Attention, perception, and action in a simulated decision-making task

Stefanie Hüttermann[1], Paul R. Ford[2], A. Mark Williams[3], Matyas Varga[2], & Nicholas J. Smeeton[2]

Abstract

Over the last decade, research on the visual focus of attention has become increasingly popular in psychological science. The focus of attention has been shown to be important in fast team sport games. We developed a method that measures the extent of the attentional focus and perceptual capabilities while performing a sport-specific task. Participants were required to judge different player configurations on their left and right side with varying visual angles between the stimuli. In keeping with the notion that the focus of attention is smaller than the visual field, attentional performance was poorest at wider viewing angles compared to perceptual performance. Moreover, team sport players were better able to enlarge the attentional focus and make correct decisions more frequently than individual athletes, particularly when a motor response was required. The findings provide a new perspective dissociating attentional and perceptual processes that affect decision making under various response modes.

Keywords: focus of attention; visual streams; working memory.

Attention, perception, and action in a simulated decision-making task

There is increasing interest in examining the role of visual attention during performance. In fast-paced team sports, for example, an athlete who has a broader visual focus of attention may make more effective decisions during a match, because more players can be tracked and monitored, facilitating access to the key information underpinning decision making (e.g., Williams, Davids, & Williams, 1999). Several different paradigms have been used to determine the breadth of visual attention, including, among others, the ‘useful field of view task’ (Wolfe, Dobres, Rosenholtz, & Reimer, 2017) and the ‘attention window task’ (Hüttermann & Memmert, 2017). Visual-perceptual and cognitive differences have been revealed between experts and novices within a sport (e.g., Mann, Williams, Ward, & Janelle, 2007, Voss, Kramer, Basak, Prakash, & Roberts, 2010), as well as between athletes from different sports (e.g., Hüttermann, Memmert, & Simons, 2014). Yet, there appears to be some transfer of decision making across sports that share similar constraints on cognitive processes, such as the number of players involved (e.g., Smeeton, Ward, & Williams, 2004) and the nature or type of activity engaged in across invasion-type sports (e.g., Roca & Williams, 2017). However, the underlying mechanisms by which transfer occurs are not yet clear. Potentially differences in the attentional capabilities developed through participation may underpin decision making more positively than individual sports participation. In this study, we developed a method that can be used to determine visual attentional and perceptual capabilities while performing a sport-specific decision-making task.

The need to make quick and accurate decisions is integral to expert performance, particularly in team sports (e.g., Raab, 2003). In such dynamic environments, the correct decision is informed by numerous factors (e.g., number of involved players), as well as existing time pressure (Tenenbaum & Bar-Eli, 1993). In various experimental tasks, there is some evidence that the response mode (e.g., verbal or motor response) influences decision-making performance in temporally demanding tasks (e.g., Farrow & Abernethy, 2003; Williams, Ward, Smeeton, & Allen, 2004). While computer-based tasks normally require participants to respond verbally or by pressing a button, representative task designs or in-situ research can require movement (motor) responses to presented stimuli. Sport-specific response modes in experimental tasks are suggested to maintain the important links between perception and action that are formed during previous experience on the task (Mann, Abernethy, & Farrow, 2010). Specifically, two visual streams are thought to pick up information for different purposes; the dorsal stream picks up visual information for the online control of movements, referred to as 'vision for action', whereas the ventral stream detects and gathers knowledge from the environment, referred to as 'vision for perception' (Goodale & Milner, 1992; Milner & Goodale, 1995). A failure to maintain perception-action coupling by using, for example, verbal responses in experiments has been argued to increase the chances of engaging the ventral visual processing stream in the brain, rather than the dorsal processing stream (van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008).

In association football, players often have to decide whether or not to pass the ball (e.g., to their left or right side), or to stop and control the ball. In order to make the best decision, players are required to perceive multiple spatially separated moving objects (e.g., teammates, opponents, the ball) simultaneously and to make judgements about these within fractions of seconds. Some of these objects in the environment behave in complex ways and necessitate that players focus attention on teammates and opponents, while simultaneously necessitating more fundamental perceptual processes such as judging the colour of a player's jersey to check whether a player is a teammate or opponent (Hüttermann, Smeeton, Ford, & Williams, 2019).

The focus of attention is typically allocated across part of the visual field (cf. Intriligator & Cavanagh, 2001). Visual attention can be characterised as a prerequisite for conscious recognition of information, that is, people only consciously perceive those stimuli/processes onto which they focus their attention at a given time (Dehaene, Changeaux, Naccache, Sackur, & Sergent, 2006). Although the attentional focus is significantly smaller than the human visual field, researchers have shown that its size can be changed depending on different factors such as age, physical workload, motivation, or expertise (Hüttermann, Bock, & Memmert, 2012; Hüttermann & Memmert, 2014, 2015; for a review, see Hüttermann & Memmert, 2017). An approach used to measure maximal attentional shifts at any given time is the 'attention-window task' developed by Hüttermann, Memmert, Simons, and Bock (2013). This task determines the maximum ability of an individual to spread visual attention peripherally when two stimuli must be perceived simultaneously. Previously, researchers have found performance differences between athletes across different sport disciplines (cf. Hüttermann et al., 2014).

