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Expert Perceptual Behavior under the Spatiotemporal Visual Constraints in Table Tennis

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ABSTRACT

OBJECTIVES The perceptual ability to detect movement is essential for expert table tennis players. A spatiotemporal occlusion paradigm was employed to examine the critical information that facilitates athletes' perception.

METHODS Thirty-one expert table tennis players, 29 participants and 2 demonstrators, volunteered to participate in the study. Four types of temporal conditions and five types of spatial occlusions were displayed in experimental videos of two opponents playing a table tennis forehand stroke. Period t1–4 represented the four temporal conditions, with 250, 500, 750, and 1000 ms of action being occluded, respectively. The five types of spatial occlusion involved showing the kinematics of only the ball, paddle, arm, trunk, or head. The participants were instructed to judge the landing direction of the ball on the basis of the information in the footage.

RESULTS The footage depicted the longest period of play. Furthermore, in separate trials, the spatial information (for the ball, torso, or head) was missing because of occlusion. The absence of such critical spatiotemporal information impaired the ability of players to make an accurate prediction.

CONCLUSION Players obtained crucial spatiotemporal information if the timeframe of the video was relatively complete and spatial information on the opponent's torso and head was available. For peak performance, expert table tennis players perceive and detect the optical flow of the ball's flight and consider invariant information concerning their opponent's torso and head.

Introduction

Anticipation skills are essential for interceptive sports such as table tennis. To attain peak performance, table tennis players must accurately perceive their opponent's actions to formulate an effective defense. Therefore, the following questions should be addressed. What is the timing for the focus of expert players on their opponent's movement? What type of spatial information regarding the opponent's body parts do athletes require for a superior offense? Answers to these questions might help establish a general rule for instructors to apply when teaching defense against an attack to table tennis players.

Evidence on temporal occlusion has confirmed that experts make precise predictions during the ball-flight period once an opponent acts [1,2]. For example, expert and novice tennis players were recruited to judge the direction of an opponent's service [1]. All tennis players observed the service situation at five levels of temporal occlusion. In the first, second, and third level, tennis players watched videos that were occluded 900 ms, 600 ms, and 300 ms before the

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racket–ball contact, respectively. In the fourth level, tennis players observed a footage in which the point of racket–ball contact was displayed. In the fifth level, the video showed the server's follow-through motion in addition to the postcontact movement of the ball until it reached the net. The findings revealed that superior prediction accuracy was possible under the coupled response condition during the ball flight. The research suggested that tennis players who judged the ball direction well could adopt a return posture to obtain information from the ball-flight trajectory [1]. Therefore, individuals rely on ball-flight optical flow to perceive dynamic patterns that aid an effective response [3].

Over forty years, numerous studies have adopted spatial and temporal occlusion methods [2,4-6]. In studies using the spatial occlusion method, participants viewed point-light displays under a range of spatial occlusion conditions and anticipated the direction or depth of badminton strokes [2,7]. The spatial occlusion presented only a single body segment such as racket + ball, arm + ball, upper body + ball, and lower body + ball. Compared with nonexpert players, expert players focused more on lower body information to accurately anticipate their opponent's actions in diverse situations. Another study employed spatial occlusion to block serve actions under the following five conditions: (A) no body segments or objects were occluded, (B) only the ball was occluded, (C) the server's racket and racket-holding arm were occluded, (D) the server's hips and legs were occluded, and (E) the server's entire body and his racket were removed so that only the server's head and the tennis ball remained visible [4]. The results indicated that the players' anticipation skills deteriorated when information from the ball toss and the arm and racket region were occluded. The main principle of the spatial occlusion paradigm is that if a spatial area is essential, its occlusion leads to a decline in performance [8]. A specific and constant relationship exists between individuals and the environment. In particular, patterns of information gathered over time and space are retained as invariants—in that structural properties remain constant with respect to varying conditions [9]. Moreover, individuals apprehend the structurally invariant pieces of information that help them perform efficiently. In a badminton competition, for instance, when preparing to return the stroke, defenders must detect their opponent's smash, clear, or drop shot. Researchers have examined how badminton experts distinguish stroke patterns from their opponent's actions [10,11]; badminton experts pick up information on their opponent's forearm and racket to differentiate different stroke types. Such invariant spatial details facilitate the prediction of the shuttlecock landing direction. Hence, individuals perceive and detect invariant information to improve their prediction capability.

Studies on attention and the oculomotor system have clarified the role of visual fixation that is consistently linked to information extraction in promoting the anticipation skills of table tennis players [12-14]. Expert table tennis players were instructed to judge the landing direction of the opponent's impending stroke. The findings highlighted that expert table tennis players primarily fixated on crucial spatial information; the opponent's torso, head, and paddle grip; and ball trajectory for judging the landing direction during a forehand stroke or a backhand drive. Moreover, prediction accuracy improved remarkably when the video displayed an extended period. Nevertheless, most studies have separated spatial and temporal occlusion to examine critical information in sports. One study combined temporal and spatial occlusion methodologies to examine skill differences in the anticipation of information [15]. These methodologies clarify the mechanisms used by experts to differentiate the combinative sources of spatiotemporal information.

Table tennis, tennis, and badminton are fast-paced sports that require an appropriate return. In such interceptive actions, the ability to anticipate the opponent's movements helps the expert player deal with challenging spatiotemporal constraints [16]. Therefore, we aimed to employ such spatiotemporal visual constraints to identify expert perceptual behavior. Key spatiotemporal cues help the table tennis player correctly judge the direction in which the ball will land.

Methods

Participants and opponents

Twenty-nine expert table tennis players, including 17 male players and 12 female players, were recruited from the National Intercollegiate Athletic Games in Taiwan to participate in this experiment. Participants were 23.31 ± 2.77 years old, and all were right-handed. They had played table tennis for an average of 13.1 ± 3.03 years. The participants, ranging from Olympic champions to regional level competitors, were considered expert athletes; those with at least 2 years of experience in a sport can be regarded as experts [17]. All participants signed a consent form to protect their rights. This study was conducted in accordance with the Declaration of Helsinki.

Two table tennis experts served as opponents to stop participants from memorizing a single opponent's movement pattern. Opponent A was 20 years old and had 10 years of table tennis experience. Opponent B was 26 years old and had 16 years of table tennis experience. Both experts played table tennis with a right-handed shake-hand grip. These two male opponents were also experts, according to the aforementioned criterion [17]. No gender-matching was necessary between the participants and the opponents because expert table tennis players should return attacks made by opponents of both genders in mixed doubles competition.

Occlusion-condition sampling

Regarding the resolution of the video recording, a camera (Coolpix P300, Nikon) was set at 120 Hz and positioned behind the end line of the table tennis table. The forehand stroke of both opponents was recorded for the experimental video. We checked the original film frame-by-frame to confirm paddle–ball contact, and we used Adobe Photoshop and Premiere software (Adobe, State of California, USA) to edit the videos according to the spatiotemporal occlusion conditions.

We edited the film according to four temporal occlusion conditions, which were abbreviated as T1, T2, T3, and T4. The paddle–ball contact was used as the cut-off point. Four sequences of temporal occlusions were presented in the following arithmetic progression: (1) T1 as the occlusion point relative to the paddle–ball contact at −750 ms; (2) T2 as the occlusion point relative to the paddle–ball contact at −500 ms; (3) T3 as the point of paddle–ball contact; and (4) T4 as the occlusion point relative to the paddle–ball contact at +250 ms <Figure 1>.

In addition to temporal occlusion, spatial occlusion was employed in which only single body segments were presented, in reference to related studies [2, 7]. A total of five spatial locations were occluded: (1) the opponent's paddle-holding arm (OA), (2) only the ball (OB), (3) the opponent's paddle (OP), (4) the opponent's torso (OT), and (5) the opponent's head (OH). <Figure 2> presents the spatial occlusion conditions.

