensuring that they would reach their required target heart rate after a maximum of 20 seconds—based on the previously described mean ratio between physical load and rest duration in soccer games, see Bradley et al., 2009; a watch with a second hand was visible for the participants), before they had to return to their target heart rate to judge the next game situation.

Soccer-specific decision-making task. The task was presented using Delphi XE 3. Participants completed the soccer-specific task under each of the three different physical load conditions (rest, moderate load, high load) in randomized order. In each of the three conditions, participants performed 24 trials, preceded by 2 additional practice trials. A central fixation cross (1000ms) appeared at the beginning of each trial. Two stimuli were subsequently presented for 300ms equidistant from and on opposite sides of the fixation cross (see Figure 2). Stimuli were randomly presented at one of eight horizontal visual angles from the participant’s view (20°, 40°, 60°, 80°, 100°, 120°, 140°, 160°) and were equally likely to appear at each visual angle. Each stimulus consisted of different player configurations (the players’ height was approximately 30cm) including one teammate being randomly surrounded by zero, one, two, or three opposing players. The teammates’ body postures indicated the direction they were moving to (either towards the centre of the pitch or towards the sideline, i.e. the centre or the outer end of the screen, respectively). The opposing players always moved towards the respective teammate on each of the participant's sides.

In each trial, participants were required to imagine they were the player in possession of the ball and to decide whether it would be best to pass the ball to one of the teammates or to stop/control the ball. The challenge was to only pass the ball to the left or right side if they perceived a teammate who was running in their direction (towards the centre) and was not surrounded by any opponent players. In contrast, participants should decide to not pass the ball when a teammate was running towards the sideline and/or was surrounded by at least one opponent player. Participants were asked to verbally report their decision (pass to the left, pass to the right, no pass) as fast as possible, but at least within a time limit of 3sec (otherwise the trial was considered a mistake). Afterwards, they had to specify the teammates' running directions for each side and the number of opponent players surrounding each teammate. (Note: Each stimulus had to be considered independently as the number of opponent players and the running direction of teammates could differ for each side. In Figure 2, for example, teammates were surrounded by two opponent players at both sides, but while the teammate at the left side was running towards the center, the teammate at the right side was running towards the sideline.).

Data analysis

In total, we analysed main task performance (accuracy rate) by summing up the trials in which all three subtasks were solved correctly (i.e. the decision-making task, the feature-recognition task, and the object-detection task; performance was also calculated for each of the three subtasks separately). For the main task and for each subtask we conducted an 8 x 3 repeated measures analysis of variance (ANOVA) with visual angle (20°, 40°, 60°, 80°, 100°, 120°, 140°, or 160°) and exercise load (rest, 70% of individual HRR, 90% of individual HRR) as the within-participant factors and accuracy rate (performance) in the respective task as dependent variable. When Mauchly's test revealed violations of the sphericity assumption for any of the variables, we used adjusted degrees of freedom based on the Greenhouse-Geisser correction. In the feature-recognition and object-detection task, responses were only treated as correct when participants reported the correct answer for stimuli at both sides (left, right).

Results

Physical load. Overall, we measured a mean resting heart rate (HR_{rest}) of 64.37 bpm (*SD* = 4.27 bpm) and calculated a mean maximum heart rate (HR_{max}) of 197.30 bpm (*SD* = 2.28 bpm). Using the Karvonen formula, we calculated a mean exercise heart rate of 157.42 bpm (*SD* = 2.30 bpm) at 70 % target HR and of 184.01 bpm (*SD* = 2.20 bpm) at 90 % target intensity. The subjective Borg rating was significantly different between the high (*M* = 18.17, *SD* = 0.75) and moderate (*M* = 13.87, *SD* = 0.90) load levels, $t(29) = 23.842$, $p < .001$, $d = 4.353$.