In this paper, we build upon the work of Hüttermann et al. (2014, 2018) by developing a sport-specific task that required athletes to use attention in more realistic game situations that necessitated perception and decision making. A representative task design enabled us to investigate whether the required response mode (verbal or motor) affects attentional and perceptual capabilities, as well as decision making. In our sport-specific task, participants had to make a decision (once verbally and once using a sport-specific motor response) where to pass a ball (decision-making task), to perceive the movement direction of their teammates (attentional task), and to recognize the number of opponent players surrounding their teammates (perceptual task). Participants were required to judge two stimuli (formation of one teammate and a maximum of three opponent players in each stimulus) equidistant to the centre of an immersive screen on their left and right body side with varying visual angles between the stimuli. The perceptual task required recognition of the number of opponent players (0-3), that is, participants had to differentiate between the jersey colour of teammates and opponents to perform this perceptual task. While this task was a recognition task, the attentional task required both the recognition of teammates (a differentiation between jersey colours) as well as an assessment of their running direction (either to the middle or to the side line) so that it demanded visual attention (cf. as proposed by feature-integration theory, see Treisman & Gelade, 1980). The decision-making task required participants to decide whether or not to pass the ball to an 'open' teammate on their left or right side. We hypothesised that team sport players would be better able to deploy attention widely and the attentional task would be more sensitive to the effects of team sport experience than the perceptual task. Moreover, we predicted that the perceptual task would be more sensitive to the verbal rather than sport-specific response mode. A working memory task was included to control for different basic working memory levels between our groups. For each of the responses (decision making: pass/no pass; attention: movement direction of teammates; perception: number of opponent players), participants were asked to rate how confident they were that their judgments were correct. To validate our measures, we compared performance across team (e.g., football/lacrosse players) and individual sport athletes (e.g., track and field athletes/swimmers) and response modes (verbal/action) to implicate attentional and perceptual processes in skilful decision making. We expected to find higher accuracy rates for decision making and sport-specific judgements in team sport athletes when compared with individual sport athletes.

Method

Participants

Forty participants aged 21 to 37 years (M_{age} = 23.98 years, *SD* = 2.79 years; 29 male, 11 female) took part in the study. Participants reported normal or corrected-to-normal vision (with contact lenses). They had at least 10 years of practice and were considered at least somewhat skilled at their respective sports. Informed consent was obtained from each participant prior to testing according to the Declaration of Helsinki and ethical approval was gained from the lead institution.

Altogether, 20 (4 female) participants were team sport athletes. Their primary sports included basketball (*n* = 3), cricket (*n* = 2), football (*n* = 9), lacrosse (*n* = 2), netball (*n* = 3), and volleyball (*n* = 1). At the time of data collection, participants trained in their team sport an average of 11.00 hours (*SD* = 1.52 hours) per week. A total of four participants reported to normally prefer passing with their left foot and 16 stated the right leg as their preferred leg. The twenty other participants (7 male) were athletes who usually performed individual sports (without a ball) such as fitness training (*n* = 11), running (*n* = 2), dancing (*n* = 2), swimming (*n* = 3), or track and field athletics (*n* = 2). They trained an average of 8.35 hours (*SD* = 2.78 hours) per week in their sport. Five of them indicated the left leg and 15 the right leg as their normally preferred dominant leg.

Materials and Procedure

Participants performed a football-specific decision-making task individually in a laboratory. For the implementation of the football-specific task, they stood approximately 3 m away from a 210° immersive dome (IGLOO Vision ltd, Shropshire, UK, radius of 3m, height: 2.20m; see Figure 1). This projection dome enables a more realistic representation of game situations than a typical flat screen display because stimuli can be presented across a much broader field of view as in real game situations. While in recent years, researchers have debated the advantages and disadvantages of flat and curved displays, especially in the area of reading (e.g., Choi et al., 2015), there has been no research using curved displays in sport.

Football-specific decision-making task. The task was presented using Delphi XE 3. Participants performed two warm up trials and an additional 24 test trials. A trial started with a central fixation cross on screen (1000ms), followed by the presentation of two stimuli for 300ms equidistant from and on opposite sides to the fixation cross (as shown in Figure 2). Each stimulus represented different player configurations (players had a height of about 30cm). A configuration was composed of one teammate of the participant surrounded by zero, one, two, or three opposing players positioned randomly either on the teammate's right or left side. Stimuli were randomly presented at one of eight horizontal distances from the centre. More precisely, each teammate on both sides was presented on the IGLOO within a viewing angle for participants of 20°, 40°, 60°, 80°, 100°, 120°, 140°, or 160°. Each player configuration was equally likely to appear at each visual angle. Figure 3 shows four exemplary trials with the opponent players wearing white jerseys and the teammates wearing black jerseys. While opposing players always faced in the direction towards the respective teammate of the participant, the teammate on both sides could either face in the direction towards the centre of the screen or towards the side lines/outer edge of the screen.

Participants were instructed to imagine they were the player in possession of the ball and had to decide which action they would execute in the respective game situation. If a teammate was running towards the participant and was not surrounded by an opponent, participants should decide to pass the ball in his direction (pass to the left or pass to the right; for example, in the left bottom picture in Figure 3 participants should decide to pass to the right side). If opponents surrounded both teammates and/or they were running towards the side line, participants should decide not to pass the ball to either of them (no pass; Figure 3: right top and both bottom pictures). Reponses were required from participants within a 3 sec time limit from presentation of the stimuli in order to prevent them benefiting from a speed-accuracy trade-off and to replicate the time period a teammate would be available before the situation changed in an actual match. Subsequently, participants were asked to rate the certainty of their response using a ten-point Likert scale ranging from 1 (very uncertain) to 10 (very certain). Afterwards, participants indicated for each side whether the teammate was running towards the centre or towards the side line and how certain/uncertain (ten-point Likert scale) they were about their decision. Finally, participants were asked to specify the number of opponents (0-3) who had surrounded the teammates on the participant's left and right side and to indicate their certainty level (ten-point Likert scale).

In the verbal response condition (Figure 1, upper picture), participants had to verbally report their decision (pass to the left, pass to the right, no pass). In the motor response condition (Figure 2, bottom picture), a ball was placed on the floor in front of the participant on each trial. Participants were required to pass the ball with their preferred foot in the direction of the free-standing teammate either to the right side (cf. Figure 3 left bottom picture), to the left side, or to put their feet on the ball if there was no free teammate moving towards the centre on both sides (cf. Figure 1 and Figure 3: right top and both bottom pictures).

Automated operation span (Aospan) task. The Aospan task was programmed and run using E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA; cf. Unsworth et al., 2005). The Aospan task was carried out sitting within a distance of approximately 50cm in front of a 13-inch display (resolution: 1366 x 768 pixels). Instructions were delivered on the screen prior to the task and participants were encouraged to ask questions to the experimenter prior to starting.

The measure was taken to examine any incidental differences in working memory between groups, which may have affected their responses during the task. Previously, researchers have demonstrated that Aospan is a reliable and valid indicator of working memory capacity (e.g., Redick et al., 2012). In this task, participants were asked to judge the correctness (true versus false) of simple mathematical exercises (e.g., 13-7 = 5) while trying to concurrently remember a series of letters. Participants completed two short practice sessions, one for solving math exercises and the other for remembering letters, before starting the main task. In each trial, participants were asked to solve a math exercise before they were presented with a to-be remembered letter for 1s. Immediately afterwards, another math exercise was to be solved following from a further letter, a math exercise, and so on. After a set of three to seven operation-letter pairs, participants were required to recall all letters from the current set in the correct order by clicking on the letter boards displayed on the monitor. In total, the Aospan task included 15 trials (3 trials each with 3, 4, 5, 6, and 7 letters to memorize). In line with the standard procedure concerning the data evaluation (cf. Unsworth et al., 2005), the Ospan score (measure of participants' working memory capacity) was the sum of letters recalled across all error-free trials. Participants were informed about the necessity to keep their math accuracy at or above 85% at all times. During recall, a percentage in red was displayed in the upper right-hand corner.

Results

The total amount of correct responses in which all three tasks were correct (decision-making task; attentional task; perceptual task) was 35.31% (*SD* = 15.90%)[1] of trials. Performance in the football decision-making task were analysed for the three single involved tasks separately.

Decision-making task. First, we analysed decision making accuracy using a repeated measures analysis of variance (ANOVA) with visual angle (20°, 40°, 60°, 80°, 100°, 120°, 140°, or 160°) and response mode (verbal response, motor response) as the within-participant factors and sport type (individual sport, team sport) as the between-participant factor. Since Mauchly's test revealed violations of the sphericity assumption for both visual angle, $\chi^2(27) = 107.374$, $p < .001$, and response mode x visual angle factors, $\chi^2(27) = 83.219$, $p < .001$, we used adjusted degrees of freedom based on the Greenhouse-Geisser correction. For analyses in which the sphericity assumption was violated, we reported the value of ε from the Greenhouse-Geisser correction. In total, participants made the correct decision (pass to the left, no pass, pass to the right) on 85.83% (*SD* = 10.98%) of trials across both decision-making tasks (verbal and motor response). They did not differ in accuracy across the two tasks (verbal: *M* = 86.56%, *SD* = 11.30%; action: *M* = 85.11%, *SD* = 13.70%), $F(1, 38) = 0.710$, $p = 405$. Decision-making performance decreased with increasing visual angle of stimuli, $F(3.397, 129.101) = 20.655$, $p < .001$, $\eta^2 = .352$, ε = .485. Team sport athletes (*M* = 92.29%, *SD* = 8.14%) outperformed individual athletes (*M* = 79.38%, *SD* = 9.65%), $F(1, 38) = 20.926$, $p < .001$, $\eta^2 = .355$, and sport type (team sport vs. individual sports) significantly interacted with response mode, $F(1, 38) = 10.565$, $p = .002$, $\eta^2 = .218$. Team sport athletes outperformed individual sport athletes in the decision-making task when a motor response was required, $t(38) = 5.799$, $p < .001$, $d = 1.83$, as well as when required to answer verbally, $t(38) = 2.131$, $p = .040$, $d = .674$ (see Figure 4). Table 1 gives an overview of all accuracy rates of team and individual sport athletes as a function of visual angle. We found a significant interaction between visual angle and sport type, $F(3.397, 129.101) = 2.897$, $p = .032$, $\eta^2 = .071$, ε = .485 (see Figure 5), but not for response mode x visual angle, $F(4.255, 161.695) = 0.986$, $p = .420$, ε = .608, or response mode x visual angle x sport type, $F(4.255, 161.695) = 1.312$, $p = .266$, ε = .608. Finally, we found a correlation between confidence ratings (evaluation on a ten-point Likert scale) and accuracy in decision making on the verbal ($r = .755$, $p < .001$) and motor response task ($r = .712$, $p < .001$). While team sport athletes had an average certainty rate of 7.80 (*SD* = 1.26) in the task with verbal response mode, individual athletes reported a lower value of 6.58 (*SD* = 0.52), $t(38) = 3.983$, $p <= .001$, $d = 1.26$. The certainty level differed between groups when a motor response was used (team sport athletes: *M* = 7.95, *SD* = 0.98; individual sport athletes: *M* = 6.32, *SD* = 0.71), $t(38) = 6.001$, $p < .001$, $d = 1.90$.

Attentional task. To analyse accuracy rate for the identification of the running direction of teammates, we conducted a 2 (sport type) x 2 (response mode) x 8 (visual angle) repeated measures ANOVA with the same within-participant and between-participant factors as before. For the factor visual angle, we adjusted degrees of freedom based on the Greenhouse-Geisser correction, $\chi^2(27) = 66.636$, $p < .001$. A correct response in a trial required an accurate report of the running direction of the teammates on both sides. In total, participants correctly identified the running direction of both teammates in about 45.57% (*SD* = 13.43%) of trials. ANOVA revealed a significant main effect for visual angle $F(4.316, 164.000) = 11.511$, $p < .001$, $\eta^2 = .232$, $\varepsilon = .617$. As shown in Table 2, the frequency of errors increased with larger visual angles. The accuracy rate for running direction differed as a function of sport type, $F(1, 38) = 37.149$, $p < .001$, $\eta^2 = .494$. Team sport athletes outperformed individual sport athletes (team sport athletes: *M* = 54.90%, *SD* = 12.06%; individual athletes: *M* = 36.25%, *SD* = 6.46%). Although we did not find a response mode effect, $F(1, 38) = 0.187$, $p = .668$, the effect of sport type varied as a function of response mode, as indicated by a significant interaction, $F(1, 38) = 9.158$, $p = .004$, $\eta^2 = .194$ (see Figure 6): While team sport athletes did not differ in accuracy across tasks, $t(19) = 1.850$, $p = .080$, individual athletes identified more trials correctly in the verbal compared to the motor response task, $t(19) = 2.426$, $p = .025$, $d = 542$. We did not find an interaction effect for visual angle and sport type, $F(4.316, 164.000) = 0.283$, $p = .901$, $\varepsilon = .617$, or for response mode x visual angle x sport type, $F(7, 266) = 1.162$, $p = 325$. Finally, there was a correlation between confidence ratings on their decision and accuracy in the identification of teammates' running direction in the verbal response task ($r = .613$, $p < 001$) and motor response task ($r = .732$, $p < .001$). The confidence levels differed between groups both in the task with verbal response (team sport athletes: *M* = 5.72, *SD* = 1.20; individual sport athletes: *M* = 4.30, *SD* = 0.71), $t(38) = 4.579$, $p < .001$, $d = 1.45$, and with motor response (team sport athletes: *M* = 6.03, *SD* = 1.11; individual sport athletes: *M* = 4.26, *SD* = 0.66), $t(38) = 6.161$, $p < .001$, $d = 1.94$.

Perception task. We conducted a repeated measures ANOVA with the same within- and between-participant factors as before, and with accuracy rate for the identification of the number of opponent players as the dependent variable. We adjusted degrees of freedom using Greenhouse-Geisser correction for the factor angle, $\chi^2(27) = 61.378$, $p < .001$. A trial was considered correct if participants reported the number of opponent players correctly for both sides. In total, participants correctly reported the number of opponent players in 76.46% (*SD* = 18.25%) of trials. There was a main effect for visual angle (see Table 3), $F(4.495, 170.823) = 5.972$, $p < .001$, $\eta^2 = .136$, $\varepsilon = .642$, showing decline in performance at wider visual angles. However, we did not find an effect of response mode, $F(1, 38) = 0.438$, $p = .512$, sport type, $F(1, 38) = 3.462$, $p = .071$, or any interaction effect (response mode x sport type: $F(1, 38) = 3.228$, $p = .080$; response mode x angle: $F(7, 266) = 0.309$, $p = .949$; angle x sport type: $F(4.495, 170.823) = 0.637$, $p = .655$, $\varepsilon = .642$; response mode x sport type: $F(7, 266) = 0.293$, $p = .937$). We found a correlation between confidence ratings and correct identification of the number of opponent players in the verbal response task ($r = .349$, $p =.028$) and motor response task ($r = .383$, $p = .015$). Participants' certainty level differed both in the task with verbal response (team sport athletes: $M = 7.08$, $SD = 1.35$; individual sport athletes: $M = 5.81$, $SD = 0.57$), $t(38) = 3.892$, $p < .001$, $d = 1.23$, and the task with motor response (team sport athletes: $M = 7.27$, $SD = 1.20$; individual sport athletes: $M = 5.60$, $SD = 0.74$), $t(38) = 5.326$, $p < .001$, $d = 1.68$.

Additional analyses. As the largest subgroup within the team sport athletes were football players ($n = 9$) and because we used a football-specific decision-making task, we checked for intragroup differences in this task, as well as in the three single tasks: decision making; attention; and perception task. Mann-Whitney U Tests for paired comparisons were applied to examine between groups differences. The results are presented in Table 4. The only significant difference between football players (M = 96.76%, SD = 5.01%) and other team sport players (M = 84.85%, SD = 13.08%) occurred in the single decision-making task with a verbal response.

Aospan task. The average score of all participants on the Aospan was 63.83 (SD = 6.40) out of a possible total of 75. Team sport athletes scored an average of 63.50 (SD = 7.11) and athletes of individual sports scored 64.15% (SD = 5.78%). The difference between groups was not significant, $t(38) = 0.317$, $p = .753$. There was no significant correlation between verbal response accuracy in the football decision-making task and performance on the Aospan ($r = .277$, $p = .084$), or between accuracy in the decision-making task with motor response and performance on the Aospan ($r = .233$, $p = .148$).

Discussion

We compared decision-making accuracy as well as attentional and perceptual processing using a sports-relevant task. In line with our predictions, team sport athletes were more accurate in their decision making across a wider attentional width than individual sports athletes. However, while performance on the attentional task differed across visual angles, between groups and response modes, there was no interaction involving viewing angle. Additionally, performance on the perceptual task differed across visual angles, but not between groups or response modes. We present the first attempt to compare how perceptual and attentional capabilities affect decision making by applying different response modes. Our findings are consistent with those reported using basic perceptual/attentional tasks (e.g., attention-window task, UFOV task) showing performance decreases with increasing distance/visual angle between stimuli. Moreover, the high correlation between the level of certainty about their choices and accuracy underlined that the team sport athletes made these decisions with greater confidence than individual sport athletes.

