# Title:

Perceptual response and information pick-up strategies within a family of sports

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### Abstract

The purpose of this study was to determine whether and how the perceptual response of athletes differed depending on their sporting expertise. This was achieved by comparing the responses of tennis and soft tennis players. Twelve experienced tennis players and 12 experienced soft tennis players viewed computer graphic serve motions simulated by a motion perturbation technique, and then scaled their anticipatory judgments regarding the direction, speed, and spin of the ball on a visual analogue scale. The first experiment evaluated the player's judgments in response to test motions rendered with a complete polygon model. The results revealed significantly different anticipatory judgments between the player groups when an elbow rotation perturbation was applied to the test serve motion. The second experiment used spatially occluded models in order to investigate the effectiveness of local information in making anticipatory judgments. The results suggested that the isolation of visual information had less effect on the judgment of the tennis players than on that of the soft tennis players. In conclusion, the domain of sporting expertise, including those of closely related sports, can not only differentiate the anticipatory judgment of a ball's future flight path, but also affect the utilization strategy for the local kinematic information.

# **Keywords:**

Visual perception; Computer graphics simulation; Motion perturbation; Spatial occlusion; Tennis; Soft tennis

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### 1. Introduction

An analogy can be made between different sports games and "members of a family". Some sports belong to a family of related games; a sport may be a descendant of another sport but also a cousin to other sports. For example, softball is a direct descendant of baseball, while cricket belongs to the bat-and-ball family of games that also includes softball and baseball. Football is another family of sports, which also includes soccer, futsal, and rugby. Although some rules and equipment differ among the members in a family of sports, the required motor skills are similar and are often transferrable from one sport in the family to another.

Lawn tennis is related to real tennis (court tennis), short tennis, wheelchair tennis and *soft tennis*. Soft tennis is a direct descendent of lawn tennis and was developed in Japan after the introduction of tennis at the end of the 19th century and is currently one of the official competitions of the Asian Games. The court size and basic rules of soft tennis are the same as those of tennis; however, the equipment used is significantly different. The soft tennis ball is made from soft rubber and is filled with air. The soft tennis racket is relatively light in weight (200 g ~ 280 g) compared with the tennis racket (230 g ~ 350 g), while both rackets are approximately the same length (normally 690 mm). The stroke techniques of soft tennis are very similar to those of tennis (Ida, Kusubori, & Ishii, 2005; Ida, Nakamura, Suda, & Ishii, 2002), e.g., the overhand serve (Fig. 1). The differences in equipment, however, may alter the outcome of a shot and may critically affect the perceptual behavior of an opponent. For example, the instantaneous ball velocity during a high performance tennis serve is known to exceed 200 km/h, whereas that of soft tennis serve was estimated to be a maximum of 190 km/h (Ida, et al., 2002).

Numerous studies have revealed that skilled tennis players predict the properties of future movements, such as the ball direction, more accurately than less skilled players. In addition to considerable evidence from empirical video display tests, the superiority of skilled players has been also demonstrated in several studies that use more natural, on-court settings and monitor player's reaction while playing (Farrow & Abernethy, 2003; Shim, Carlton, Chow, & Chae, 2005). However, little is known about the differences in perceptual behavior between sports, partly because it is difficult to match the environment, situation, and action of different sports even within a family of related games. By performing a well-controlled comparison between skilled player groups from different domains of expertise, it will be demonstrated how a domain-specific training differentiates the perceptual-cognitive adaptation to each play of game, which has not been evident from a traditional approach using different skill levels in only one kind of sport. Brain activities, particularly related to the initiation of movement (motor potential), were shown to vary between fencing athletes and karate athletes when they responded to an attack displayed on a display monitor (Del Percio, et al., 2008). This study

also demonstrated other multifactorial contributors on the cortical activation, such as side of the attack and hemisphere. It appears that in the context of these intertwined neural mechanisms, the specific expertise associated with different sports within a family can be observed as a difference in the perceptual response.

The visual system can recognize human movements performed by graphically represented models. For example, the point-light model that provides minimal kinematic information with a cluster of moving spots can evoke a compelling impression of human action. This response is known as biological motion perception (Johansson, 1973). Using the point-light display technique, it has been shown that observers were capable of predicting the direction of shots in tennis (Shim, et al., 2005; Ward, Williams, & Bennett, 2002), in squash (Abernethy, Gill, Parks, & Packer, 2001), and in badminton (Abernethy & Zawi, 2007). Meanwhile, by applying a motion linearization technique with principal component analysis (Troje, 2002), the motions of tennis passing shots were synthesized and displayed with a stick-figure model (Huys, Smeeton, Hodges, Beek, & Williams, 2008). The results revealed that tennis players could predict the ball direction by extracting the information embedded in the low-dimensional dynamic modes of the opponent's motion.