Total score. The total percentage of correct responses, in which all three tasks (decision-making task; feature-recognition task; object-detection task) were answered correctly, averaged across all three exercise conditions, was 43.33% (*SD* = 7.26%; see Figure 3)[1]. The ANOVA revealed a main effect of visual angle, $F(4.307,124.902) = 36.011$, $p < .001$, $\eta^2 = .554$, $\varepsilon = .615$ (Mauchly's test of sphericity: $\chi^2(27) = 64.293$, $p < .001$), demonstrating that accuracy decreased with increasing visual angles. There was a significant effect of exercise load (rest: *M* = 44.86%, *SD* = 14.25%; 70 % HRR: *M* = 47.08%, *SD* = 13.14%; 90 % HRR: *M* = 38.06%, *SD* = 9.95%), $F(2,58) = 4.193$, $p = .020$, $\eta^2 = .126$, $\varepsilon = .631$; we performed follow-up comparisons (Bonferroni corrected adjusted alpha of 0.017) indicating that participants performed better under moderate exercise load, compared to the high load condition, $t(29) = 2.863$, $p = .008$, $d = .523$, with no difference between moderate load and rest condition, $t(29) = 0.729$, $p = .472$, nor between the rest and high load condition, $t(29) = 1.930$, $p = .063$. Furthermore, the ANOVA did not reveal a significant interaction between visual angle and exercise load, $F(8.835,256.201) = 0.980$, $p = .456$ (Mauchly's test of sphericity: $\chi^2(104) = 135.677$, $p = .029$).

Decision-making subtask. In total, participants made the correct decision (pass to the left, no pass, pass to the right) in 91.16 % (*SD* = 4.47 %) of the trials averaged across all exercise loads. Decision-making performance decreased with increasing visual angles between the stimuli (or more specifically remained high until the visual angle was increased beyond a certain point), $F(3.282,95.174) = 34.748$, $p < .001$, $\eta^2 = .545$, $\varepsilon = .469$ (Mauchly's test of sphericity: $\chi^2(27) = 130.849$, $p < .001$). Participants performed comparably well under all three exercise loads, $F(2,58) = 1.962$, $p = .150$. We did not find a significant interaction between angle and exercise load, $F(6.020,174.566) = 1.586$, $p = .154$, $\varepsilon = .430$ (Mauchly's test of sphericity: $\chi^2(104) = 259.109$, $p < .001$).

Feature-recognition subtask. A correct response in a trial in the feature-recognition task required accurate reporting of the running direction of the teammates at both sides of the participant's visual field. In total, participants correctly identified the running direction of both teammates in 52.36 % (*SD* = 6.10 %) of all trials. The ANOVA revealed a significant main effect for visual angle $F(4.532,131.439) = 19.715$, $p < .001$, $\eta^2 = .405$, $\varepsilon = .647$ (Mauchly's test of sphericity: $\chi^2(27) = 47.985$, $p = .008$), again indicating a decline of performance with increasing angles. In addition, participants differed in accuracy across the three exercise loads, $F(2,58) = 4.352$, $p = .017$, $\eta^2 = .130$ (see Figure 4). In the feature-recognition task, participants attained highest success rates at moderate load (*M* = 55.97%, *SD* = 12.22%) compared to the high load condition (*M* = 47.36%, *SD* = 9.57%), $t(29) = 2.849$, $p = .008$, $d = .520$, with no difference between moderate and rest condition (*M* = 53.75%, *SD* = 12.10%), $t(29) = 0.731$, $p = .471$, nor between rest and high load condition, $t(29) = 2.110$, $p = .044$ (Bonferroni corrected adjusted alpha of 0.017). Furthermore, the ANOVA did not reveal an interaction effect for visual angle and exercise load, $F(8.785,254.756) = 0.623$, $p = .773$, $\varepsilon = .627$ (Mauchly's test of sphericity: $\chi^2(104) = 132.743$, $p = .042$).

