【二次出版】

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The analysis of accuracy in the services of various sports

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【Abstract】

This study aimed to quantitatively assess athletes' ability to minimize "deviation" from target, as well as "variation" in accuracy when performing a series of serves, in several sports that start with a serve. The study also included an analysis of factors that have possible influence on service accuracy through comparison and identification of distinctive patterns of five different sports: volleyball, badminton, soft tennis, regular tennis, and table tennis. Subjects were instructed to serve a ball/shuttle in succession aiming at targets situated in different locations in the opposing court, and the distance between the target and the landing point of each serve was measured. Measurements were then normalized by dividing them by the distance between the service position and the target for comparison and analysis. The results showed 5 – 10% deviation in all sports with volleyball having the greatest deviation in all trial conditions, demonstrating a significant difference from other sports. Variation in landing locations ranged from 2 to 4% with significant differences among volleyball, badminton, and table tennis. In addition, badminton showed wider distributions in the lateral direction, whereas regular tennis, soft tennis, and table tennis showed elongated distributions in the longitudinal direction relative to the direction of serve, suggesting that these differences may be due to use/non-use of a racquet and different degrees of difficulty in racket manipulation, as well as different serve rules, serve court/box size, etc.

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I. Introduction

The serve is one of the most distinctive techniques in sports. Unlike the reception, stroke, spike, smash, and other techniques, the serve is the first offensive action a player can take according to his/her own rhythm and timing without being affected by an opponent's move. In addition, a player can use a serve to restrict an opponent's next move and control the game to his/her advantage if he/she can accurately and reproducibly serve a fast ball/shuttle to hard-to-receive spots for the opponent. Moreover, instruction and coaching books of various sports (Japan Tennis Association, 2005; Japan Soft Tennis Association, 2004; Japan Table Tennis Association, 2012) describe that serves will become more effective if one can execute different types of serves (with different combinations of speed, trajectory, spin, and timing) using the same motion to prevent the opponent from anticipating. In fact, elite players of sports that start with a serve use serves to unsettle the opponent to disrupt his/her next move or win an ace thereby gaining an upper-hand in the game. Generally, players serve a ball/shuttle while aiming at a specific target, which requires accuracy to minimize "deviation" from the target and "variation" in landing points of serve shots executed by repeating the same motion. In this paper, the term "accuracy" refers to players' ability to minimize both deviation and variation.

Service accuracy has been studied by a number of researchers from various angles. Many of the previous studies have quantified accuracy by designating target zones and measuring the number or rate of successful landings in such zones, or by allotting points to each serve according to predesignated target zones (Blackwell et al, 2002, