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Superior Gaze Strategies of Elite Badminton Players and the Significance of Natural Research Conditions

Estrategias de la mirada superiores en jugadores de bádminton de élite y la importancia de las condiciones naturales de investigación

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Abstract

Gaze behavior and performance of internationally ranked players and "near"-expert players were investigated under field conditions for the game situation service-return in badminton. According the literature, it was assumed that expert players focus more frequently on the racket arm, wrist, and racket of the opponent, while less experienced players focus on the shuttle. Thus, gaze strategy would have an influence on performance. The results contradicted the initial hypotheses: the higher the performance level of the athletes, the more frequently they directed their gaze to the shuttle. Non-professional players were found to focus more often on the upper body and face. To improve gaze behavior in the service situation, on-court drills with focusing on the shuttle region are assumed to be advantageous for athletes of all skill levels. Our research showed that players use other visual search strategies when observing a real opponent then when confronted with a two-dimensional stimulus.

Keywords: *Gaze behavior, racket sports, experts-near-experts, elite badminton .*

Resumen

La conducta de la mirada y el desempeño de jugadores de categoría internacional y "casi" expertos fueron investigados en condiciones de campo para la situación de juego servicio-devolución en bádminton. Según la literatura, se asumía que los jugadores expertos se enfocan con más frecuencia en el brazo de la raqueta, la muñeca y la raqueta del oponente, mientras que los jugadores menos experimentados se enfocan en el volante. Por tanto, la estrategia de la mirada tendría una influencia en el desempeño. Los resultados contradicen las hipótesis iniciales: entre más alto sea el nivel de desempeño de los atletas, más dirigen la mirada al volante. Los jugadores no profesionales se enfocaron más en la parte superior del cuerpo y el rostro. Se supone que los ejercicios en campo enfocados en el área del volante sirven para mejorar la conducta de la mirada en la situación de servicio en los atletas de todos los niveles de habilidad. Nuestra investigación demuestra que los jugadores usan unas estrategias de búsqueda visual al observar a un oponente real diferentes a las que usan con un estímulo de dos dimensiones.

Palabras clave: *Conducta de la mirada, deportes de raqueta, expertos-casi-expertos, bádminton de élite.*

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INTRODUCTION

In many sports, fast and efficient perception of various visual stimuli has high impact on the performance of an athlete (Hüttermann et al., 2018; Jendrusch, 2011; Jin et al., 2011). Especially in fast team and racket sports, the outstanding speed and ball velocities present a minimal time frame for the motor response of a player, e.g. the defence of a spike in volleyball or the action of the goal keeper in handball. In these game situations, successful motor reactions are hardly possible without an efficient perception and anticipation of the opponent´s actions, because the flight time of the moving object is shorter than the physiologically required time for information processing (Müller & Abernethy, 2012). In badminton, e. g., world class players generate shuttle velocities of more than 100 m/s (Gawin, Beyer, Büsch, & Høi, 2012). The defending player must begin his action before the shuttle trajectory is clearly visible. Otherwise, the remaining time is insufficient to perceive and process the information and to initiate the motor response to intercept the shuttle at the anticipated point of contact.

The importance of visual perception for performance in elite sports is highlighted in a quickly increasing scientific body (Klostermann & Moeinirad, 2020). Commonly, the characteristics of visual performance are studied by comparing the visual strategies of experts and non-experts (Hüttermann et al., 2018; Mann et al., 2007; Vickers & Adolphe, 1997). Aspects of superior perceptual-cognitive performance of expert performers are higher response accuracy, faster reaction time, and different gaze behavior (Gegenfurtner et al., 2011; Mann et al., 2007) and many studies have revealed significant performance differences between experts and non-experts for these aspects (e.g., Mann et al., 2007; Rienhoff et al., 2016; Vickers, 1996; 2016).

Regarding response accuracy, there is evidence that experts react more accurately than non-experts in specific game situations. For example, highly skilled badminton players are able to anticipate the trajectory or direction of a shuttle more precisely than less skilled players by “reading” the movement of the opponent at an early state of action (e. g., Abernethy & Russell, 1987a; Hagemann & Strauß, 2006). This superior perception is based on different utilization of relevant information from visual cues. Non-experts commonly observe the movement of the racket to anticipate the shuttle´s trajectory, whereas experts pick up information about the intended action at an early stage by recognizing the movements of the playing side arm (Abernethy & Russell, 1987b). This strategy enables them to calculate the appropriate response earlier and their prediction of the ball´s trajectory will more likely be correct.

