Eye tracking in naturalistic badminton play — comparing visual gaze pattern strategy in world-rank and amateur player

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ABSTRACT

A professional player's expertise rests on the ability to predict action by optimally extracting the opponent's postural cues. Eye tracking (head-mounted system) data in a naturalistic singles badminton play was collected from one professional world-ranked player facing five amateur players (10 serves or 50 trials) and two amateurs playing against four other amateur players each (10 serves or 80 trials). The visual gaze on the opponent body, segregated into 3 areas-of-interest covering the feet, face/torso, and hand/racket of the opponent and the shuttle, was analysed for a) the period just before the serve, b) while receiving the serve and c) the entire rally. The comparative analysis shows the first area-of-interest for professional player as the opponent's feet while executing the serve and the hand/racket when receiving a serve. On the other hand, the amateur players show no particular strategy of fixation location either for the serve task or while facing a serve. The average fixation duration (just before serve) for the professional was 0.96s and for the amateurs it was 1.48s. The findings highlight the differences in the postural cue considered important and the preparatory time in professional and amateur players. We believe, analytical models from dynamic gaze behavior in naturalistic game conditions as applied in this study can be used for enhancing perceptual-cognitive skills during training.

CCS CONCEPTS

• **Human-centered computing** → Graphics input devices;

KEYWORDS

Badminton, Eye-Tracking, Visual gaze patterns, perceptual-cognitive skills, racket sports, Quiet-Eye

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1 INTRODUCTION

Expert players are found to build a dynamic strategy and gameplay from their judgement of the opponent's expertise level. In competitive settings, an expert quickly gauges and deciphers the opponent's tactics from overt visual cues like facial expressions, body posture, and spatial position on the court. In addition, the player retrieves from memory models formed by previous encounters with the opponent. In the absence of prior information, the player builds the same early on in the game. A professional player's skill is based on training this ability to form emergent or evolving models. An amateur player's focus is on winning the game based either on the experience obtained from previous games or by applying a fixed learned model for all. The decoding process applied by players to extract information from opponent's gameplay is of interest to cognitive science researchers and sports personnel. Hence, visual behavioral characteristics are crucial to determine this underlying process.

In studies to date, the player's game behavior is examined by the analysis of eye movement collected predominantly in controlled lab environment using simulations/videos of games (tennis - [Murray and Hunfalvay 2017]; soccer - [Lex et al. 2015]; Basketball - [Wilson et al. 2015] and for a few studies employ real-time naturalistic gameplay (soccer - [Kurz et al. 2018; Timmis et al. 2014], volleyvall - [McPherson and Vickers 2004], and recent review on eye tracking for sports - [Kredel et al. 2017]). Sports like badminton, lawn and table tennis, and volleyball are best studied in real-time gameplay unlike single-player target sports (golf or archery), as the target of interest is not stationary and also depth data is dynamic. The correlation between eye gaze (visual input), attention to moving target and the dynamic cognitive processes required for accurate responses in naturalistic conditions is critical for researchers of many domains. In particular, attempts are on to infer the underlying cognitive and motor skills from two main indices, a) the visual search patterns (gaze patterns) which indicates information processing methodology, and b) fixation or gaze duration in the preparatory, anticipatory and execution phases of the gameplay implying attention. Though gaze-scan pattern adapted by players might vary at the individual level even within a group [Savelsbergh et al. 2005] dependent on training methodology and perceptual differences, it has been possible to evolve a relatively generic model for strategies for optimal motor response as detailed in the next paragraph. Of particular importance is the gameplay strategy comparison of expert versus non-expert/amateur. The importance of systematic studies is predominantly for training.

Visual information extraction can be understood from gaze behavior [Piras et al. 2014] and analysis indicate task relevant strategy translating to appropriate motor response [Chen and Zelinsky 2006; Savelsbergh et al. 2002; Williams et al. 2004]. It has been shown that fixations at different spatial locations is a deliberate strategy to extract the information required to strategize [Memmert et al. 2009]. Studies on gaze behavior have extracted gaze location data in externally-paced skills in squash [Abernethy 1990], anticipation triggered search strategies in soccer [Savelsbergh et al. 2005], baseball and cricket [Moran et al. 2016]. It has been shown that expert players exhibit higher perceptual-cognitive skills and motor coordination exemplified in response-times and accuracy, fixation-duration and difference in a parameter called 'quiet-eye' period [Klostermann et al. 2013; Mann et al. 2011]. As per definition, 'quiet-eye' is the final fixation or gaze on an object or location before response typically linked to successful outcome [Vickers 1996, 2007, 2009]. Technically defined as the critical period when the eyes remain relatively still (within 3° of visual angle) before a player executes a movement [Vickers 2016a]. This period can also be understood as the time taken to access task relevant cues and strategize appropriate motor actions [Vickers 1996]. A meta analysis of 42 studies showed that in general, experts have lower number of fixations but of longer duration thus longer quiet-eye time. But, there is also evidence that the time window for information retrieval from the surroundings rather than gaze data of one object/location is critical for performance [Oudejans et al. 2005, 2002], findings which have led to in-depth discussion on the concept of the quiet-eye [Vickers 2009, 2016a,b]. In our study, we examine the visual tracking pattern and the fixation duration on areas-of-interest (AoI) just before the task. Though similar in concept to the 'quiet-eye' , we extended the focus to a set of AoI's rather than only the last gaze location.

Racket-sport - Badminton studies. The badminton serve is important as it allows the player to force the opponent to a particular position in the court and hence gains time to strategize the spatial coordinates of the response shot. Attention to the lower body — especially the feet — gives kinematic patterns of the position and the direction or readiness to move in any direction. That is, a defensive stance where both feet are parallel conveys ability to cover wide angles, while a net stance means being ready to move to the net fast after returning the serve. An opponent at the far end anticipating a long serve would usually have a defensive stance and hence will not be ready for a short serve. Though the feet spatial cues are sufficient, it was found that the visual information from the racket/hand, shuttle and torso were also equally important [Wilson et al. 2015]. We expect that the visual information or positional cues extracted are different for a self-paced task (a serve) and while returning a serve, as was also found for soccer game [Vine and Klostermann 2016].

The quiet-eye in badminton as per definition [Vickers 1996, 2016b] will be the last fixation location before serve or when receiving the serve. But the last landing gaze area does not inform about the advance visual information picked up by players. That is, the visual scanning just prior to the task is relevant to sports with moving targets and/or opponents. Towards understanding this, seminal studies by Abernethy and Russell [Abernethy and Russell 987a,b] and a recent one [Chia et al. 2017] examined visual search patterns for a serve in badminton. Using a video film test, the important conclusion from the study was the ability of the expert player to extract information from a spatial cue(s) than a non-expert (by Abernethy and Russell [Abernethy and Russell 987a,b]). However, they also found that visual search characteristics — duration and location — did not differ between the two groups. These findings lead them to conclude that not only visual search strategy but the way in which this information is used distinguishes expert and non-expert gameplay. When experts and non-experts were shown video recordings with international level players executing the serve, it was found that experts fixated on kinematic locations from which they can decipher serve types with higher frequency and for longer duration than non-experts [Alder et al. 2014]. In [Mavalankar et al. 2015], where data was collected in naturalistic gameplay conditions, it was seen that when playing with unknown opponents (that is, whose gameplay or expertise was not known), the players focused on the hand/racket and also showed differential fixation duration just before a serve as the game progressed.

Though naturalistic settings results in higher noise in the signals, data collected provide insights about the anticipation, prediction and rapid readjustment processes, that is, evolving strategy applied by players by training one-self to filter out 'visual noise' . In this work, we study scanpath reflecting the visual search strategies for two conditions with emphasis on the self-paced serve's preparatory phase. We do this by comparing play of a world ranked professional player and amateur players. The understanding being that a comparison of the visual information extraction pattern for each player category will provide insights to methods applied to optimize strategies. For the study, we extend the definition of quiet-eye period to a set of AoI's rather than just the last location before executing the serve. We hypothesize that AoI's considered to be relevant and the gaze duration will be less for an expert, due in part to their ability to extract crucial kinematic movement information faster from only a specific set of AoI's. Our premise is that visual search patterns applied by experts are focused on predicting the movement readiness from the 'quiet-eye' period in our case is the total preparatory phase of the player just before executing the serve or receiving one.