Object-detection subtask. A response in a trial in the object-detection task was considered correct only if participants reported the accurate number of opponent players for both sides. In total, participants attained an accuracy rate of 78.29 % (*SD* = 11.68 %) across all trials. There was a main effect for visual angle, $F(3.613,104.767) = 44.893$, $p < .001$, $\eta^2 = .608$, $\varepsilon = .516$ (Mauchly's test of sphericity: $\chi^2(27) = 67.992$, $p < .001$), pointing out that participants' accuracy decreased from the centre to the periphery. Moreover, the ANOVA revealed a main effect of exercise load, $F(2,58) = 12.622$, $p < .001$, $\eta^2 = .303$ (see Figure 5). Participants performed worse under high load (*M* = 69.17 %, *SD* = 8.93 %), compared to moderate load (*M* = 83.89 %, *SD* = 17.39 %), $t(29) = -4.337$, $p < .001$, $d = .792$, and to the rest condition (*M* = 81.81 %, *SD* = 18.13 %), $t(29) = -3.518$, $p = .001$, $d = .642$, with no difference between moderate load and rest condition, $t(29) = 0.869$, $p = .392$ (Bonferroni corrected adjusted alpha of 0.017). We found a significant interaction between exercise load and visual angle, $F(7.593,220.185) = 11.046$, $p < .001$, $\eta^2 = .276$, $\varepsilon = .753$ (Mauchly's test of sphericity: $\chi^2(104) = 195.736$, $p < .001$). The decline in performance, as a result of increasing visual angles, became more pronounced in the high load compared to the rest or moderate load conditions (see Figure 3).

Discussion

This study investigated the impact of physical load on soccer players' perceptual and attentional capabilities as well as on their decision making in soccer game situations. In support of our predictions, the total performance in the soccer-specific task (i.e., the conjunction of the feature-recognition, object-detection, and decision-making tasks) confirms previous study results, in that performance in complex tasks can be influenced through different physical loads placed upon athletes (e.g., McMorris et al., 1999; Royal et al., 2006; Tenenbaum et al., 1993).

Whilst no differences in physical load condition were observed in the decision-making task, there was a decline in feature-recognition performance at the high exercise load compared to the moderate load condition and a decline in object-detection performance was found at the high exercise load condition only when stimuli presentation exceeded 120 degrees of visual angle. It is clear that when physiological arousal approaches a maximal level though performance declines.

Apart from the total performance in the soccer-specific task, we analysed participants' performances in the separate subtests (decision-making, feature-recognition, object-detection), in order to understand how different dimensions of decision-making performance were influenced by the physical load conditions. The results suggest that athletes' visual attention and perception capabilities were affected by changes in physical exercise load. Overall, performances was higher in the moderate (70 % of HRR) compared to the high load condition (90 % of HRR) but not compared to the rest condition. This pattern of findings was consistent for attentional and perceptual capabilities. However, the moderate load condition did not result in higher levels of performance than the rest condition resulting in a performance-load curve that does not strictly comply with an inverted-U shape.

But although athletes' attentional and perceptual capabilities were affected—at least partially—by physical exercise loads, we did not find an impact on their sport-specific decision-making performance. On the one hand, this result supports the findings of previous studies that physical load does not impact the quality of the final decision (e.g., Hepler, 2015; Paradis et al., 2016). It appears that while it is not possible to perceive all information in the peripheral field in detail (e.g., the positioning or running direction of players), decision making is not negatively affected (cf. Olde Rikkert et al., 2015) at least those decisions that have been required in the decision-making task. However, on the other hand, there are also contradictory findings reporting a positive effect of physical exercise on decision making (e.g., Royal et al., 2006; Tenenbaum et al., 1993). For example, Tenenbaum and colleagues (1993) observed improved accuracy of decision making in handball players during aerobic exercise (11-12 METS). It is difficult to draw clear conclusions as to why there are contradictory findings because the exercise protocols do not compare exactly across studies. However, findings may be attributed to different psychological tasks used in the different studies and experiences in making decisions during exercise. Tenenbaum et al. (1993) used generic tests of short-term memory general intelligence, attentional style, and concentration. In the present study, sport-specific stimuli were used and the decision-making task to choose the correct opponent to pass to, matched the experience of the participants. In fact, sport specific experience improved psychological task performance in the Tenenbaum et al. (1993) study. The answer to the question of why improvements in performance were seen in Tenenbaum et al. (1993) and not here could be attributed to order effects, which were not controlled for in the exercise condition in Tenenbaum et al. (1993). Therefore, there may have been a warm-up effect on the psychological tasks confounded performance in the exercise conditions. In this study, exercise load was counterbalanced and tasks differed. However, it should be considered that attentional processes in real soccer game situations are oftentimes more complex than the challenge to decide whether to pass the ball to the left, to the right, or whether to control it/not pass at all. Considering these and further factors, future studies should investigate the influence of physical load on the decisional behaviour of athletes as a function of task specificity and complexity.

Differences in performance were found between the high and moderate load conditions in the feature-recognition and object-detection task. The high load condition was chosen to extend previous research by Hüttermann and Memmert (2014), who showed an inverted-U relationship between the intensity of physical load and cognitive performance for non-athletes, and a linear relation for athletes. However, intensities were 50, 60, and 70 % of the age-dependent predicted maximal heart rate. The linear relationship between exercise intensity and visual attention was explained by the fact that an intensity level of 70 % was rather a moderate than a high intensity for trained athletes; and it was assumed that higher intensities may lead to a decline in performance. Participants in the current study performed the decision-making task with 70 % and 90 % of heart rate reserve, as well as under rest. It was found that perceptual and attentional performance declined at the highest load. As participants reported RPE values of 14 for 70 % exercise HRR and 18 for 90 % exercise HRR on the Borg scale ranging from 6 (no exertion at all) to 20 (maximal exertion), we can assume that the targeted intensity levels were reached. It remains a task for future studies to test to what degree the performance in the soccer-specific task can be influenced by different intensities of physical load as a function of the performance- and fitness-levels of participating athletes. Further, the physical load ratios could be adapted according to the divisions the athletes are active in.

An interaction between visual angle and physical load was found in the object-detection subtask but not in the other subtasks. Performance in this task declined more rapidly in the 120 degree visual angle condition in the 90 % physical load condition than in the 70 % condition and more rapidly in both 70 % and rest conditions for visual angles greater than 120 degrees. This result was not expected, and any attempted explanation, therefore, has to be considered as a post-hoc rationalisation. This finding supports the assumption that the object-detection subtask has elements that are independent of the other two tasks because this interaction was not found in the decision-making or the feature-recognition subtask. However, the authors are not aware of any literature to help explain why exercise at a high load differentially affected the object-detection subtask, but not the feature-recognition or decision-making subtasks. Potentially, this interaction effect in the subtask might also be explained by increases in statistical power. Alternatively, in contrast to decision-making or attentional processes, perceptual processes in the extremities of the peripheral vision may be differently affected by exercising at high intensity than in other parts of the visual field. However, systematic, hypothesis-driven, future research is needed to provide an evidence-based explanation of this finding.

The current study does not come without limitations. To simulate the changing load intensities found in soccer match-play (cf. Bloomfield et al., 2007), participants were required to maintain their target heart rate from onset of the presentation of each trial until their ratings/responses for the respective game situation. Subsequently, they were given a few seconds to reduce the load at their own discretion (however, they had to continue pedalling), before returning to their target heart rate and being presented with the next game situation. Participants used the time between the trials in different ways, meaning some participants reduced the load intensity more than others did. Even though load levels also vary among different players in real soccer games, future studies should try to achieve a better comparability of results by predetermining a standardized load level for the breaks between the trials. Nevertheless, it should be noted here that a cessation of exercise of a few seconds (after the 20 seconds participants had to reach the required target heart rate), in between the predetermined loads, is a relatively short time period, during which no great changes in the participants' heart rates were seen compared to the predetermined target heart rate.

In the current study, decision making was analysed as the accuracy of decisions, i.e., we measured the quality of decisions, but not the speed of decision making. As previous studies have found no impact of physical arousal on the quality but on the speed of decision making (e.g., Hepler, 2015), the integration of a reaction time measure might be a potential avenue for future research. Another potential avenue of investigation could involve further manipulations of the task demands, such as the integration of dynamic game scenes (e.g., moving and looming stimuli) instead of static pictures. In the current study, participants performed the decision-making task while bicycling on an ergometer, although treadmill running would better correspond to the natural demands on soccer players. (In addition, it took some time until every participant was able to finally reach the 90 % exercise HRR using the bicycle ergometer.) Future research should search for alternatives ensuring both the safety of the participants (this may indeed be a problem using a treadmill) and the possibility of exercising at high intensities.