Another performance factor is response time. Experts show significantly shorter response times - the time interval necessary for perception, information processing and the start of the motor response - than non-experts (Mann et al., 2007; Gegenfurtner et al., 2011). There is consistent evidence that highly skilled athletes terminate decision making earlier and, therefore, reach the required position, e. g. when defending a spike in volleyball or a penalty throw in handball “just in time” (Hossner et al., 2014; Lienhard et al., 2013; Schorer, 2006).

Highly skilled volleyball players finalized the decision for motor response at an earlier point of time and therefore more accurately than less skilled players, but commonly commenced the motor response later (Hossner et al., 2014; Lienhard et al., 2013). Research by Vickers and Adolphe (1997) revealed similar results. Expert volleyball players initiated the motor response at a later point of time when receiving a service than near-experts (Vickers & Adolphe, 1997). The less skilled players changed their position even before the server made contact with the ball, while the experts remained in the receiving position longer while tracking the oncoming ball.

Goalkeepers at a high performance level in handball also started their motor response later than non-experts (Schorer, 2006). This behavior enabled them to initiate the movement just in time, allowing them to execute the motor task successfully. Initiating movement too early would have allowed the opponent to change their strategy. According to Schorer (2006), this “just-in-time” reaction indicates an essential skill of high performing athletes in sports that afford a complex timing.

These observations are associated with motor tasks in which a player must reach a ball or the required position of the anticipated motor action just in time. However, demands differ in game situations in which athletes have to act as quickly as possible – as in many typical game situations in badminton. For example, the service return in the doubles disciplines requires starting the movement towards the shuttle as soon as possible (Gawin et al., 2013). Such game situations differ fundamentally from the just-in-time paradigm. The motor response must not only be started just in time, but immediately. There is also evidence that experts reach the required position faster than non-experts because of their superior anticipation (Mann et al., 2007).

Another aspect of gaze behavior concerns gaze strategies. The large number of studies in this field and the increasing heterogeneity of results caused Klostermann and Moeinirad (2020) to review the state in gaze behavior research in the recent decades. Considering at least 81 studies, they extracted four “main gaze variables” (Klostermann & Moeinirad, 2020, p. 153), number and duration of gaze fixations, location and duration of the final fixation (Quiet Eye, QE). Relatively consistent results have been published in the recent years for the last two variables – the gaze location and QE, for example, that expert athletes focus different visual cues when compared to less skilled performers and that they utilize longer final fixations.

The QE phenomenon seems to be consistent across many domains of sport. Mann et al., (2007) list publications about QE in various sports, such as rifle shooting, billiards, golf, volleyball, or basketball. For further information about the Quiet Eye theory, please see Gonzales (Gonzalez et al., 2015), Vickers (2016), Mann et al., (2007), or the review by Rienhoff, Tirp, Strauss, Baker and Schorer (2016).

The gaze location, an athlete focuses central-foveal, is assumed to contain task and decision-relevant information (Nakashima & Kumada, 2017). There is evidence that a specific gaze strategy is related to performance, and that there are differences between experts and non-experts (e. g., Gegenfurtner et al., 2011; Hubbard & Seng, 1954; Land & Tatler, 2001; Savelsbergh et al., 2002; Vickers, 2006; Vickers & Adolphe, 1997). Especially in interceptive sports, like net or racket games, superior gaze strategies are assumed to strongly influence performance. Perception, information processing, and initiating the motor response are all one process, which causes a minimal time frame and high time pressure. Therefore, many studies deal with the analysis of gaze behavior of athletes in racket or net sports, e. g. baseball, tennis, table tennis or badminton:

Long before mobile eye trackers were introduced, Hubbard and Seng (1954) analyzed the gaze behavior of professional baseball batters. They could show that the participants initially fixated the trajectory of the oncoming ball but then stopped the eye movement before hitting the ball at a region before the point of contact. This outcome was confirmed in a study involving volleyball by Vickers and Adolphe (1997). Highly skilled athletes in volleyball differ from less skilled athletes in their gaze strategies when receiving a service. Like the baseball players, the experts stopped their eye movement before the point of contact. Near-experts, in contrast, followed the trajectory of the ball more frequently until the ball made contact with the lower arms (Vickers & Adolphe, 1997).