Furthermore, computer graphics (CG) of humanoid characters and virtual environments (VE) are also of use in the assessment of perceptual behavior, and occasionally perception-action coupling, in sports. In previous studies, pre-impact anticipatory cues could be extracted from a CG polygon humanoid model that simulated the tennis serve, although the judgment response of participants viewing these model simulations was less accurate than the judgment response of participants who watched a matched video display (Fukuhara, Ida, Kusubori, & Ishii, 2009). In addition, tennis players were sensitive to changes in the opponent's arm motion that was simulated by another polygon model (Ida, Fukuhara, Kusubori, & Ishii, 2011; Ida, Fukuhara, Sawada, & Ishii, 2011). Using a VE display for baseball batting, it was shown that the stepping pattern of skilled batters was related to the motion of the pitcher (Ranganathan & Carlton, 2007).

CG and VE displays enable researchers to manipulate or perturb the motion stimuli arbitrarily and in accordance with what they intend to test. For example, for three types of tennis serves: flat, slice, and topspin, the spatial extent of the human movement was expanded or reduced with reference to the average of these three serves and presented using a polygon humanoid model (Pollick, Fidopiastis, & Braden, 2001). The results indicated that the serve motion became more accurately categorized as the degree of spatial exaggeration increased. Meanwhile, on the basis of a motion synthesis technique for tennis shots (Huys, et al., 2008), several manipulations, e.g., spatial occlusion, neutralization (Huys, et al., 2009), and interchange (Canal-Bruland, van Ginneken, van der Meer, & Williams, 2011; Williams, Huys, Canal-Bruland, & Hagemann, 2009), were conducted to perturb the motion and to assess the effect of the perturbations on the information pick-up of

players. This series of studies showed that the racket and racket-arm were the best sources of information available for the anticipation of the shot direction. In addition, these studies also suggested that skilled players benefitted from global visual information from multiple locations on the body as well as the limited local information from the racket and racket-arm. Another perturbation operation that modulates the upper arm joint rotation around the anatomical rotation axis was applied to the tennis serve of a polygon model (Ida, Fukuhara, Kusubori, et al., 2011). The results showed a monotonic shift in the anticipatory judgment of the ball direction with the perturbation rate.

Although these computationally simulated displays may be an approximation to real situations, such a simulation provides a certain level of insight into the perceptual response of sports players. In particular, computer modeling is of use in controlling, or abstracting, the displayed information at an intended level. Observers from different members in a family of sports may notice and be biased by trivial information other than the stroke motion, e.g., specific ritual actions, design of equipment, and brand of sports gear, but CG modeling enables the elimination of these non-essential cues. Thus CG displays would be effective in elucidating the specific perceptual responses underlying players' action. Furthermore, a motion perturbation technique that computationally manipulates the kinematic parameter can generate a standardized set of test motion patterns. Therefore these test motions should be helpful for finding out the pattern of adaptive

differentiation within a family of sports, or specialization, on a common basis of evaluation.

The ability to pick up information from local kinematics has been examined with a more conceptually straightforward technique that spatially occludes one or more local motions of a displayed humanoid model. The local motions of the badminton stroke were presented in isolation using a point-light model, and it was demonstrated that world-class badminton players extract the information necessary to predict the shuttle direction from the racket and the lower body (Abernethy & Zawi, 2007). A digital painting technique was also utilized to conduct a spatial occlusion on the video clip of a tennis serve (Jackson & Mogan, 2007). The results showed that the occlusions of the ball toss and the arm-and-racquet region significantly decreased the judgment accuracy of skilled players in comparison with the non-occluded tennis serve movement. A more computational approach was the spatial occlusion of synthesized tennis stroke motions (Huys, et al., 2009). The occlusion was such that the arm and racket were removed from the model, which significantly deteriorated the anticipatory judgment of the shot direction. In line with previous analyses, these spatial occlusion approaches have shown evidence that the end-effector, i.e., the racket, provides information that helps predict the future movement of the ball, and that skilled players also attempt to pick up informative cues from other body areas.