We reported that both team and individual sport athletes were more accurate in identifying the number of opponent players along greater visual angles (across the whole screen they had an accuracy rate of 76% in this visual perception task) when compared with their ability to identify the running direction of teammates on the football decision-making task (across the whole screen they had an accuracy rate of 46% in this visual attention task). This reduced accuracy in identifying the movement direction of teammate players could possibly be explained by the fact that the identification task required visual attentional capabilities rather than only perceptual capabilities when identifying opponent players. As participants had to detect both colour and shape (their teammates' jersey colour and their running direction), this task was classified as being attention-demanding (Schneider, Dumais, & Shiffrin, 1984). In keeping with the idea that the visual focus of attention is smaller than the visual field (for an overview, see Hüttermann & Memmert, 2017), attentional performance decreased significantly with increasing viewing angles when compared to perceptual performance. This finding suggests that team sport players were able to enlarge the focus of attention compared to individual athletes (i.e., they perceived the running direction of teammates over a wider breadth of attention), but there was no difference between groups of athletes when identifying the number of opponent players. It appears that team sports players are able to identify more items in the visual field (cf. Roca & Williams, 2017; Smeeton, Ward, & Williams, 2004).

The comparison of individual and team sport athletes helped to validate our measures of perceptual and attentional capabilities during a sport-relevant task. In alignment with published reports which show that athletes participating in different sports (e.g., individual or team sports) generally do not differ when tested using basic measures of visual perception (e.g., Hüttermann et al., 2014), the groups did not differ in performance on the perceptual task (i.e., when indicating the number of opponent players). Furthermore, consistent with previous research that has shown differences between various sports in attentional capability on basic tasks using general stimuli (e.g., Hüttermann et al., 2013; 2014), we found better attentional performances for team sport athletes compared to individual athletes (i.e., when identifying the movement direction of teammates) in our sport-specific task. As nearly half of the team sport athletes in the current study were football players, we checked for any intra-group differences to gain a better understanding as to whether particular subgroups could be causing the total group differences. Although football players made more correct decisions to pass the ball, they did not show better attentional or perceptual performances or achieved a higher total score (including performances of all three single tasks) compared to players from other team sports (e.g., basketball, netball, lacrosse). These findings strengthen our conclusions that differences in visual attentional capabilities between individual and team sport athletes cannot be attributed to any bias caused by intra-group differences.

From a practical point of view, players have to select and execute the best decision/s for their team in every game situation. In our task, the difficulty in making the right decision (i.e., where to pass the ball), actually lay not only in the requirement to perceive various teammates and opponent players simultaneously, but rather in the demand to bring all the information together. Participants made the correct decision (pass to the right/left side, no pass) on 86% of trials. This finding indicates that even though participants did not report all information correctly (e.g., all details of the attentional task), they were able to attend to the information enabling them to make the correct decision in most cases. However, in actual football matches, the decision of when and where to pass the ball is typically not made in the absence of a defender as was the case in our experiment; it is based on how closely 'marked' a teammate may be and, therefore, where the ball must be placed for her/him to receive it first.

We distinguished between a verbal and a motor response when making the decision where to pass the ball. While team sport athletes did not differ in performance across response modes, individual sport athletes made more correct decisions using a verbal rather than a motor response. This result was mirrored on the attentional task. This result is contrary to our predictions. We expected, based on the two visual processing streams account (Goodale & Milner, 1992; Milner & Goodale, 1995; van der Kamp et al., 2008), that superior performance would been seen in the motor response condition, particularly for the team sport group. To explain this contrary finding, we argue that with increasing levels of expertise performers develop more domain-specific expertise that leads towards to more automated processing of information (Ericsson & Lehmann, 1996), reducing time delays and improving decision-making efficiency (Eysenck & Calvo, 1992). In the individual sports group, with the least domain specific experience, more processing resources were required for the attention and decision-making task than the perceptual task. As a result, response efficiency was affected. When a motor response was required by this group, capacity was reached, and response effectiveness was affected resulting in a change in performance on the attention and decision making task. These processes may have been more automatic in the team sports players and as a result there was sufficient capacity to cope with the change in response mode. This finding highlights the importance of visual attentional and motor resources when examining the effect of response modes in the study of decision-making in sport. This result does not rule out the importance of a sport-specific response mode during a decision-making task. The effect size difference between the team and individual sport groups were larger in the motor response mode condition for both decision-making and attentional tasks. However, it may be the case that this response mode effect results from reduced capacity in the group without domain-specific skill when a complex motor response is required.

While the team sport decision-making task required a series of responses, participants were asked to additionally conduct a working memory task (Aospan task; cf. Unsworth et al., 2005). As we did not find a correlation between high Ospan scores and performance in the football task, we can conclude that results in our football task were due to attentional and perceptual capabilities rather than working memory capacity.

In the current study, we focused on decision-making accuracy. However, in keeping with the demands of the real-world task, we encourage researchers to measure both the speed and accuracy of response in future research in an effort to enhance measurement sensitivity. Moreover, in light of evidence highlighting the impact of anxiety and fatigue on performance (e.g., Casanova et al., 2013; Vater, Roca, & Williams, 2016), in future researchers should examine how such stressors impact with the factors measured in the current paper. While the current study highlights the impact of sport-specific experience on perception, attention and decision-making, it may be interesting to examine the extent to which these effects are specific to a particular sport or transfer across several related sports (Müller & Rosalie, 2019). Finally, research is needed to explore whether, and how, some of the effects highlighted may be trained and whether any such improvements transfer to the field situation (e.g., Hüttermann & Memmert, 2018).