Studies in the fields of tennis and table tennis focused on the question of how the ball was observed during and after the execution of the opponent´s action (e. g., Lafont, 2008; Ripoll & Fleurance, 1988; Rodrigues et al., 2002). Apparently, experienced table tennis players merely directed their gaze at the ball in the initial phase of the trajectory when receiving the ball laterally (Ripoll & Fleurance, 1988; Rodrigues et al., 2002). After that, the gaze was oriented towards a space that was located in front of the anticipated trajectory or at the region of ball contact (Ripoll & Fleurance, 1988). This result, again, was considered a confirmation of Hubbard and Seng's findings (1954), highlighting the conclusion that experts seem to be able to execute a successful stroke without constantly tracking the ball.

To analyze the service situation in badminton, Alder et al., (2014) combined the measurement of kinematic data and eye movements of elite and less skilled badminton players (Alder et al., 2014). The aim was to uncover the kinematic parameters that provide early information about the intention of the server. For this purpose, the serves of elite badminton players were videotaped and the kinematics were analyzed. These video scenes subsequently served as stimuli in a life-size temporal occlusion test while the gaze behavior of the receiving players was measured. Analyses revealed that professional badminton players more frequently directed their gaze to the racket and the racket wrist of the server than less skilled players, who tended to fixate the shuttle (Alder et al., 2014).

The service situation in elite badminton doubles has undergone in-depth analyses because this game situation has a profound impact on performance during competitions (Li, 2005; Liu & Zheng, 2009; Tian, 2004; Zhong & Xie, 2008). About one third of all points in doubles matches are initiated or made in the service situation comprising at least service, return, and second return (Gawin, Beyer, Büsch, & Hasse, 2012). Basically, the server has the choice between two tactical options – a low short service and a so-called flick serve to the rear court (figure 3). The returning player should anticipate the intention of the server and execute his movement towards the shuttle as quickly as possible to hit the shuttle in a superior position for an offensive return. Top players need about 300 ms to reach the shuttle after a short serve, and it has been found that successful elite male players make contact with the shuttle significantly faster when returning the service (Gawin et al., 2013).

Many of the studies above, especially those dealing with gaze behavior in badminton (Abernethy & Russell, 1987a, 1987b; Alder et al., 2014), were conducted using two-dimensional video sequences as stimulus material. However, according to Shim and colleagues (Shim et al., 2005) and Mann et al., (2007), there is evidence that using two-dimensional video footage as stimulus affects the outcome of the analysis of real-world tasks. It is likely that participants show different visual search behavior when faced with real opponents in their natural environment. Moreover, the review article by Hüttermann and colleagues (2018) summarizes that 69 % of the eye tracking studies considered were carried out in the lab. In the majority of these studies, athletes had to react to stimuli on a video screen. Even some research under field conditions, e. g. Alder and colleagues (2014), did not use real opponents but rather man-sized video screens on the court. These experimental conditions are likely to bias the outcome of these studies and the transfer to the natural environment to develop practical implications (Hüttermann et al., 2018). Therefore, since stimuli are presented in a laboratory setting and lack one dimension, one might challenge the assumption of addressing the specificity of the experts' skills. The same applies to the required motor responses presented in many studies.

Meanwhile, it is possible to measure the gaze behavior of players under real-world conditions using mobile eye-trackers, and it can be supposed that measurements on court with real opponents will lead to divergent results compared to applying only video-based stimuli.

In the first step, the objective of this study is to reveal efficient gaze strategies of athletes in relevant game situations by identifying the strategies of elite performers (players competing at an international level) in comparison to players of an intermediate level of play. In a second step, the influence of the gaze strategies on situation-specific performance in elite badminton players will be analyzed to develop practical implications.

Therefore, the gaze behavior of elite badminton players and intermediate club level players in the game situation service return was investigated in the first part of the current study. In the second part, the motor performance of the elite players was measured, and the correlation between their gaze strategies and their performance during the service return was analyzed. According to the studies in racket sports listed above, it was hypothesized that…

1) …elite badminton players are more likely to focus on peripheral segments of the opponent, such as the playing side arm, the racket, and wrist, when preparing for their motor response, while less-skilled players focus more frequently on the shuttle, and
2) …that the gaze strategies of elite players are related to their specific performance in the rally opening situation.

METHODS

Sample

Badminton players of diverse skill levels were recruited for the current study. The sample was divided into elite badminton players (professionals) and intermediate club level players (non-professionals). The intermediate players group consisted of 13 experienced players (3 female, 10 male, age 31.5 ± 10.4 years) who competed in the regional league system. They all were badminton players at an intermediate level of play and were chosen because of their highest possible performance level of club players in the nearby region.

For the elite group, 22 nationally and internationally ranked (14 female, 8 male, age 23.2 ± 4.9 years) members of the German national team, German junior national team, or national teams of other nations were recruited for this study. This recruitment comprised all healthy national team players, who participated at a training intervention at the German national training center in Mülheim an der Ruhr at the time of this study. The elite group was subdivided into two subgroups: six olympic athletes ("A-National", 4 female, 2 male, age 29.0 ± 3.6 years) and 16 further members of the German national team who compete internationally but not at an Olympic level ("B-National", 9 female, 7 male, age 20.9 ± 3.0 years).). This subdivision was based on the assumption that different performance groups of elite level would display further differences in gaze behavior. All athletes were informed about the aims and risks of the study in advance by the coaches and the authors and gave their consent to participate in the study.

Instruments

The gaze behavior of the players was recorded using a mobile eye tracker by SMI (ETG2). The highest sampling rate of the infrared cameras in the eye tracking glasses that capture the eye movements is 60 Hz in combination with a front camera that records the eye view of the participant at 30 Hz. In the present study, the sampling rates of the front and the eye recording cameras were synchronized, and therefore the gaze behavior was measured at a frequency of 30 Hz. This caused a time interval of 33.3 ms between frames. The algorithm to discriminate fixations from saccades is based on a threshold that is integrated into the eye tracker software. This threshold is either an angle velocity of more than 100°/s or a combination of angle velocity (8°/s) and skewness. Basically, when the recorded eye movement exceeds these thresholds, the eye event is classified as a saccade. According to Hessels and colleagues (Hessels et al., 2018), this method of eye event detection meets the computational method of defining fixations and saccades. Therefore, in this study, fixations and saccades were differentiated by the in-built algorithm of the eye tracker. For the discussion about the importance of a clear definition of eye movements, see the review by Hessels et al., (2018).

The athletes' kinematics were analyzed using the high-speed camera system Marathon Ultra by GS Vitec (Bad Soden, Germany). Two synchronized cameras with a sampling rate of 500 Hz (at 1200 x 800 pixels) were located perpendicularly to each other behind the badminton court and were positioned such that the back of the receiving player could be filmed out of two perspectives. A spherical reflective marker was attached to the back of the receiving player in the middle of the spine at the height of the fifth lumbar vertebra. This marker was used to track the velocity of the participant´s center of mass movements when receiving the service (s. figure 1).

Study Design and Implementation

The tests in elite badminton for group "A-national" and "B-national" were conducted on badminton courts of regular size in the German national training centers in Mülheim/Ruhr and Saarbrücken. During one series of trials, four athletes were engaged on the court: one serving player, one receiving player, and the double partners of these two players to complete the double teams and to provide competition-like conditions (figure 2).

Figure 1. Female elite badminton player while receiving a service offensively.

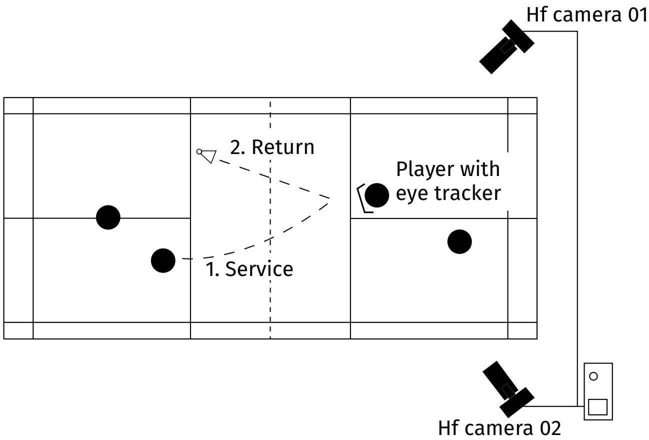

Figure 2. Experimental setup.

The recorded subject was equipped with the eye tracker and was instructed to return every service in an offensive manner by moving to the shuttle as quickly as possible. Every kind of service, a short (low) serve or a flick serve (high and long), was allowed, so that the subject had to react to these two stimuli like in an ordinary doubles competition (figure 3).