In this study, two experiments investigating the anticipatory judgment of tennis and soft tennis players were conducted using simulated motion perturbation and spatial occlusion. The first experiment was designed to examine the characteristics of the judgments made by tennis and soft tennis players. In this experiment, the test motions were created by perturbing the joint rotation of the original motion and by rendering the resulting motion with a CG polygon humanoid model as shown in Figure 2 (Fukuhara, et al., 2009; Ida, Fukuhara, Kusubori, et al., 2011). This perturbation approach was conceptually different to previous perturbation techniques, such as the spatial exaggeration from the average of three serve motions (Pollick, et al., 2001) and the interchange of selected body regions in simulated ground strokes (Canal-Bruland, et al., 2011; Williams, et al., 2009). The current perturbation technique based on joint rotation has the advantage of adherence to the anatomical constraints of the joint rotation axis. In addition, the polygon-type humanoid model is generally regarded as more realistic than traditional simplified models such as the point-light model (Abernethy, et al., 2001; Abernethy & Zawi, 2007; Ward, et al., 2002) and stick-figure model (Canal-Bruland, et al., 2011; Huys, et al., 2009; Huys, et al., 2008; Williams, et al., 2009), because it mimics the shape, color, and texture of the human body segments. In the second experiment, spatially occluded polygon models were used, and the functional contribution of local information to the judgment of players was evaluated by taking the response to the complete model from the first experiment as the reference. A spatial occlusion of computationally created tennis motions was used in the study that adopted the synthesized motion of ground strokes rendered by

stick-figure models (Huys, et al., 2009). Another spatial occlusion in the current study focused on the existence or lack of the racket because only the distal parts of the racket-arm had been analyzed and perturbed. Although the occluded areas were limited in the experiment, this approach enabled a detailed discussion about the effect of the perturbation that rigorously adhered to the anatomical constraint of a single joint rotation.

The primary purpose of the current study was to determine whether and how the judgment of tennis and soft-tennis players differed from one another when they anticipated the outcome of the simulated CG serve. Although this study builds on numerous others that have investigated skill development using the "skilled and less skilled" paradigm, instead, a "skilled and (differently) skilled" paradigm was used to reveal aspects of skill development including skill differentiation and specialization. The comparison between two related skilled groups would provide further insight into the perceptual-cognitive expertise in terms of adaptive differentiation in the judgment strategy, which occurs as a result of the expertise-specific training. In addition, this approach is likely to also have an advantage in focusing on the effect of cognitive process because it excludes other potential biasing factors depending on the level of expertise such as property of visual system and level of motivation. Another aim of this study was to provide further understanding about how this motion perturbation caused observers to change their judgment. It was expected that the selection of the perturbed joint rotation (forearm pronation or elbow extension, see 2.2. Visual Stimuli) would affect the response

patterns of both expertise groups as shown in a previous study of tennis players (Ida, Fukuhara, Sawada, et al., 2011). In addition, the study has also suggested that tennis players' prediction of the ball direction and spin shifted with an increase in the absolute rate of perturbation applied to the racket-arm. Thus, it was also expected that the gap of the anticipatory judgment between the domains of expertise is obvious under higher perturbation conditions. Furthermore, a hypothesis was proposed that a correlation between the responses to the complete model and the spatially occluded model would remain but that the occlusion of the end-effector would critically change the observer's response.

### 2. Experiment 1

### 2.1. Participants

Twelve experienced tennis players with a mean age of 21.1 years (range 19-23) and mean experience of 7.1 years (range 5-10), and 12 experienced soft tennis players with a mean age of 20.9 years (range 18-24) and mean experience of 7.0 years (range 4-12) participated in the experiment. All of the participants were college students or graduate students who were competing in college level games and who trained several times a week. The tennis (soft tennis) players had no experience participating in competitive soft tennis (tennis) during high school, college, or graduate school. The participants gave their informed consent prior to the experiment. The

experiment was approved by the local ethical committee of the Tokyo Institute of Technology.

#### 2.2. Visual Stimuli

The visual stimuli used in Experiment 1 were created by an procedure used in a previous study (Ida, Fukuhara, Kusubori, et al., 2011). A skilled 23-year-old right-handed tennis player with 10 years of experience, who was unfamiliar to all the participants, served as a model player. The original serve motion data were obtained through a video-based motion measurement. A motion perturbation procedure, i.e., a computational operation on the original motion, was then carried out to generate simulated motion data. A polygon humanoid character was then used to render the test animations on the basis of the collected and generated motion data.

The flat serve of the model player, aimed at the center of the right service box, was videotaped with two synchronized high-speed cameras (HSV-500C<sup>3</sup>, Nac Inc., Tokyo, Japan) operated at 250 Hz, and then digitized frame-by-frame using motion analysis software (Frame-DIAS II, DKH Inc., Tokyo, Japan). Using the obtained three-dimensional coordinate data, the anatomical joint angular velocities (Winter, 2005), i.e., the rotational speed of the joint around an anatomical axis, were estimated for every racket-arm joint. The forearm pronation/supination and the elbow extension/flexion were chosen to be perturbed because the angular