In conclusion, our findings suggest that decision making and attentional processes, rather than perceptual processes, are more developed in team sport players when compared to individual sports athletes. In our football-specific decision-making task, team sport players were better able to enlarge their focus of attention and make correct decisions more frequently than individual sport athletes, particularly when a motor response was required. Overall, attentional performance was poorer at wider viewing angles when compared to perceptual performance.

References

Casanova, F., Garganta, J., Silva, G., Alves, A., Oliveira, J., & Williams, A. M. (2013). Effects of prolonged intermittent exercise on perceptual-cognitive processes. *Medicine and Science in Sports & Exercise, 45*, 1610-1617.

Choi, B., Lee, S., Lee, J. E., Hong, S., Lee, J., & Kim, S. (2015). A study on the optimum curvature for the curved monitor. *Journal of Information Display, 16*, 217-223.

Dehaene, S., Changeaux, J. P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: A testable taxonomy. *Trends in Cognitive Sciences, 10*, 204-211.

Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task. *Annual Review of Psychology, 47*, 273-305.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion, 6*, 409-434.

Farrow, D., & Abernethy, B. (2003). Do expertise and the degree of perception - action coupling affect natural anticipatory performance? *Perception, 32,* 1127-1139.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15,* 97-112.

Hüttermann, S., & Memmert, D. (2014). Does the inverted-U function disappear in expert athletes? An analysis of the attentional behavior under physical exercise of athletes and non-athletes. *Physiology & Behavior*, *131*, 87-92.

Hüttermann, S., & Memmert, D. (2015). The influence of motivational and mood states on visual attention: A quantification of systematic differences and casual changes in subjects' focus of attention. *Cognition & Emotion*, *29,* 471-483.

Hüttermann, S., & Memmert, D. (2017). The attention window: A narrative review of limitations and opportunities influencing the focus of attention. *Research Quarterly for Exercise and Sport, 88*, 169-183.

Hüttermann, S., & Memmert, D. (2018). Effects of lab- and field-based attentional training on athletes' attention-window. *Psychology of Sport and Exercise, 38,* 17-27.

Hüttermann, S., Bock, O., & Memmert, D. (2012). The breadth of attention in old age. *Ageing Research, 10*, 67-70.

Hüttermann, S., Memmert, D., & Simons, D. J. (2014). The size and shape of the attentional "spotlight" varies with differences in sports expertise. *Journal of Experimental Psychology: Applied, 20,* 147-157.

Hüttermann, S., Memmert, D., Simons, D. J., Bock, O. (2013). Fixation strategy influences the ability to focus attention on two spatially separate objects. *PLoS ONE, 8*, e65673.

Hüttermann, S., Smeeton, N. J., Ford, P. R., & Williams, A. M. (2019). Color perception and attentional load in dynamic, time-constrained environments. *Frontiers in Psychology,* 9, 2614.

Intriligator, J., & Cavanagh, P. (2001). The spatial resolution of attention. *Cognitive Psychology, 43*, 171-216.

Mann, D. L., Abernethy, B., & Farrow, D. (2010). Visual information underpinning skilled anticipation: The effect of blur on a coupled and uncoupled in situ anticipatory response. *Attention Perception & Psychophysics, 72,* 1317-1326.

Mann, D., Williams, A. M., Ward, P., & Janelle, C. (2007). Perceptual cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology 29*, 457-478.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford Press, Oxford.

Müller, S., & Rosalie, S. M. (2019). Transfer of expert visual-perceptual-motor skill in sport. In: R. Jackson & A. M. Williams. *Perception and Decision Making in Sport: Theories and*

Applications (pp. 375-393). Routledge.

Raab, M. (2003). Decision making in sports: Influence of complexity on implicit and explicit learning. *International Journal of Sport and Exercise Psychology, 1*, 406-433.

Redick, T. S., Broadway, J. M., Meier, M. E., Kuriakose, P. S., Unsworth, N., Kane, M. J., & Engle, R. W. (2012). Measuring working memory capacity with automated complex span tasks. *European Journal of Psychological Assessment, 28*, 164-171.

Roca, A., & Williams, A. M. (2017). Does decision making transfer across similar and dissimilar sports? *Psychology of Sport and Exercise, 31*, 40-43.

Schneider, W., Dumais, S. T., & Shiffrin, R. M. (1984). Automatic and control processing and attention. In: Parasuraman, R., Davies, D. R., editors. *Varieties of attention*. Orlando, FL: Academic Press, 1-27.

Smeeton, N. J., Ward, P., & Williams, A. M. (2004). Do pattern recognition skills transfer across sports? A preliminary analysis. *Journal of Sports Sciences, 22*(2), 205-213.

Tenenbaum, G., & Bar-Eli, M. (1993). Decision making in sport: A cognitive perspective. In R. N. Singer, M. Murphey, & L. K. Tennant (Eds.), *Handbook of research on sport psychology* (pp. 171-192). New York: Macmillan.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97-136.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Method, 37*, 498-505.

van der Kamp, J., Rivas, F., van Doorn, H., & Savelsbergh, G. (2008). Ventral and dorsal system contributions to visual anticipation in fast ball sports. *International Journal of Sport Psychology, 39,* 100-130.

Vater, C., Roca, A., & Williams, A. M. (2016). Effects of anxiety on anticipation and visual search in dynamic, time-constrained situations. *Sport, Exercise, and Performance Psychology, 5*, 179-192.

Voss, M. W., Kramer, A. F., Basak, C., Prakash, R. S., & Roberts, B. (2010). Are expert athletes “expert” in the cognitive laboratory? A meta-analytic study of cognition and sport expertise. *Applied Cognitive Psychology, 24*, 812-826.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport*. London, UK: E & F.N Spon.

Williams, A. M., Ward, P., Smeeton, N. J., & Allen, D. (2004). Developing anticipation skills in tennis using on-court instruction: Perception versus perception and action. *Journal of Applied Sport Psychology, 16*(4), 350-360.

Wolfe, B., Dobres, J., Rosenholtz, R., & Reimer, B. (2017). More than the useful field: Considering peripheral vision in driving. *Applied Ergonomics, 65*, 316-325.

Footnotes

[1]Although this accuracy rate seems to be very low at first sight, it should be considered that a trial was only evaluated correctly if participants made the correct decision and gave correct answers in the perceptual and attentional tasks—also including situations that required visual angles of up to 160°, i.e. lying outside the maximal shift of attention measured in previous research (e.g., Hüttermann et al., 2013, 2014).

Figure Captions

Figure 1. Experimental setup showing a participant in front of the IGLOO. Participants had to make their decision where to pass a ball either verbally (upper picture) or by a motor response (bottom picture).

Figure 2. Sequence of events in one exemplary trial.

Figure 3. A representation of four exemplary trials showing the teammates in black jerseys and the opponent players in white jerseys. Participants should decide to pass the ball to the right side only in the playing situation presented left top; in all other situations they should not pass. The teammate on the participant's left side is running towards the side line in all presented situations except the left bottom one. The right teammate is running towards the centre in both left presented situations and towards the side line in both right situations. Correct responses regarding the number of opponent players would be 0 (left side) and 0 (right side) in the left top situation, 0 (left side) and 1 (right side) in the right top situation, 3 (left side side) and 2 (right side) in the left bottom situation, and 2 (left side) and 2 (right side) in the right bottom situation.

Figure 4. Effect of response mode on accuracy rate in the decision-making task for team sport and individual sport athletes. Symbols represent across-participant means and error bars represent standard deviations. (Notes: $^{*}p<.05$, $^{**}p<.001$)

Figure 5. Effect of visual angle on accuracy rate in the decision-making task for team sport and individual sport athletes. Symbols represent across-participant means and error bars represent standard deviations. (Notes: $^{*}p<.05$)

Figure 6. Effect of response mode on accuracy rate in the attentional task for team sport and individual sport athletes. Symbols represent across-participant means and error bars represent standard deviations. (Notes: *p<.05, **p<.001)

Tables

Table 1. Mean percentage and 95% Confidence Interval of correct responses in the decision-making task, in degrees of visual angle as a function of response mode (verbal, motor response) and sport type (individual and team sport athletes).

	Visual angle								
	20°	**40°**	**60°**	**80°**	**100°**	**120°**	**140°**	**160°**	**Average**
Decision making									
Verbal response									
Individual sport athletes	93.33 [87.26, 99.40]	93.33 [87.47, 99.20]	93.33 [88.35, 98.32]	86.67 [76.13, 97.21]	83.34 [76.61, 90.06]	81.67 [70.79, 92.55}	63.33 [49.85, 76.82]	68.33 [53.34, 83.32]	82.92 [73.73, 92.11]
Team sport athletes	98.33 [92.26, 104.40]	95.00 [89.13, 100.87]	98.33 [93.35, 103.32]	91.67 [81.13, 102.21]	95.00 [88.28, 101.73]	86.67 [75.79, 97.55]	78.33 [64.85, 91.82]	78.33 [63.34, 93.32]	90.21 [81.02, 99.40]
Average – both groups	95.83 [91.54, 100.13]	94.17 [90.02, 98.32]	95.83 [92.31, 99.36]	89.17 [81.71, 96.62]	89.17 [84.41, 93.92]	84.17 [76.48, 91.86]	70.83 [61.30, 80.37]	73.33 [62.73, 83.93]	86.56 [80.06, 93.06]
Motor response									
Individual sport athletes	96.67 [92.61, 100.73]	93.33 [88.35, 98.32]	88.34 [83.11, 93.56]	85.00 [77.68, 92.32]	75.00 [63.97, 86.03]	70.00 [58.78, 81.22]	53.33 [41.01, 65.66]	45.00 [28.86, 61.14]	75.83 [66.80, 84.87]

Team sport athletes	98.33 [94.28, 102.39]	98.33 [93.35, 103.32]	100.00 [94.78, 105.22]	100.00 [92.68, 107.32]	95.00 [83.97, 106.03]	93.33 [82.12, 104.55]	88.33 [76.01, 100.66]	81.67 [65.52, 97.81]	94.37 [85.34, 103.41]
Average – both groups	97.50 [94.63, 100.37]	95.83 [92.31, 99.36]	94.17 [90.48, 97.86]	92.50 [87.32, 97.68]	85.00 [77.20, 92.80]	81.67 [73.74, 89.60]	70.83 [62.12, 79.55]	63.33 [51.92, 74.75]	85.10 [78.72, 91.50]

Table 2. Mean percentage and 95% Confidence Interval of correct responses in the attentional task of the teammates' running direction in degrees of visual angle as a function of response mode (verbal, motor response) and sport type (individual and team sport athletes).

	Visual angle								
	20°	**40°**	**60°**	**80°**	**100°**	**120°**	**140°**	**160°**	**Average**
Attentional Task									
Verbal response									
Individual sport athletes	46.67 [32.61, 60.73]	51.67 [40.86, 62.48]	53.34 [40.72, 65.95]	53.33 [40.26, 66.41]	36.67 [22.69, 50.64]	35.00 [20.32, 49.68]	21.67 [9.40, 33.93]	21.67 [10.62, 32.71]	40.00 [22.69, 52.75]
Team sport athletes	56.67 [42.61, 70.73]	71.67 [60.86, 82.48]	58.33 [45.72, 70.95]	58.33 [45.26, 71.41]	46.67 [32.69, 60.64]	50.00 [35.32, 64.68]	38.33 [26.07, 50.60]	36.67 [25.62, 47.71]	52.08 [39.27, 64.90]
Average – both groups	51.67 [41.72, 61.61]	61.67 [54.02, 69.31]	55.84 [46.92, 64.75]	55.83 [46.59, 65.08]	41.67 [31.78, 51.55]	42.50 [32.12, 52.88]	30.00 [21.33, 38.67]	29.17 [21.36, 36.97]	46.04 [36.98, 55.10]
Motor response									
Individual sport athletes	35.00 [23.03, 46.97]	40.00 [27.58, 52.42]	33.33 [20.43, 46.24]	41.67 [30.32, 53.02]	35.00 [19.88, 50.12]	31.67 [16.99, 46.34]	23.33 [9.62, 37.05]	20.00 [10.58, 29.42]	32.50 19.80, 45.20]
Team sport athletes	68.33	71.67	63.33	75.00	60.00	50.00	40.00	33.33	57.71

	[56.37, 80.30]	[59.25, 84.09]	[50.43, 76.24]	[63.65, 86.35]	[44.88, 75.12]	[35.32, 64.68]	[26.28, 53.72]	[23.92, 42.75]	[45.01, 70.41]
Average – both groups	51.67	55.83	48.33	58.33	47.50	40.83	31.67	26.67	45.10
	[43.21, 60.13]	[47.05, 64.62]	[39.21, 57.46]	[50.31, 66.36]	[36.81, 58.19]	[30.46, 51.21]	[21.97, 41.37]	[20.01, 33.32]	[36.13, 54.08]

Table 3. Mean percentage and 95% Confidence Interval of correct responses in the perceptual task of the number of opponent players in degrees of visual angle as a function of response mode (verbal, motor response) and sport type (individual and team sport athletes).

	Visual angle								
	20°	**40°**	**60°**	**80°**	**100°**	**120°**	**140°**	**160°**	**Average**
Perceptual task									
Verbal response									
Individual sport athletes	76.67	86.67	80.00	75.00	76.67	65.00	70.00	61.67	73.96
	[64.49,	[75.83,	[68.07,	[62.82,	[61.50,	[51.18,	[55.41,	[45.70,	[60.63,
	88.84]	97.50]	91.93]	87.18]	91.84]	78.83]	84.60]	77.63]	87.29]
Team sport athletes	88.33	86.67	85.00	83.33	76.67	81.67	75.00	66.67	80.42
	[76.16,	[75.83,	[73.07,	[71.16,	[61.50,	[67.84,	[60.41,	[50.70,	[67.08,
	100.51]	97.50]	96.93]	95.51]	91.84]	95.49]	89.60]	82.64]	93.75]
Average – both groups	82.50	86.67	82.50	79.17	76.67	73.33	72.50	64.17	77.19
	[73.89,	[79.00,	[74.07,	[70.56,	[65.94,	[63.56,	[62.18,	[52.88,	[67.76,
	91.11]	94.33]	90.94]	87.78]	87.39]	83.11]	82.82]	75.46]	86.62]
Motor response									
Individual sport athletes	75.00	73.33	75.00	66.67	75.00	66.67	63.33	53.33	68.54
	[64.07,	[62.55,	[63.13,	[54.94,	[62.45,	[52.62,	[47.18,	[36.85,	[55.47,
	85.93]	84.12]	86.87]	78.39]	87.55]	80.72]	79.49}	69.82]	81.61]
Team sport athletes	90.00	90.00	91.67	81.67	78.33	85.00	75.00	71.67	82.92

	[79.07, 100.93]	[79.22, 100.78]	[79.80, 103.53]	[69.94, 93.40]	[65.78, 90.89]	[70.95, 99.05]	[58.85, 91.15]	[55.18, 88.15]	[69.85, 95.99]
Average – both groups	82.50	81.67	83.33	74.17	76.67	75.83	69.17	62.50	75.73
	[74.77, 90.23]	[74.04, 89.29]	[74.94, 91.72]	[65.88, 82.46]	[67.79, 85.54]	[65.90, 85.77]	[57.75, 80.59]	[50.85, 74.16]	[66.48, 84.97]

Table 4. Mann-Whitney U test results indicating the comparison of football players and other team sport players in the football-specific task as well as in the subtasks (decision making, perception, attention) as a function of response mode (verbal, motor).

	Football players (n=9)		**Other team sport players (n=11)**		**U**	**Z**	**p**
	Mean Rank	**Sum of Ranks**	**Mean Rank**	**Sum of Ranks**			
Verbal response							
Football-specific task	11.72	105.50	9.50	104.50	38.50	-.845	.412
Decision-making task	14.00	126.00	7.64	84.00	18.00	-2.467	.016
Perceptional task	12.33	111.00	9.00	99.00	33.00	-1.274	.230
Attentional task	12.56	113.00	8.82	97.00	31.00	-1.439	.175
Motor response							
Football-specific task	12.78	115.00	8.64	95.00	29.00	-1.568	.131
Decision-making task	9.05	99.50	12.28	110.50	33.50	-1.334	.230
Perceptional task	11.67	105.00	9.55	105.00	39.00	-.806	.456
Attentional task	13.33	120.00	8.18	90.00	24.00	-1.953	.056