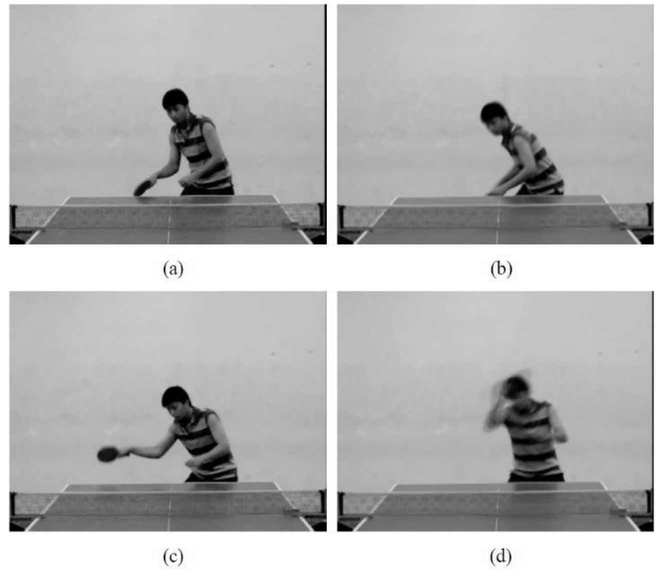


Figure 1. Sample final frames from the displays presented in the experiment. Occlusion occurred at (a) the occlusion point relative to the paddle–ball contact at −750 ms (T1), (b) the occlusion point relative to the paddle–ball contact at −500 ms (T2), (c) the point of paddle–ball contact (T3), or (d) the occlusion point relative to the paddle–ball contact at +250 ms (T4).

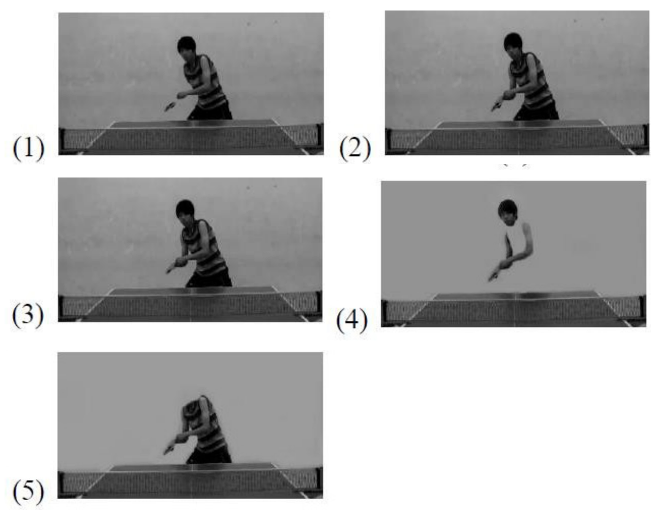


Figure 2. Spatial occlusion conditions are shown from left to right. The (1) paddle-holding arm (OA), (2) ball (OB), (3) paddle (OP), (4) torso (OT), and (5) head (OH) were spatially occluded.

Spatial and temporal occlusions were integrated into spatiotemporal occlusions. For instance, the experimental trial randomly displayed T1 plus OA, T2 plus OT, or T4 plus OB, and so on, instead of only the T1, T2, T3, T4 and OA, OB, OP, OT, and OH conditions. Each participant completed two 80-item experimental trials involving 4 (temporal occlusions) × 5 (spatial occlusions) × 2 (right- and left-direction paths) × 2 (opponents) variables. All videos in the trials were randomly displayed from the receiver's perspective; thus, the participants underwent the 80 randomized trials twice.

Experimental setting and procedure

A projector (PJD6531w, ViewSonic) was placed approximately 3 m behind the DaMat screen (width: 160 cm and height: 180 cm) to display the video of the opponent performing a forehand stroke. Both opponents were instructed to land the ball in a target area (a quarter circle with a radius of 20 cm) in the corner of the right or left side of the table. To increase the consistency in the task design, participants adopted a preparatory posture 0.3 m away from the end of one half of a table tennis table to judge the ball-landing direction. Moreover, the screen displayed opponents playing a forehand stroke from behind the other half of the table. The experiment was set up to resemble the typical on-court view of players <Figure 3>.