velocities of these motions demonstrated a relatively high and unidirectional behavior, i.e., the forearm pronation and elbow extension persisted throughout the forward swing phase. To calculate the angular velocity of each anatomical joint, the resultant joint angular velocity was firstly calculated as the relative angular velocity of the distal segment with respect to the adjacent proximal segment in three-dimensional space:  $\omega_{\text{forearm(joint)}} = \omega_{\text{distal forearm}} - \omega_{\text{proximal forearm}}, \omega_{\text{elbow}} = \omega_{\text{proximal forearm}} - \omega_{\text{upper arm}}$ . The forearm pronation/supination angular velocity and the elbow extension/flexion angular velocity were then determined as the scalar projection of each resultant joint angular velocity onto the corresponding rotation axis:  $\omega_{\text{pronation/supination}} = \omega_{\text{forearm},joint)} \cdot k_{\text{forearm}}, \omega_{\text{extension/flexion}} = \omega_{\text{elbow}} \cdot i_{\text{elbow}}$ . Here  $k_{\text{forearm}}$  and  $i_{\text{elbow}}$  were the longitudinal axis of the forearm and the medial-lateral axis of the elbow, respectively. The central dot,  $\bullet$ , designates the dot product operation.

The perturbation operation was executed by modulating the angular velocity of each joint separately. The perturbation was defined such that displacements were generated simultaneously in all the distal segments of the perturbed joint, which is a basic concept of conventional forward kinematics calculations (Zatsiorsky, 1998). Meanwhile, the position and orientation of all the proximal segments, including the target joint, remained unchanged. The perturbation duration was set as the period of the forward swing phase, which began at the initiation of the forward swing (t = -0.12 s) and ended when the racket and ball made contact (t = 0). The perturbation rate was determined by the modulation coefficient, *C*, of the joint angular velocity:

 $\omega^{\text{mod}}_{\text{pronation/supination}} = C\omega_{\text{pronation/supination}}, \omega^{\text{mod}}_{\text{extension/flexion}} = C\omega_{\text{extension/flexion}}$ . The modulation coefficients were 0.70, 0.85, 1.00, 1.15, and 1.30, which correspond to perturbation rates of  $-30\%, -15\%, \pm 0\%, +15\%$ , and +30%, respectively. The  $\pm 0\%$  perturbed motion was approximately the same as the original motion, and was used as the control motion. In addition, the negative and positive perturbations corresponded approximately to a decrement and increment, respectively, of the forearm pronation or elbow extension speed. Finally, by performing a forward kinematics calculation with the modulated angular velocities of the anatomical joints, nine perturbed motion patterns were generated, including ±0% perturbation (control), -30%, -15%, +15%, and +30% with forearm perturbation; and -30%, -15%, +15%, and +30% with elbow perturbation. Note that the forearm perturbation did not generate a displacement of the wrist joint center but changed the orientation of the hand segment holding the racket. Therefore, the forearm perturbation apparently changed only the motions of the hand and racket, while the elbow perturbation displaced the forearm segment in addition to displacing the hand and racket from their positions in the original motion.

Test animations were rendered using CG animation software (Maya 4.5, Alias Inc., Toronto, Canada). The perturbed motion data were transformed into a skeleton-joint model, frame by frame, using a customized procedure developed using a script language for Maya (Maya Embedded Language, MEL). A polygon template character named "Jackie" (Maya 4.5 Documentation and Lessons) and a racket model created from

polygon objects were used for the rendering. The tossed ball was removed because the perturbed motion may cause the model to miss the ball or cause off-center contact between the ball and racket. To provide a realistic perspective for test subjects, the viewing point was set above the cross point of the baseline and sideline of the receiver's singles court at a height of 1 m. The test animation ran for 1.6 s with a frame rate of 50 Hz, and the animation was switched off immediately after the identical timing of the racket-ball contact. Figure 2 shows the test animation of the control motion ( $\pm 0\%$  perturbation, see also Mov. 1 and 2). The perturbed motions were checked to ensure that there was no apparent hyperpronation or hyperextension: the forearm pronation angle and elbow extension angle at racket-ball contact was -7° and -3° from the fully pronated and extended positions, respectively, for the fastest perturbations (+30%). The resultant linear velocity of the racket head immediately before racket-ball contact was 34.83 m/s for the control motion and ranged from 26.48 m/s to 40.73 m/s for the perturbed motions. This was comparable to previously reported mean racket head speeds, prior to the contact with the ball, of 43.2 m/s (SD 3.1) for tennis flat serves and 40.3 m/s (SD 2.9) for tennis kick serves stroked by high performance male players (Reid, Elliott, & Alderson, 2007), 31.1 m/s for tennis serves by elite males (Elliott, Marsh, & Blanksby, 1986), and 35.0 m/s (SD 2.1) for soft tennis serves by skilled males (Ida, et al., 2002).