Although decision-making performance did not decrease with high exercise load, it would be interesting to train the players' cognitive skills under physical load in future research in order to investigate whether this training would have a positive effect on the players' decision making in soccer (see Alder, Broadbent, Stead, & Poolton, 2019, for a study in badminton). There is research demonstrating training approaches for visual attentional capabilities (e.g., Hüttermann & Memmert, 2018), perceptual attentional capabilities (e.g., Swart et al., 2012), and decision making (e.g., Hepler, 2015) in sport athletes, however, future research might develop specific programs integrating all of these cognitive skills/tasks in one training.

In summary, the findings of the current study suggest that different physical exercise loads can temporarily affect attentional and perceptual capabilities of sport athletes, but they do not positively or negatively affect their sport-specific decision making. Depending on the complexity of the decision-making process, in future, training possibilities should not only be considered for attentional and perceptual skills, but also, for sport athletes' decision-making skills, in order to train the skills needed to meet the cognitive demands on sportspeople as comprehensively as possible.

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Footnotes

[1] Although this accuracy rate seems to be very low at first sight, it should be considered that a trial was only evaluated as correct when participants made the correct decision and gave correct answers in the feature-recognition and object-detection task—also including situations with visual angles of up to 160°, i.e. lying outside the maximal shift of attention measured in previous research (e.g., Hüttermann, Memmert, & Simons, 2014; Hüttermann, Memmert, Simons, & Bock, 2013).

Figure legends

Figure 1. The figure shows the experimental setup with a subject sitting on the bicycle ergometer in front of the 2.4 x 6.0m IGLOO dome.

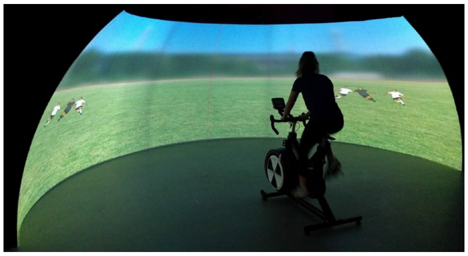

Figure 2. Sequence of events in one exemplary trial.

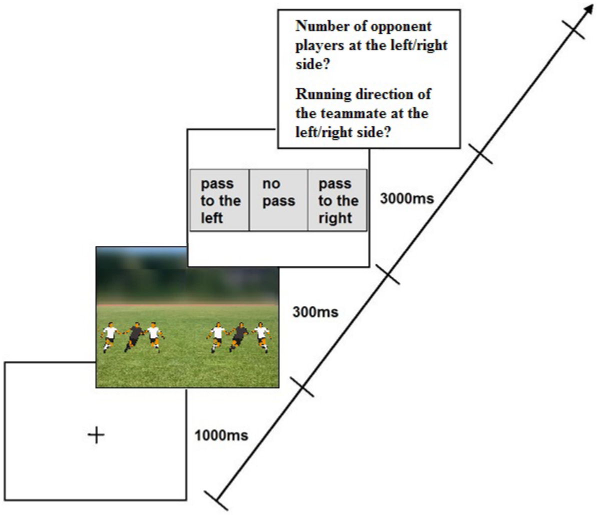

Figure 3. Percentage of participants' total accuracy rates, their decision making, the identification rates of the teammates' running direction, and the identification rates of the number of opponents in the soccer decision-making task, in degrees of visual angle as a function of physical exercise intensity (rest, moderate, high). Symbols represent across-participant means, and error bars show standard deviations. (Note: *p<.017; **p<.001; Bonferroni corrected post-hoc comparisons had an adjusted alpha of 0.017. Y-axis scale adjusted to 120 % to allow plotting of error bars)

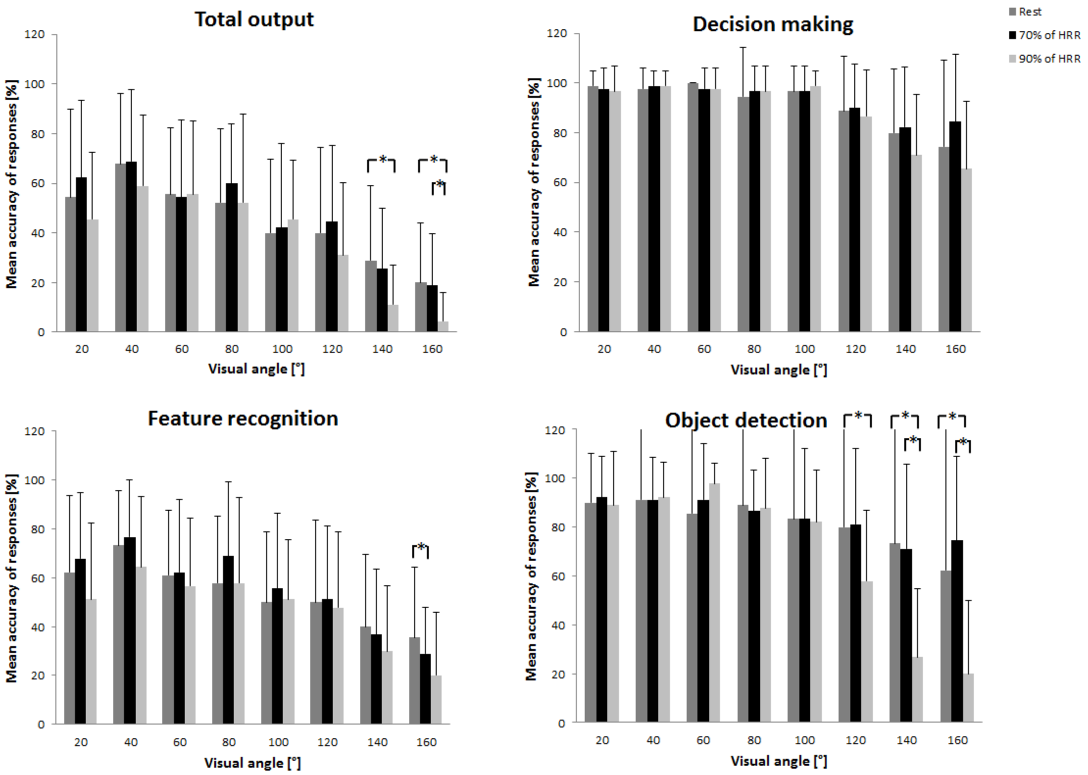

Figure 4. Percentage of participants' accuracy rates in the feature-recognition subtask (identification rate of the teammates' running direction) as a function of physical exercise intensity (rest, moderate, high). Symbols represent across-participant means, and error bars show standard deviations. (Note: **p*<.017; Bonferroni corrected post-hoc comparisons had an adjusted alpha of 0.017.)

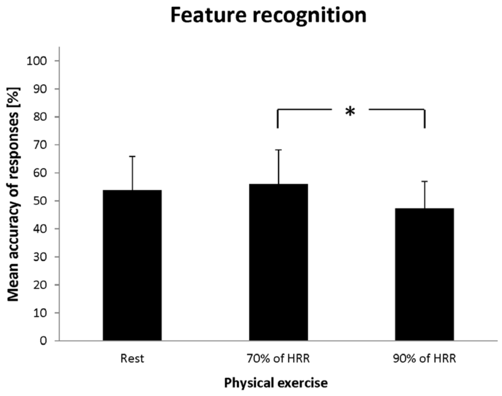

Figure 5. Percentage of participants' accuracy rates in the object-detection subtask (identification

rate of the number of opponents) as a function of physical exercise intensity (rest, moderate, high). Symbols represent across-participant means, and error bars show standard deviations. (Note: **p*<.017; Bonferroni corrected post-hoc comparisons had an adjusted alpha of 0.017.)