Wearable eye tracking equipment enables collection of the gaze data in naturalistic conditions hence giving richer insights into visual information processing. A wearable eye tracker (Tobii Glasses 2) was used to collect eye movement and the fixation duration which is an estimate of attention allocation at particular regions of interest important for game strategy, though it was shown that stress can also influence fixations [Abernethy 1990]. We collected data in an indoor badminton court in natural gameplay conditions from one world rank (10th as of 2017 world ranking in Badminton) professional badminton player pitched against five amateur opponents and two amateurs playing against four amateur (equal rating) players each, all in singles-match format.

We show that search patterns applied by an expert player is different from those of non-expert players. To submit this differential pattern, we present scanpath analysis, fixation location(AoI) and duration when executing a serve, receiving a serve and in a rally. Our approach allows for a wider interpretation of last fixation location and the information extracted from it by including the search strategies prior to the final AoI. The results indicate that the time prior to executing a serve is lower for the expert player and importantly the expert while executing a serve fixates on the feet for all serves and on the hand/racket of the opponent when receiving a serve. The findings from this study can be applied or extended to assess the performance of any sport with interceptive response.

The interpretations that can be drawn from the data should be understood in the light of the eye tracking in sports studies [Kredel et al. 2017] calling for methods to improve veracity of the gaze data especially when correlating to positioning. The elusiveness is the interpretational limitations of gaze data and the underlying mechanisms of information processing. The study and the data presented in this report add to the knowledge base of sports research, especially badminton.

2 EXPERIMENTAL SETUP AND METHODOLOGY

2.1 Participants

The participants in our study, were all males, in the age group 20-35 (average: 25 years). There were two sets of players from whom eye tracking data was collected. The first set consisted of a professional player (PP) currently ranked word-ranked 10 (was ranked 15 at the time the experiment was conducted). The second set consisted of 2 amateur players (AP) playing college level tournaments. The opponents (OP) were five against the professional and four each against the amateur players are also college tournament players. While the PP undergoes rigorous training for 6-8 hours a day, the AP's/OPs have regular 2-hour practice at least 4 days a week and have been playing this sport for 8-10 years, though they have not undergone any formal competitive training. Post-match, the PP gave a rank of 5 (on a scale of 1-10, 10 being extremely good) to all the 5 OP's, while the AP's ranked their OP's between 7-9.

2.2 Procedure

A head mounted Tobii Pro Glasses 2 eye tracker was used for this study. The experiment was conducted in an indoor badminton court of standard dimensions. The players used their own rackets. The eye movement overlaid on the video (recorded by the single camera on the device) is streamed live to a hand held tablet by a point-to-point wireless connection. The eye tracking data was recorded from the PP — playing 5 opponents in a singles match format and two AP's who played against 4 opponents each again in singles match. A warm-up play for 10 minutes for each pair of players was followed by the sessions each of approximately 10 minutes. A nine-point standard Tobii calibration process of the eye tracker was completed. In the calibration process for wearable trackers, the participant focuses both eyes on a small target card held 0.91meters away. The eye movements in this procedure are gauged as per the visual pattern of the card and rotation angles of the eyeball are determined with relation to the device. The gaze direction is then mapped to the image captured by the scene camera. A light-weight data storage device connected by a wire to the glasses is clipped on to the player. The storage device is connected to a hand held display (Dell tablet) by wireless mode to enable monitoring the real-time eye movement. In between the sessions, re-calibration was done whenever loss of eye data capture was observed or when gaze location is consistently away from the region of interest. The intermediate calibration is performed by moving a larger target sheet around the opponent player.

The players were asked to perform five serves and receive five serves from the opponent. The rules for serve was as per singles match rules. The participants were allowed to continue the rally till one of them dropped a shot to ensure immersive naturalistic gameplay. The stadium had only one court and at the time of data collection only the experimenters and the players were present. Participation was voluntary and adhered to all ethical practices. Informed consent was received from each player and eye tracking studies are approved by the institute's internal review committee.