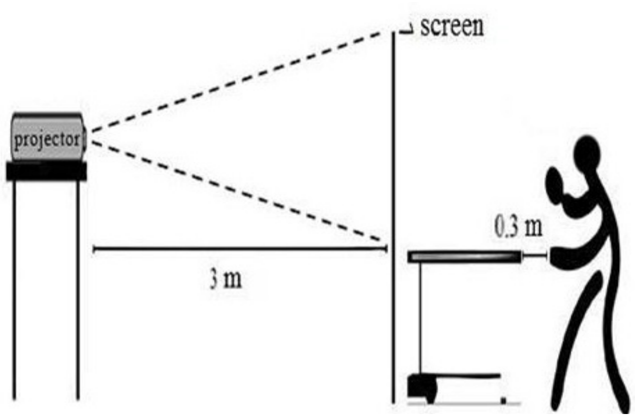


Figure 3. Experimental setting

Participants used a shake-hand paddle grip (Baum Carrera SENSO, DONIC) to indicate their prediction action. They performed a forehand or backhand action to indicate their anticipation of the direction in which the ball may land on the table. For instance, if participants judged that the ball may land on the left side of the table, they used a defensive backhand to block the ball; conversely, if they anticipated that the ball may land on the right side of the table, they performed a defensive forehand to block the ball. Participants were given 2 seconds to make the decision for their prediction for each trial. After each trial video, participants were required to make instantaneous decisions as if planning to defend the ball.

Nine practice trials involving four temporal occlusion videos (T1, T2, T3, and T4) and five spatial occlusion videos (OA, OB, OP, OT, and OH) were provided in a pretest to enable participants to become familiar with the experimental procedure. The subsequent 160 experimental trials took approximately 17 minutes to complete. After completing 80 trials, participants rested for 3 minutes to prevent fatigue. The experimental trials were separated by 5 seconds to ensure that the participants had sufficient time to judge each trial. Irrespective of the landing direction (on the right or left side), a digital camera (HDR-SR12, Sony Handycam) was used to record the entirety of the participants' return actions that stemmed from their prediction.

Measurements and statistical analysis.

Accurate predictions were defined as participants using a forehand stroke to return a ball landing on the right side and a backhand stroke to respond to a ball landing on the left side. The percentage of accurate predictions was calculated as a dependent variable under the spatiotemporal occlusion condition.

The data analysis was conducted in three stages. First, interobserver reliability in the data collection was evaluated through Pearson product-moment correlation for paddle–ball contact. We used the Pearson correlation coefficient was to quantify the degree of interobserver reliability that was obtained from two male expert coaches for judging the timing of paddle–ball contact. The coefficients were significantly similar ($r = 1.000$; $p < .01$). This result indicated that the two coaches had high homogeneity when assessing the cut-off point of paddle–ball contact. Therefore, the experimental video contained consistent visual cues.

Second, an independent-sample *t* test was used to confirm that no gender difference existed in perception capabilities at the start of the study. Hence, this *t* test was performed on the full data set. An independent-sample *t* test indicated that the experts' prediction capability did not differ significantly between male and female players in the pretest ($t(27) = -1.58$; $p > .05$). All participants' prediction levels were initially similar and were also not affected by gender differences. Consequently, the direction prediction results were influenced by the manipulation of spatiotemporal occlusion.

Finally, data on the prediction accuracy of all participants were analyzed using a 4 (temporal occlusions) × 5 (spatial occlusions) factorial two-way repeated measures analysis of variance (ANOVA). Simple main effect tests were conducted on the post hoc analysis findings for the interaction term of significant temporal occlusions × significant spatial occlusions. The alpha level was set at .05. Eta-squared (η^2) and Cohen's d were calculated as indicators of effect size.

Results

Repeated measures ANOVA demonstrated a significant interaction between temporal occlusion and spatial occlusion ($F(12, 336) = .32$; $p < .05$, $\eta^2 = .16$). <Figure 4> illustrates the interaction between the two factors. Simple main effect tests revealed that with the temporal occlusion (T3), in which the opponent's stroke is displayed from the beginning to the paddle–ball contact, the prediction accuracy when the opponent's torso and head (OT and OH) were spatially occluded was significantly poorer than when the opponents' paddle-holding arm, the ball, and the paddle (OA, OB, and OP) were spatially occluded ($p < .05$). Furthermore, with the temporal occlusion (T4), in which the time frame from the beginning to the ball crossing over the net was displayed, the prediction accuracy when the ball (OB: 79.31 ± 14.67) and the opponent's torso (OT: 90 ± 13.63) were spatially occluded was significantly lower than when the opponent's paddle-holding arm, paddle, and head (OA, OP, and OH) were spatially occluded ($p < .05$). For all of the spatial occlusion situations, the experts' prediction in the T4 condition was significantly more accurate than in the other temporal occlusion conditions (T1, T2, and T3; $p < .05$).