### 2.3. Procedure

The participants sat in front of a large screen on which the test animation was projected. The visual angle of the test serve motion was adjusted to be equivalent to that in a real game, which is approximately 6.4°. The experiment was conducted using a stand-alone program constructed on application development software (REAL Basic, ASCII Solutions Inc., Tokyo, Japan). This software allowed the presentation of a QuickTime movie, collection of the user's responses, and automatic output of the collected data.

In the preliminary session, the participants viewed all of the test animations to familiarize themselves with the visual stimuli. Thereafter they proceeded to the main session. During a single trial of the main session, the test animation with  $\pm 0\%$  perturbation was presented three times as the control motion, followed by any one of the perturbed motions (including the  $\pm 0\%$  perturbation), which was also repeated three times. If there was any unintended playback behavior, such as frame skipping or jumpiness, the participants were asked to ignore the affected test motion and continue making judgments from the next test motion onwards. At the end of each individual trial, the participants were asked to make an anticipatory judgment regarding the ball direction, ball speed, and ball spin of the perturbed motion by comparing each motion with the control motion. They were also requested to make the judgments on the basis of their own sporting expertise. The judgments of the ball speed and ball spin were investigated because these properties are often covered in the coaching books for both

tennis and soft tennis, in addition to the judgment of ball direction, which has been of interest in most studies on the anticipation of tennis movements. The response for each test motion was rated on a visual analogue scale (VAS) relative to the control motion (VAS = 0). The VAS score ranged from -50 (left) to 50 (right) for the anticipated direction, -50 (slow) to 50 (fast) for the anticipated speed, and -50 (light) to 50 (heavy) for the anticipated spin. The participants took part in 27 trials consisting of nine perturbed motions that were each repeated three times. No feedback was provided to the participants during the trials.

#### 2.4. Data Analysis

All statistical analyses were conducted using the statistics software SPSS 17.0 (SPSS Japan Inc., Tokyo, Japan). The dependent variables were the VAS scores of the anticipated direction, anticipated speed, and anticipated spin. An arcsine transformation was applied to the VAS scores prior to the statistical analysis. The data set was separated into the forearm perturbations and elbow perturbations. Mixed-design two-way analysis of variance tests (ANOVAs) were then performed with the area of expertise (tennis or soft tennis) as a between-subject factor and the perturbation (-30%, -15%,  $\pm$ 0%, +15%, or +30%) as a within-subject factor. If the two-way ANOVA found a significant effect including the area of expertise of participants then a sub-effect test was also performed, if appropriate, where a Bonferroni adjustment was applied to pairwise multiple comparisons. If

Mauchly's test of sphericity showed a violation of the sphericity assumption, a Huynh-Feldt correction was applied to adjust the degrees of freedom. Partial eta-squared  $(\eta_p^2)$  values were collected as a measure of the effect size. The significance level was set at  $\alpha = 0.05$ .

### 2.5. Results and Discussion

#### 2.5.1. Forearm Perturbation

Figure 3 shows the VAS scores of the anticipated judgments for the test motions with forearm perturbations. For the anticipated direction, a two-way ANOVA showed that there was a significant main effect of the perturbation, F(3.37, 74.06) = 9.61, P < 0.001,  $\eta_p^2 = 0.304$ . Other two-way ANOVAs showed that there was also a significant main effect of the perturbation in the anticipated speed, F(3.59, 78.95) = 2.87, P = 0.033,  $\eta_p^2 = 0.115$ , and in the anticipated spin, F(2.99, 65.67) = 16.376, P < 0.001,  $\eta_p^2 = 0.427$ . The area of expertise of players appeared to have no significant effect on all anticipation tasks, although the anticipated direction displayed a marginally significant interaction between the area of expertise and the perturbation, F(3.37, 74.06) = 2.45, P = 0.063,  $\eta_p^2 = 0.100$ .

The results of these ANOVAs indicated that the participants changed their anticipatory judgments of ball

direction, speed, and spin with the perturbation rate regardless of their area of sporting expertise. The forearm perturbation operation generated a change in the motion of the hand and racket only. Thus, the findings implied that the participants modified their judgment based on the kinematic information of the end-effector. No obvious trend was observed between the expertise of play and all anticipatory judgments, which indicate that players from tennis and soft tennis predicted the future ball flight in a similar fashion. However, further testing of the anticipation of the ball direction may reveal some of the effects of expertise.