2.3 Data Analysis

The sampling rate of the eye tracking was approximately 50Hz. The video recording from the eye tracker was analysed manually in 2-3 seconds time-frame windows using the Tobii studio's processing tools. The fixation duration (threshold > 70ms) from four areas of interest (AoI) of the opponent: a) face/torso, b) hand/racket, c) feet, and d) shuttle, was obtained. The fixation time was reduced to 70ms as against the 100ms ([Vickers 1996] Vickers, 1996), as we noticed players making extremely small fixations at AoI's critical for game strategy. The preparation duration just before the serve - when the shuttle leaves the racket - was tracked for each trial. The temporal ordering of the fixation location and duration or scanpath were analysed for each serve and the subsequent rally. For this report, the eye tracking data for the first (S1) and the fifth (S5) serve when executing the serve and sixth (S6) and tenth (S10) serve when the opponent is executing the serve were analysed. A state-diagram mode of representing the scanpath is prepared and state transitions labelled serially along with fixation duration for each state. The mean and standard deviations in the fixation duration are only reported as the data (only one PP) is not dense for rigorous statistical methods.

3 RESULTS

Of the 50 trials data recorded from the PP and 80 trials from APs, only 20 trials of PP and 32 trials of APs were analysed. We present the data for the serve and the rally separately.

3.1 Fixation duration and Scan-path pre-serve

Figure 1 and Figure 2 are the samples of PP's play with an OP with the 4 AoI's as states and the arrows indicating the transition direction. Figure 3 and Figure 4 represent the scanpath of an AP with an OP. Similar diagrams were generated for the 5 serves received/executed. We noted the first and last gaze in the AoI for each trial. For the serve S1, the PP's first gaze landing is the feet for 4 opponent players while it was either the face/torso or the hand/racket for the amateur players. For serve S5, the feet were the first AoI for both player categories. It is interesting to note the change in first fixation location (AoI) of the APs between the S1 and S5.

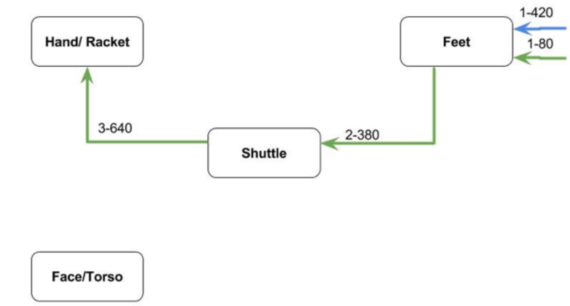

Figure 1: The scanpath and the fixation duration data of the Professional Player (PP) against Opponent player (OP) just before Serve-1 (S1 - blue) and Serve-5 (S5 - green). The notation : 1-80, here 1 is the first fixation point and 80 is the duration in msec.

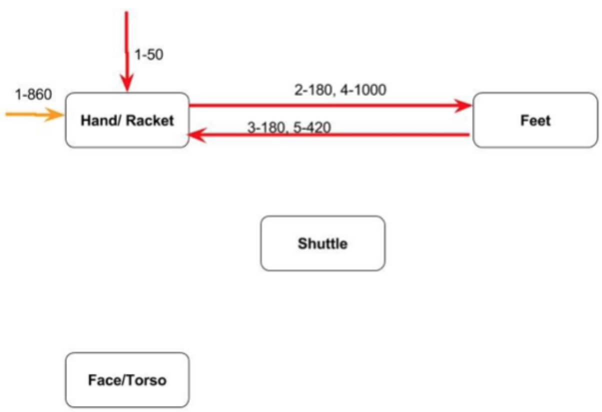

Figure 2: The scanpath and the fixation duration data of the Professional Player (PP) against Opponent player (OP) just before Serve-6 (S6 - red) and Serve-10 (S10 - yellow). The notation : 1-50, here 1 is the first fixation point and 50 is the duration in msec.

The last AoI of S1 for PP was the hand/racket for 4 opponent players and it was equally distributed between the shuttle and the hand/racket for APs. For serve S5, the PP's last AoI was either hand/racket or shuttle while there was no pattern observed in the amateur data. Considering both the serves, the last fixation AoI was consistently the hand/racket for PP while for the APs no fixed gaze location was evident. The shuttle was not always the last AoI for PP, while APs fixated on the shuttle as the last AoI more frequently than the PP. These findings, though very sparse considering data was collected from only one professional player is in partial agreement to reports of the shuttle occupying fixation attention by less skilled players whereas skilled players show higher variability [Chia et al. 2017].