After the return, the rally was continued until a point was made to ensure natural test conditions. The subjects' eye movements were recorded over the whole series, while only the kinematics of the service and service return were captured by the high frequency cameras. Using this procedure, each subject executed 24 trails on average.

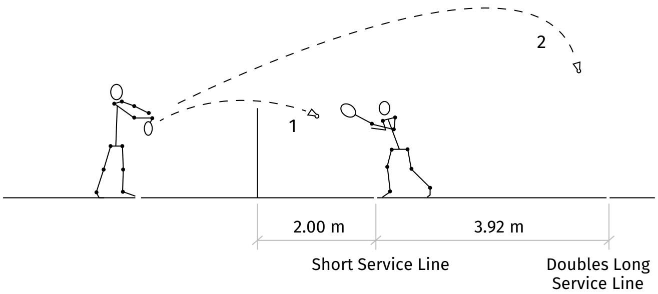

Figure 3. Trajectory of the short serve (1) and flick serve (2) in doubles.

Including the execution of long services in the experimental setup is necessary to provide an experimental setup similar to competition conditions. However, as frequency and relevance of flick serves in elite badminton is low (Gawin et al., 2013), this study only evaluated returns following a short service. This assured standardization of the results.

The measurements for the non-professional players took place in their respective training venues and were conducted the same way as for the professional players The only exception was that the kinematics was not recorded for the non-professionals because this project had to be concentrated on the performance of elite athletes.

Gaze and Performance Variables

Gaze strategies

Divergent from the many studies listed above, gaze orientation in this project was measured frame by frame in the time interval of one second before action. The intention was to reveal a gaze strategy that included all eye events during the second before action, and not only the mere fixations, as gaze strategy also comprises the searching movements to identify regions of interest. Moreover, during gaze fixation, slow movements of the gaze axes are possible and likely to happen in the specific slow-paced situation in this study. The result is that gaze regions can change within one fixation. For example, gaze direction can move from the shuttle to the racket and to the trunk of the player within one fixation. Therefore, we expected to gain additional details of athletes' gaze strategies using this method, instead of only recording the gaze direction of the final fixations. Another reason for the application of frame by frame analysis instead of interpreting the final fixations was the outcome of earlier studies by the authors of this paper (e. g., Gawin et al., 2017; Zwingmann et al., 2017). The QE durations of some players differed more than 100 % when repeating the experiment under the same conditions and the appearance of final fixations seemed to be more closely related to the eye tracker´s detection algorithm than to specifically adopted gaze behavior. Therefore, the eye tracker video files were evaluated frame by frame for the second before the server´s racket made contact with the shuttle. In this time interval, the specific regions of gaze focus were recorded (s. table 1). The result was a pattern of gaze movements of the individual player during the second before the start of his reaction to the action of the serving player. For the analysis of gaze direction, the eye tracker videos were exported from the eye tracker software (beGaze, SMI, Paris, France) to an avi-format and were then visualized and evaluated in the software Kinovea.

Table 1.
Categories: Regions of gaze direction.

Variable	Definition
"Central"	The gaze is directed at the shuttle, the racket, or the shuttle (=left) hand (Racket/Shuttle/Left Hand). Note: the racket hand is quite distant from this central region.
"Upper Body"	The gaze is directed at the head, the neck the trunk, or the arms.
"Lower Body"	The gaze is directed at the hips or the legs.
"Unspecific"	The gaze is directed at a region that does not meet one of the specifications above. When "unspecific", the gaze is usually aimed at a region just beside the opposing player or the wall behind the court.

Kinematics

The velocity of the player´s starting movement towards the service served as the indicator for performance. This value was calculated by recording the point of time when the server's racket made contact with the shuttle and the time event when the subject's body reached a velocity threshold of 2 m/s (t_v2.0, figure 4). Therefore, this variable comprised the time for information intake, information processing, and the motor response. It expressed how fast the subject is capable of adapting his motor reaction to the specific stimulus. For this variable, the velocity of the marker attached to the back of the subjects was calculated using the three-dimensional video data from the high frequency cameras. The 3D coordinates of this marker were manually determined frame by frame by using the software Simi Motion (Simi Reality Motion Systems GmbH, Unterschleißheim, Germany), and the velocity-time-curves were smoothed by the moving average with a window size of five frames to compute the threshold of 2 m/s.