### 2.5.2. Elbow Perturbation

Figure 4 shows the VAS score of the anticipated judgments for the test motions with perturbed elbow movements. A two-way ANOVA for the anticipated direction revealed that there were no significant effects. Another two-way ANOVA for the anticipated speed indicated a significant interaction between the expertise of players and the perturbation of the motion, F(3.39, 74.66) = 3.86, P = 0.010,  $\eta_p^2 = 0.149$ . Post-hoc pairwise comparisons demonstrated significant differences between the groups at the +15% perturbation and the +30% perturbation with P values of 0.044 and 0.046, respectively. Furthermore, a two-way ANOVA for the anticipated spin showed that there was also a significant interaction between the expertise of players and the perturbation of the motion, F(4, 88) = 5.37, P = 0.001,  $\eta_p^2 = 0.196$ . Post-hoc pairwise comparisons demonstrated significant differences between the groups at the -15% perturbation, the +15% perturbation, and the +30% perturbation with *P* values of 0.004, 0.037, and 0.049, respectively. This ANOVA also showed that the main effect of the perturbation of the motion was significant, F(4, 88) = 9.61, P < 0.001,  $\eta_p^2 = 0.304$ .

In contrast to the forearm perturbation, the elbow perturbation elicited several effects due to the differences in the sporting expertise of participants. For positive perturbations, there were differences in the anticipation of ball speed between the two groups. The anticipation of the ball spin also varied between the two groups for the positively perturbed motions, as well as the motion with -15% perturbation. These results indicated that the modification of the elbow joint rotation acted as a key differentiator between the anticipatory judgments of the two groups. Furthermore, although no statistical effect was observed, the mean scores of the anticipated direction as functions of the perturbation rate for the two groups displayed opposing trends (Fig. 4a). One of the consequences of the elbow perturbation, in comparison with the forearm perturbation, was that the displacement of the forearm segment was accompanied with that of the hand and racket. Thus, the findings suggest that the anticipatory judgment is more readily influenced when the changes in the arm movement coincide with that of the end-effector.

### 3. Experiment 2

### 3.1. Participants, Visual Stimuli, and Procedure

The participants of Experiment 2 were identical to those in the Experiment 1. The approval of the experiment and informed consent of the participants were given along with those for Experiment 1.

In Experiment 2, the complete polygon model used in Experiment 1 was spatially occluded in order to test the effectiveness of local information. Two types of spatial occlusion models were used to create the test animation for the same set of perturbed motion data used for Experiment 1: the racket-occlusion model in which the racket was removed and the body-occlusion model that presented only the racket (Fig. 5).

The experimental procedure was similar to that of Experiment 1. The order of the occlusion conditions viewed in the models was counterbalanced among the participants. In each block, a preliminary session was conducted that familiarized the participants with the visual stimuli by presenting all the test animations. It was then followed by the main session in which the participants rated their anticipatory judgments of ball direction, ball speed, and ball spin of the perturbed motions in comparison with the control motion on a VAS. The VAS was set relative to the control motion (VAS = 0) and ranged from -50 (left) to 50 (right), -50 (slow) to 50 (fast), and -50 (light) to 50 (heavy) for the direction, speed, and spin, respectively. The participants took part in a total of 54 trials, which consisted of 27 trials for the racket-occlusion condition and 27 trials for the body-occlusion condition.

#### 3.2. Data Analysis

In Experiment 2, the interrelation between the complete polygon model and each of the occlusion models was examined. To do this, Pearson product-moment correlation coefficients (r) between the CG models were calculated using data pooled across participants from each expertise group and across the perturbations of the motion (Huys, et al., 2009). If the correlation coefficient of the complete model with any of the occluded models was found to be positive, it could be interpreted to indicate that the residual information in the occlusion model conveyed the essential information contained in the full kinematic information. Arcsine transformed values of the VAS score were used for the analysis. The significance level was set at  $\alpha = 0.05$ .

### **3.3. Results and Discussion**

Figure 6 and 7 show the VAS scores of the anticipated judgments for the occluded test motions with forearm and elbow perturbations, respectively. Table 1 shows the Pearson's correlation coefficients between the CG

models. For the anticipated direction, correlations between the complete model and the body-occlusion model were relatively high for both tennis and soft tennis players. This indicated that the racket was the dominant information source in predicting the ball direction. For the anticipated speed, both occlusion models showed medium correlations with the complete model in the tennis group, whereas all the correlations in the soft tennis group were low. This indicated that the tennis players attempted to utilize both the arm and racket information to judge the ball speed. The substantial impairment of the soft tennis players' judgment of the ball speed when visual information was limited suggests they did not attempt to utilize both arm and racket information. The anticipated ball spin also showed reasonably high correlations between the complete model and body-occlusion model for both groups. The racket seemed to provide informative anticipatory cues for ball spin as well as for ball direction.

Characteristically, every correlation coefficient of the tennis group was higher than that of the soft tennis group. This result strongly suggested that the tennis players were less susceptible to the occlusion operation than the soft tennis players. Tennis players may have a higher ability to extrapolate the outcome of the stroke motion from isolated kinematic information. Comparatively high correlations with the complete model were found in the body-occlusion model. This implies that both players pick up anticipatory cues predominantly from the kinematics of the end-effector. However, it should be noted that the correlation results could not rigorously determine the degree of effectiveness of the local information because the spatial occlusion of the serve motion was an artificial operation and created an unnatural and unrealistic test motion.