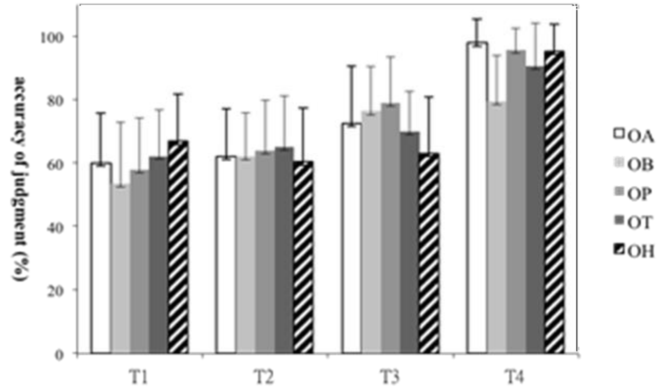
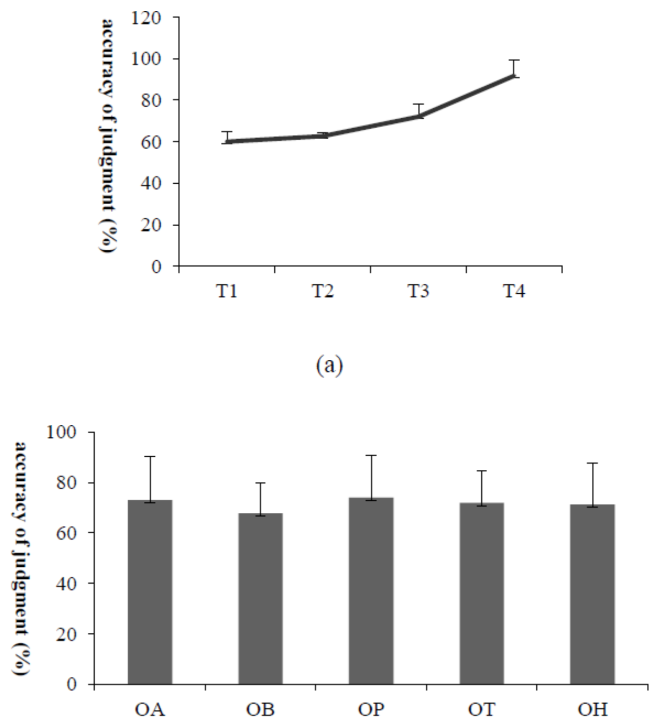


Figure 4. Prediction accuracy for different spatiotemporal occlusions



(a)

(b)

Figure 5. Main effect of (a) temporal occlusion and (b) spatial occlusion on the accuracy of table tennis experts' prediction of stroke direction.

The ANOVA results revealed significant main effects for temporal occlusion ($F(3, 84) = 97.86$; $p < .05$; $\eta^2 = .78$) and spatial occlusion ($F(4, 112) = 3.46$; $p < .05$; $\eta^2 = .11$). For temporal occlusion, a paired comparison revealed that the experts' predictions at T3 (72.07% ± 6.18%) were more accurate than that at T1 and T2 (60.00% ± 4.96% and 62.67% ± 1.82%). When the video displayed the time frame from the beginning of the stroke to paddle–ball contact, the experts' predictions were more precise than when the video showed the time frame from the beginning to the slight backswing or complete backswing. Furthermore, the accuracy at T4 (91.72% ± 7.44%) was higher than that at T1, T2, or T3. Therefore, when the video provided full information from the beginning to when the ball crossed over the net, the experts detected sufficient information to correctly judge the landing direction. In terms of spatial occlusion, compared with the OB condition (67.78% ± 12.16%), the experts' predictions were more accurate in the OA, OP, and OT conditions (73.06% ± 17.4%, 74.03% ± 16.95%, and 71.88% ± 12.83%, respectively). <Figure 5> demonstrates the main effect. Information on the ball-flight trajectory was the critical spatial information affecting the experts' perception and actions.

Discussion

The authors aimed to experimentally manipulate spatiotemporal constraints to identify the spatiotemporal cues that help experts anticipate the landing direction of the ball. The main findings of this study were that expert perceptual behavior was weakened under the spatiotemporal constraint of the opponent's torso, the opponent's head, and the ball being occluded, as revealed through video and that lasted from the beginning to when the ball contact crossed over the net and contacted with the player's paddle. Thus, expert table tennis players could concentrate on the center of their opponent's body and the ball at a late stage of the opponents' movement to help them anticipate better.