Statistics

The data for the regions of gaze direction consist of absolute and relative frequencies. Therefore, the differences in gaze patterns between the different skill groups were analyzed using a χ^2 test (SPSS version 26). In order to determine, which cells contribute to the differences between groups, standardized residuals of the contingency tables were analyzed (Sheskin, 2003).

To assess the correlation between gaze direction and performance, R (R Core Team, 2012) and lme4 were used (Bates et al., 2014). A linear mixed effect model was established with the fixed effect of gaze direction. Repeated measurements required the subject ID to be included as a random effect.

The visual inspection of the residual plots did not show any obvious heteroscedasticity or violations of residuals' normal distribution within the model. Statistical significance of model effects was evaluated by performing a likelihood ratio test of the full model against the null model without the fixed effect gaze direction. Alpha was set to .05.

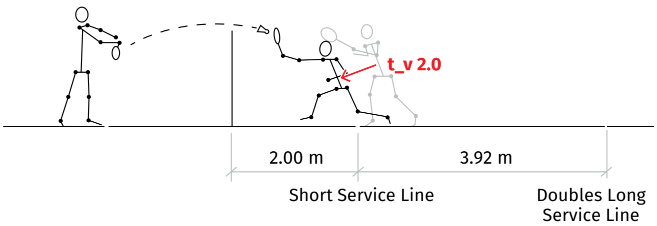

Figure 4. The performance variable t_v2.0, which is the velocity of the player´s reaction to the service.

RESULTS

Differences in gaze behavior of professional and non-professional players

The region that was focused on most frequently, was the "central" region (racket head, shuttle, and left hand. The left hand here is defined as the hand that holds the shuttle). The differences between the groups were most obvious in this category. The higher the performance level of the athletes, the more frequently they directed their gaze to this central region. Another obvious difference was found in the category upper body. The non-professional players tended to focus on the upper body (head, trunk, shoulders, and arms) more than the professional players. Remarkably, some subjects in the group of the non-professionals even kept their gaze steady on the opponent's face during the entire situation. Among all playing levels, the lower body (hip and legs) region seems to be less relevant than the other recorded regions of interest.

Although the frequency was zero for every group, the category "racket side hand" is displayed in the figure above to illustrate the contrast to Alder et al., (2014). Carefully interpreting the results of Alder and colleagues (2014), they detected a final fixation of this region in more than 20 % of all trials on average in professional players. In the current study, none of the players, neither professional nor non-professional, focused on this location.

The differences between the three groups in this study appear to be significant with a small effect (χ^2 [6] = 4801.97, p < .01, Cramers V = .24). The post hoc analysis of the standardized residuals of each contingency table's cell are depicted in table 2.

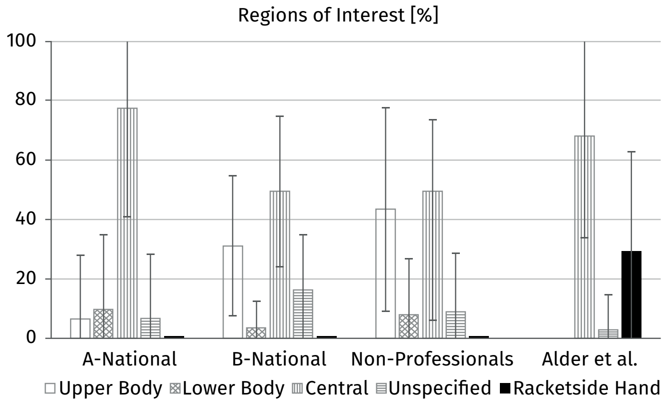

Figure 5. The regions that were focused on (error bars 95% confidence intervals).

Table 2.
Standardized residuals and p-values of each cell.

Categories		Expertise		
		A-National	B-National	Club Players
Upper Body	Frequency	522	6590	5899
	Expected Frequency	2432.7	6441.4	4136.9
	%	4.00%	50.60%	45.30%
	Standardized Resid.	-51.5	3.1	39.8
	p-values	0.000	0.002	0.000
Lower Body	Frequency	760	712	1098
	Expected Frequency	480.5	1272.3	817.1
	%	29.60%	27.70%	42.70%
	Standardized Resid.	14.6	-22.8	12.3
	p-values	0.000	0.000	0.000
Central	Frequency	6200	10468	5403
	Expected Frequency	4126.7	10926.8	7017.6
	%	28.10%	47.40%	24.50%
	Standardized Resid.	51.4	-8.9	-33.5
	p-values	0.000	0.000	0.000
Unspecified	Frequency	526	3434	1218
	Expected Frequency	968.1	2563.5	1646.4
	%	10.20%	66.30%	23.50%
	Standardized Resid.	-16.8	25.8	-13.6
	p-values	0.000	0.000	0.000

The analysis of the residuals show the lowest value for the category "upper body" in the group of the B-National players (s. table 2). But nevertheless all depicted p-values are below .05 and therefore all cells contribute to a significant outcome concerning the differences between groups.

Correlation between gaze direction and performance in service return in professional players

One result of the first part of this study was that professional badminton players (A-national and B-national group) tended to direct their gaze on the central region, comprising shuttle, racket head, and left hand, more frequently than less expert players (non-professional group). We hypothesized that any differences in gaze regions found between the professional and non-professional players could be considered advantageous for the professional players, which in turn would result in better performance in returning the service. Consequently, we suggested that such gaze behavior – enhanced focus frequency on the central region – would have a positive impact on specific performance. For this reason, we examined the correlation between gaze direction – expressed by the region "central" – and players' performance in returning the service.

The velocity of a player's motor reaction to the service (t_v2.0, see figure 6) was used to differentiate specific performance.

On average, the male players required about 270 ms to reach the threshold velocity of 2.0 m/s when initiating service return. They acted about 60 ms faster than the female players (s. figure 6).

The gaze strategy of focusing on the central region appeared to have no significant correlation with t_v2.0 in any of the players (females: χ^2 [1] = 1.604, p = .21; males: χ^2 [1] = .040, p = .84).

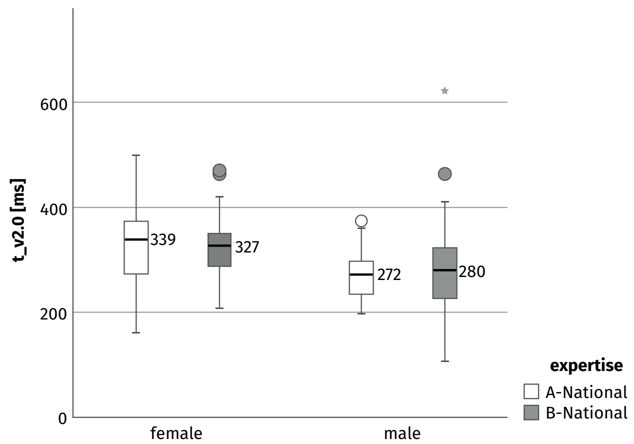

Figure 6. Players' motor reaction time to the service (t_v2.0) for the female and male elite players.

DISCUSSION

Gaze direction

Based on literature about eye tracking in racket sports, we expected to find that highly skilled players focus more frequently on distal segments of the moving opponent, such as the playing side arm, racket and wrist, and less expert players would tend to direct their gaze towards the shuttle. Our results cannot confirm this hypothesis. The observed gaze behavior of the different skill groups in this study turned out to be just the opposite. The higher the player's level, the more frequently they directed their gaze to the central region – comprising shuttle, racket head, and shuttle hand. Some of the former Olympic participants even focused on the shuttle for 100% of the recorded time. There are presumably expertise dependent gaze strategies in this game situation. It can be concluded that gaze behavior of top badminton players in the service situation is characterized by almost constant focus on the shuttle and the nearby regions. In the non-professional players the frequency of focus on the central region decreases significantly. The gaze focus of non-professional players seems to be towards the more peripheral regions, such as arm, upper body and face.

Alder and colleagues (2014) also examined the service situation, providing a comparable experimental setup with the exception that 2D-videos served as stimulus and that the players' response included a movement towards the anticipated virtual point of contact and a verbal statement concerning the shuttle's trajectory, not the specific motor response. The racket-side wrist – the hand that holds the grip of the racket – was a region where the players fixated their gaze in more than about 20% of all trials in that study. In our study, no participant focused on the racket-side hand or wrist. Moreover, the participants in this study rarely directed their gaze to the racket-side, the racket arm, or racket shoulder, of their opponents. The results in this study were obtained by recording the gaze behavior of athletes in a game situation with real opponents that came very close to the conditions in a real competition, especially, when considering stimulus and applied motor response. Therefore, it can be concluded that the research conditions are likely to have an influence on the obtained results. Apparently, even, or particularly, expert players use other visual search strategies when confronted with a two-dimensional stimulus on a video screen than when observing a real opponent.

The results in this study support one important outcome from Hüttermann and colleagues (2018) and from Klostermann et al., (2020) concerning ecological validity and representativeness of the experimental situation. They concluded that the transfer of results and practical implications from laboratory-based studies can be conflicted by unnatural research conditions.

The correlation between gaze direction and service return performance in professional players

To analyze the impact of gaze direction on performance, the parameter "velocity of the motor reaction" (t_v2.0) was defined and measured in this study. This parameter should reflect the complete reaction, beginning with the perception of the opponent´s service, information processing, and the movement towards the shuttle. In preparation of the study, this performance parameter was discussed with the German national coaches and subsequently established on the assumption that a badminton player in the doubles disciplines usually intends to travel to the shuttle as fast as possible after recognizing the kind of the service.

Next, because the most-skilled players focus on the central region - shuttle, racket head, and shuttle hand - more frequently than less-skilled badminton players, it seemed plausible that frequent focus on this region would lead to a shorter time for the motor reaction in the analyzed experienced players. This hypothesis could not be confirmed. The established linear mixed effect model did not show a significant correlation between gaze behavior and the velocity of the motor reaction in any of the participants.

The purpose of this model was to reveal the correlation between gaze strategy and a kinematic performance parameter that would reliably reflect player performance in the game situation "service return in doubles". However, this reduction apparently neglects further impact factors on the success in this specific situation. It is most likely that gaze direction itself cannot explain the superior performance of elite badminton players.

Conclusions and practical implications

The comparison of the different skill groups in this study revealed that athletes competing at high and at the highest levels of expertise utilize gaze strategies divergent from less experienced athletes. The elite players tend to anchor their gaze at the central region - shuttle, racket and racket hand. They concentrate their attention on this region, do not show fast eye movements and seem to be less distracted by peripheral stimuli. It is likely that this behavior also provides an efficient strategy for players with lower expertise and can serve as a reference. Basically, to improve specific performance in the service situation competition-like on-court drills that include additional perceptional tasks are advantageous for athletes of all skill levels. Many studies about visual perception in sports provide evidence for improvements in gaze behavior through training interventions, e. g., in golf (Moore et al., 2012; Vine et al., 2011), soccer (Wood & Wilson, 2011), basketball (Harle & Vickers, 2001; Oudejans et al., 2005), Ice-hockey (Mitroff et al., 2013), volleyball (Adolphe et al., 1997), and badminton (Hülsdünker et al., 2020a, 2020b; Hülsdünker et al., 2019). These studies show that specific training of visual perception was not only effective in changing gaze strategies, but also enhanced performance. Literature suggests the conclusion that on-court training of service situations involving additional perception tasks and applying methods that guide attention of the returning player implicitly can be beneficial. This can be achieved using specifically marked shuttles with colored dots, stripes or varying symbols (figure 7).

The receiving player has to recognize and name the color of the upper dot on the shuttle's surface immediately before the server has to execute the service. By this method the returning player is unconsciously forced to directly focus on the central region comprising shuttle and racket head.

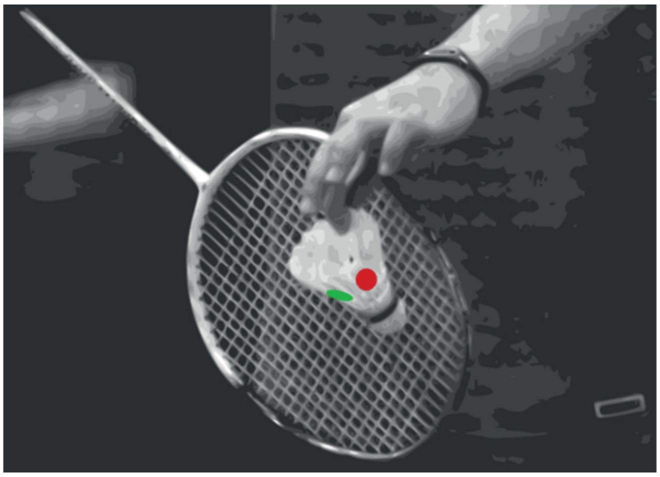

Figure 7. Colored marked shuttles as device for training of visual attention (image source: own lab).

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