### 4. General Discussion

In the two experiments, the anticipatory judgment of the outcome of an opponent's serve was assessed for tennis and soft tennis players, where any adaptive differentiation, or specialization, depending on the player's expertise was of particular interest. To simulate the performer-observer (server-receiver) situation, CG animation displays were introduced in which the joint rotation of the displayed humanoid player was computationally perturbed at his upper extremity. Because this operation was designed not to violate certain anatomical constraints, i.e., the joint degrees of freedom and range of motion, the simulated motions were acceptable examples of practical motion patterns (see 2.2. Visual Stimuli). In addition, the effectiveness of localized information was investigated using a spatial occlusion technique. From the results of Experiment 1, a difference in the anticipatory judgment of tennis and soft tennis players was found when the elbow joint rotation was perturbed, while both groups of players significantly changed their judgment regardless of the forearm or elbow perturbation. Although response discrepancy between the groups was not necessarily obvious for the higher perturbation (i.e., -30% and +30%), significant effects of the expertise were found in the

perturbation conditions at elbow but not for the  $\pm 0\%$  perturbation condition. Furthermore, the results of Experiment 2 showed that the kinematics of the racket was the dominant information source used by both tennis and soft tennis players to make judgments on the ball's future movement. The results also suggested that the isolated display of parts of the motion had a smaller effect on the judgment of the tennis players than on the judgment of the soft tennis players. These findings from the Experiment 1 and 2 implies that a domain-specific adaptive differentiation become observable in the information pick-up performance within a family of sports, which has been rarely argued in the conventional studies that examined the difference between two or more skill levels. It should be noted that the tossed ball was removed both in Experiment 1 and 2 in order to exclude the effect of racket-ball relative position information in the perturbed motions, although it has been shown that the removal of the ball significantly deteriorates the anticipatory accuracy of a tennis serve (Jackson & Mogan, 2007).

The results of Experiment 1 provided evidence that the anticipatory judgment could be affected by a perturbation of the upper extremity depending on the domain of expertise of players (tennis or soft tennis). This was clearly observed in the trials with elbow perturbations but not in the trials with forearm perturbations. The selection of the target joint for the perturbation determines whether a differentiation between groups is observed or not. Numerous studies have revealed the effect of expertise on perceptual skill within the

conventional "skilled and less skilled" paradigm. The findings of this study raise new questions about the perceptual skill of participants in analogous activities, e.g., the perceptual skill of players of different sports within a family of sports, which appears to diverge from one another. It has been shown that motor skills are transferred from short tennis to tennis in the early stages of learning the game (Coldwells & Hare, 1994). On the other hand, the results of our study implied that the developed skills could cause a differentiation in the perceptual response. The differentiation pattern, however, was complicated and occasionally reversed depending on the selection of the perturbed joint and degree of the perturbation for each of the anticipatory judgments (Fig. 4). For the live serve action, the situation is more complicated because of the involvement of the whole body and the higher redundancy of each link segment.

In addition, the findings of Experiment 2 suggested a difference in the utilization of the kinematic information between the tennis and soft tennis players when presented with spatially occluded movements. The results of correlation analyses (Tab. 1) implied that both player groups were able to extrapolate the outcome of the complete motion from the isolated racket or body information because every correlation coefficient was positive. It also indicated that the tennis players were more attuned to the limited available information than the soft tennis players. In the task of anticipating the direction of the tennis forehand shot, it has been reported that perceptually less skilled players (Huys, et al., 2009). In this context, the tennis players in this study may be more perceptually skilled than the soft tennis players regarding the utilization of local information. However, the baseline of the judgment criteria were uneven between the player groups (responses to the complete model were different between the groups), hence the absolute level of their perceptual skill was not properly evaluated by the magnitude of these correlations. Nonetheless, the correlation results provided at least an estimate of the internal conformity between the complete and occlusion models within each group. Moreover, because the test animations were based on the motion of a tennis player, there is a potential advantage for the tennis players. Further study will determine the relative perceptual skill level of tennis and soft tennis players without bias.

The perturbation operation in this study significantly changed the observer's judgments of the ball's future direction. This was consistent with the findings of our previous studies on the anticipatory judgments of tennis players (Ida, Fukuhara, Kusubori, et al., 2011; Ida, Fukuhara, Sawada, et al., 2011). In addition to this, the changes in the observer's judgment due to the perturbation operation extended to the soft tennis players but in a different fashion. A previous study, in which running motion was rendered with a polygon humanoid model, showed that observers were able to perceive the perturbation of the arm motion and the trunk rotation and adapt their responses accordingly (Hodgins, O'Brien, & Tumblin, 1998). Further study using an anatomically

valid perturbation could provide new insights into the link between the perception of the observer and the motion of the performer or model.