When the video duration was short (T1 and T2), expert table tennis players failed to make accurate predictions. However, they made more precise predictions when the footage showed the opponents' movement from the beginning of the stroke to the paddle–ball contact (T3) and from the beginning to when the ball crossed over the net (T4). In studies on badminton and tennis, players were requested to predict the depth and direction of an opponent's stroke and service [1,2]. All participants watched temporally occluded videos, and they made a lower percentage of prediction errors when the film had a shorter occlusion duration. In dynamic sports situations, expert and novice table tennis players observe the backhand drive and forehand topspin technique to predict the final landing position of a ball. Related results have indicated that the rate and fixation of microsaccades were significantly improved during the postbounce period and for long durations [12,13]. Moreover, in team sports situations, senior futsal players adopted suitable behavior to cope with the task when the observational time increased [18]. In our research, the footage had temporal occlusions with fewer constraints, which provided more optical flow information. Expert table tennis players could obtain critical visual cues to accurately judge the ball-landing direction. Therefore, temporal information concerning an opponent's movement patterns and the ball-flight trajectory can augment a player's prediction capability.

Our investigation highlighted that errors in prediction arose as the ball was occluded. This finding is similar to those of previous studies [4,15] in which tennis players judged the landing direction of their opponent's serve. In the aforementioned studies, the relevant videos randomly displayed occlusion of the ball, the server's arm and racket, the server's lower body, or the server's whole body. Their results indicated that the players failed to accurately judge the landing direction if the ball was occluded. During a competition, the environment contains ample information, including information on the opponent, coach, and teammates. Excellent table tennis players must direct their attention to the right information to improve performance or prediction. Scholars who have adopted an ecological approach to psychology have emphasized invariants or structural properties that remain constant under changing conditions [9]. Thus, in past and present studies, the opponent's movement patterns continuously change over the timeline. Observers' attention was most likely attracted through the microsaccades directed toward the racket and ball trajectory [13,14]. Furthermore, if the invariant ball information was occluded, expert table tennis players could not detect critical information to accurately judge the landing direction. Therefore, the ball-flight trajectory is the invariant information required by expert table tennis players to judge ball-landing paths.

When interpreted separately, the temporal or spatial occlusion main effects in this study indicate the information detected by expert table tennis players to correctly judge the landing direction. However, in real-life situations, table tennis players must detect temporal and spatial information simultaneously. Therefore, both factors were combined to create a spatiotemporal occlusion to explore the crucial spatiotemporal information necessary for experts to judge the landing direction. According to our research findings, when expert table tennis players watched the video footage from the beginning of the stroke to paddle–ball contact, the opponent's torso and head constituted the key spatial information for judging the landing direction. Moreover, expert table tennis players could not perceive the chief spatiotemporal information to advantageously judge the landing direction when they watched the footage from the beginning of the stroke to when the ball crossed over the net in which the opponent's torso and the ball were occluded. These results lead to a conclusion similar to those of previous studies [14,19], which employed eye trackers to examine participants' points of focus. These studies reported that table tennis and tennis experts spent more time observing the center of their opponent's body before returning the ball. Athletes perhaps fixed their focus on these central areas for improved attention on chiefly those areas and less on the surrounding regions [14]. Expert table tennis players interacted with the video stimulus—if the spatial information on the ball and torso were occluded during the complete temporal period, they could not detect structural invariant information to improve the precision of their prediction. Consequently, expert table tennis players had to direct their attention to the film displaying the opponent's movement pattern from the beginning of the stroke to the ball flight; in the meantime, they detected spatial information concerning the ball and opponent's torso and head to execute an appropriate action.

Conclusions

Because the video displayed only part of the opponent's movement patterns and the ball-flight trajectory was occluded, expert table tennis players judged the ball landing direction inaccurately. Moreover, players paid attention to detecting the movement patterns of the opponent's torso and head to determine suitable action.

The optical flow and invariant spatial features facilitate the pivotal step of verifying the information that must be perceived to become adept at a specific task. This evidence-based study demonstrates that at the training level, knowing the fundamentality of perceptual properties in this sport and the particular cues detected by top players can benefit the design of instruction and perceptual training.

Conflicts of Interest

The authors declare no conflicts of interest. The founding sponsors had no role in the design of the study; the collection, analyses, or interpretation of data; the writing of the manuscript; and the decision to publish the results.

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