While receiving the serve (S6), the first AoI for PP was the feet (3/5 trials) and it was the hand/racket area mostly for the APs. For serve, S10, the first AoI was hand/racket (3/5) and feet (2/5) by the PP

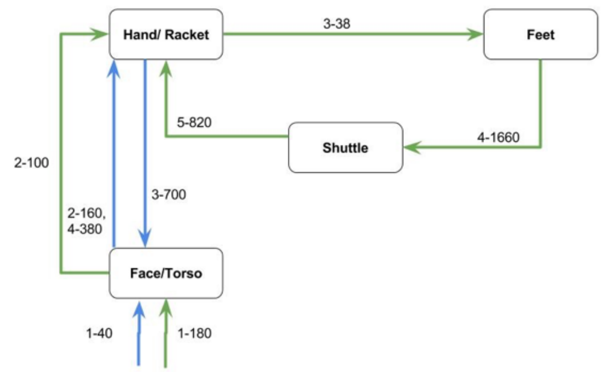

Figure 3: The scanpath and the fixation duration data of the Amateur player (AP) against Opponent Player (OP) just before Serve-1 (S1 - blue) and Serve-5 (S5 - green). The notation :1-40, here 1 is the first fixation point and 40 is the duration in msec.

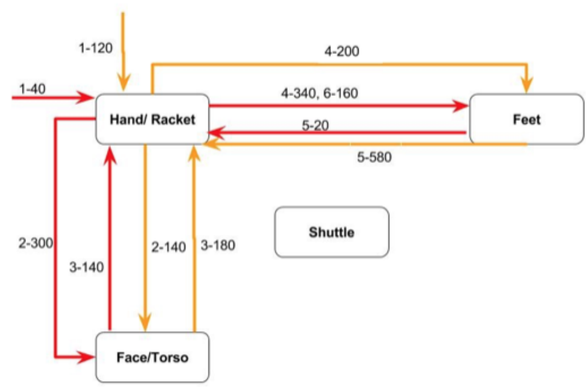

Figure 4: The scanpath and the fixation duration data of the Amateur player (AP) against Opponent Player (OP) just before Serve-6 (S6 - red) and Serve-10 (S10 - yellow). The notation :1-40, here 1 is the first fixation point and 40 is the duration in msec.

and hand/racket (50% of the players) or the feet and shuttle for the rest of the APs. The last AoI of the PP for S6 was hand/ racket or feet while it was hand/racket or shuttle or feet for the APs. By serve S10, the PP and APs last AoI was the hand/racket. The findings suggest the feet to be an important postural cue for the PP at the beginning of the trial when executing a serve or receiving one, but as the game progresses the hand/racket is important. But, the amateur players focus is consistently on the hand/racket when receiving the serve. Interestingly, the number of AoI's with fixations was fewer for the professional player compared to the amateur players, also discussed in the review by [Mann et al. 2011] on visual behavior of skilled players.

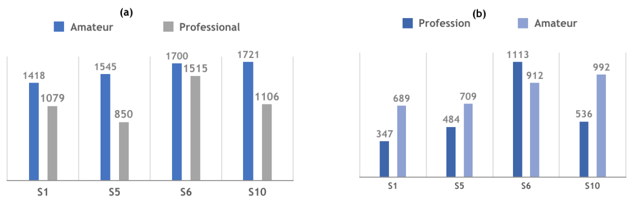

Figure 5: (a) The average scanpath duration for the amateur and professional player(s), executing a serve (S1, S5) and receiving a serve (S6, S10). (b) the average fixation duration on the last AoI. All the durations are in msec.

The average fixation duration calculated across all trials for the PP and the APs for the entire scanpath is shown in Figure 5a. For all the serve conditions (S1, S5, S6, S10), the average fixation duration is significantly higher (Standard deviation — S1 = 946.37ms; S5 = 978.97ms; S6 = 1039.82ms; S10 = 989.40ms) for the APs compared to the PP (Standard deviation — S1 = 364.97ms; S5 = 730.92ms; S6 = 1448.134ms; S10 = 486.60ms). The average fixation duration on the last AoI also shows a similar trend (Figure 5b), with fixation duration being significantly lower for the PP except for S6 (serve received). In studies on quiet-eye, it has been reported that expert or skilled players take a longer time on the last location of interest compared to unskilled players whereas the results from our study suggests an opposite trend.