The results of Experiment 2 suggested that the racket kinematics, rather than the motion of the body, was the most informative cue used in the anticipatory judgment of ball direction and ball spin. This supports previous findings where the distal part of the motion, or the end-effector movement, was the most valuable (Abernethy & Zawi, 2007; Canal-Bruland, et al., 2011; Huys, et al., 2009; Jackson & Mogan, 2007; Williams, et al., 2009). These studies have also suggested that skilled players benefit from being able to use multiple information sources located across the entire body rather than depending on a single source. The results of this study were consistent with these suggestions, in that the bodily motion without the racket (racket-occlusion model) appeared to present somewhat analogous cues to the participants as did the complete motion that included the racket. More characteristically, for the anticipation of ball speed, the correlation between the response to the racket-occlusion model and the response to the complete model was higher than the correlation between the response to the body-occlusion model and the response to the complete model. Collectively, these findings support previous suggestions on the use of local information, regarding not only the anticipation of ball direction but also that of ball speed and spin.

There were a number of potential limitations due to the simulation display of the test motion: the lack of the sense of presence due to CG modeling; the validity of the perturbation technique; indeterminable relation between the perturbed motion and output ball flight; only one original motion performed by a tennis model player; elimination of the tossed ball. In particular, the removal of the ball might critically impair anticipatory judgments as shown in a study using a video-editing technique for spatial occlusion (Jackson & Mogan, 2007). For the validation of the CG modeling and perturbation technique, further comparative studies with a matched real environment or video display are necessary, where a kinematic analysis of the server should be helpful to quantify the extent of variation (range of perturbation amplitude) in natural serve motions. Such a motion analysis is also of use to determine the quantitative relation between the serve kinematics and the resulting ball flight. In addition, the simulated display (CG animation) and uncoupled response (VAS scoring) had the potential to distort the visual information pick-up strategy on court as well as the judgment performance as suggested by a previous comparative study among *in-* or *ex-situ* verbal and action response conditions (Dicks, Button, & Davids, 2010). It should also be noted that the years of experience of some participants might be insufficient. Further assessment of more experienced and more skilled experts may highlight characteristic differences due to the expertise of players. The results of correlation analyses between the complete and occluded motions could not solely account for the effect of the occluded local information, because the change of the anticipatory judgment could result from not only the removal of the selected local information but also

from the disjunction of the racket and body that removes the relative motion information between those parts (Jackson & Mogan, 2007). Nonetheless, the techniques of computer-simulated displays and spatial occlusion are powerful tools that can provide valuable insight into the live response to an on-court opponent.

In conclusion, the domain of sporting expertise, even among sports with similar required motor skills, has the potential to influence the anticipatory judgment of future events. Furthermore, the difference in the domain of expertise can also differentiate the information pick-up strategies from localized sources in the motion. The simulated display techniques used has the advantage that the stimulus-response condition was under our control, and thus it allowed us to explore beyond the traditional "skilled and less skilled" paradigm.

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### **Table Title:**

Table 1. Pearson's correlation coefficient (r) between occlusion models

### **Figure Captions:**

Figure 1. Snapshots in time showing the motion of a soft tennis overhand serve.

Figure 2. CG control motion for Experiment 1.

Figure 3. Mean VAS score (error bar: SD) of anticipatory judgments of (a) ball direction, (b) ball speed, and (c)

ball spin for complete test motions with forearm perturbation.

Figure 4. Mean VAS score (error bar: SD) of anticipatory judgments of (a) ball direction, (b) ball speed, and (c)

ball spin for complete test motions with elbow perturbation (\* P < 0.05).

Figure 5. (a) Racket-occlusion model and (b) body-occlusion model.

Figure 6. Mean VAS score (error bar: SD) of anticipatory judgments of (a) ball direction, (b) ball speed, and (c)

ball spin for occluded test motions with forearm perturbation.

Figure 7. Mean VAS score (error bar: SD) of anticipatory judgments of (a) ball direction, (b) ball speed, and (c)

ball spin for occluded test motions with elbow perturbation.

# **Movie Captions:**

Movie 1. Test animation of the simulated motions: control motion ( $\pm 0\%$ )-forearm pronation (-30%)-forearm

pronation (-15%)-forearm pronation (+15%)-forearm pronation (+30%).

Movie 2. Test animation of the simulated motions: control motion ( $\pm 0\%$ )-elbow extension (-30%)-elbow

extension (-15%)-elbow extension (+15%)-elbow extension (+30%).