3.2 The Rally

The complete rally for the professional player was analysed to examine the visual behavior during the rally. Figure 6, 7, 8 and 9 are a comprehensive state-diagram representation of 5 OPs playing the professional for the 4 serve conditions. As can be inferred, the first fixation location is the feet in majority of the conditions. When receiving a serve, the first AoI is either the feet or hand/racket. The diagrams for the APs were complex due to extremely long rally and hence not included in this report.

4 DISCUSSION

In this study, the visual search strategy applied by a professional player and amateur player(s) was determined by analysing the scanpath for the two game conditions - executing a serve and receiving one. Three parameters were considered for this study, the scanpath covering AoI's just before a serve, the fixation duration and the visual behavior in a complete rally. In previous studies, the quiet-eye was shown to be important for superior motor performance, but the underlying mechanism was not well known. In an attempt to interpret this process, we showed that gaze duration at the final object/location should be understood from the previous gaze landing positions especially the first location — for example the feet of the opponent — thus providing insights to the cognitive processes applied to evolve strategies.

Findings by [Chia et al. 2017] on the serve indicate differential visual search strategies for skilled and unskilled players, where the skilled players scanned more regions on the court than unskilled who only focused on the shuttle. Similarly, differential scan behavior was observed for the amateur players in our study. The

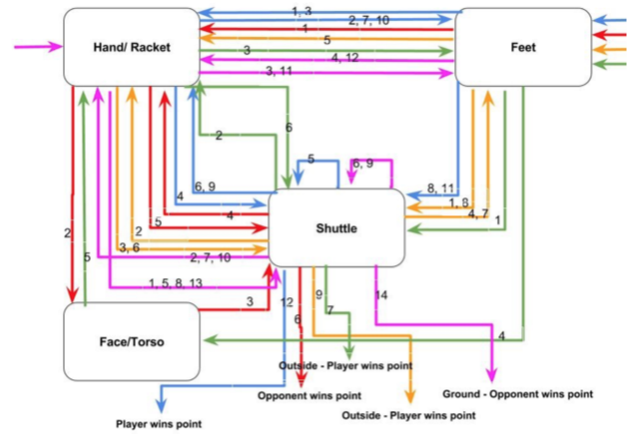

Figure 6: The state diagram of a complete rally for Serve-1 (PP is executing a serve) when the PP is playing against the 5 OP's. Each colour arrow indicates each OP player.

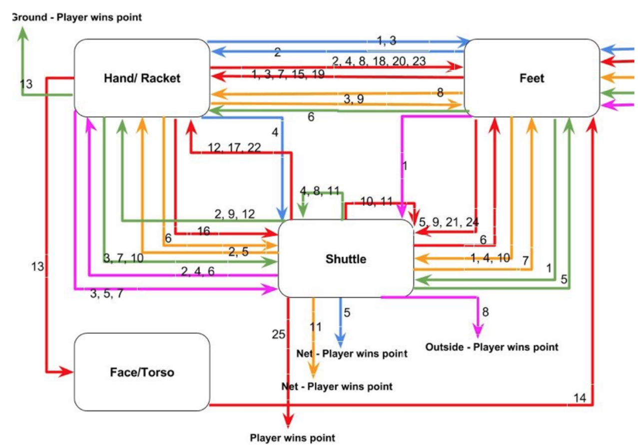

Figure 7: The state diagram of a complete rally for Serve-5 (PP is executing a serve) when the PP is playing against the 5 OP's. Each colour arrow indicates each OP player.

amateur players attention to the hand/racket are indicative of a process aimed to estimate return response location and force from angle of the arm/racket, which was also reported in a similar naturalistic setup to compare gaze behavior when playing with known/unknown players [Mavalankar et al. 2015]. The amateur players attention was on the hand/racket or face/torso while executing the serve. Wherein they are possibly attempting to predict the return location and force from the angle of the racket or reading the emotions or stress on the opponent's face [Cheshin et al. 2016; Shih and Lin 2016]. But the professional player's first fixation is the feet of the opponent as it provides vital cues on opponent's readiness [Del Villar et al. 2007] to move across the court and predict the return position of the shuttle. Post experiment, the PP confirmed he is able to predict the readiness/speed of moving across the court from

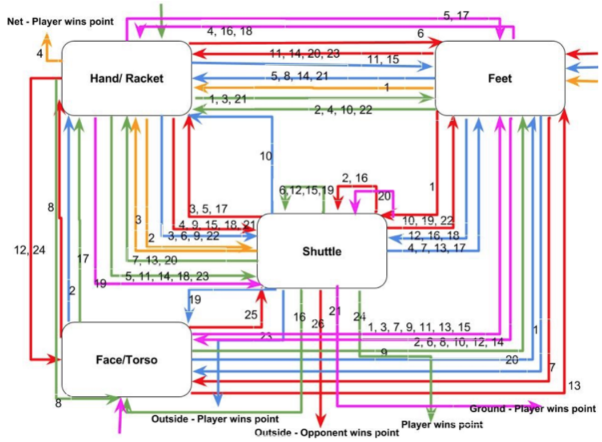

Figure 8: The state diagram of a complete rally for Serve-6 (PP is receiving a serve) when the PP is playing against the 5 OP's. Each colour arrow indicates each OP player

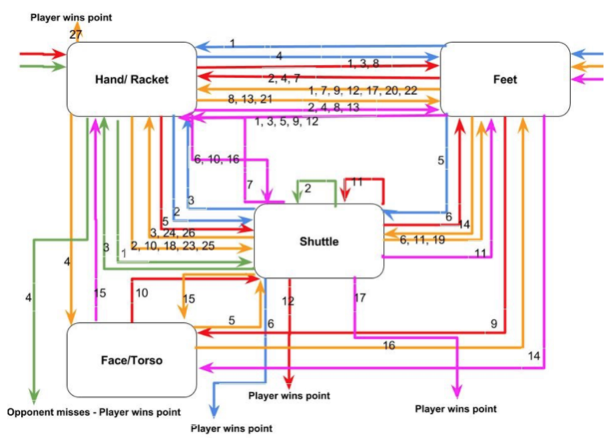

Figure 9: The state diagram of a complete rally for Serve-10 (PP is receiving a serve) when the PP is playing against the 5 OP's. Each colour arrow indicates each OP player.

the cues provided by the angle and position of the feet. The PP's training strategy to deduct facial expressions as a distraction, also confirmed verbally post experiment, while the torso seems to not provide any new kinematic information about the game strategy to the PP was evident by the sparse gaze data at this AoI. The second AoI was the hand/racket, the upper limb position cues and holding angle of the racket gives information on the probable trajectory of the shuttle on return strategy of the opponent.

The number of fixations for the professional player were less than those of the amateur players in contrast to [Abernethy and Russell 987a,b; Alder et al. 2014] but in line with [Chia et al. 2017] . But a few studies have also reported that highly skilled players exhibit a search strategy of fewer fixations of longer durations than novice players [Piras et al. 2014] and longer visual fixation duration on the target [Lee et al. 2009; Vickers 1996]. A reason for the fewer fixations for PP could be the ability to filter 'noise' in the visual search space that is, extract only the relevant cues for a winning strategy. The authors would like to stress that while the findings are significant and add to the knowledge about eye tracking as a method to understand the correlation between visual information and cognitive processes, it is only an introduction. A larger sample set of expert or world-rank players data is required to make strong inferences.

5 CONCLUSIONS

The visual cues extracted from not one spatial location (first or the last) but the process to reach the final location extends the concept of the quiet-eye phenomenon to dynamic sports. The scanpath analysis also gives insights about the cognitive processing for a game strategy derived by extracting the postural cues of the opponent. The inferences from this study can be limited due to the following reasons: the sparsity of PP data (only one PP) and/or the lower fixation duration compared to amateur players could be due to the professional players confidence playing against amateurs and hence lower concentration on the gameplay. But, during the gameplay, the experimenters did not notice any disinterest in the PP at any time. Even with the above limitations on the inferences that can be made, the results add to the growing research on sports sciences.

6 AUTHOR CONTRIBUTIONS

Author Aditi Mavalankar conducted the experiment and carried out initial analysis, Nithiya Shree Uppara was involved in analysis and preparation of the manuscript. Kavita Vemuri was involved in experiments, analysis and manuscript preparation. All authors contributed to the data analysis, drafting of the manuscript as well as the final approval of the work to be published.

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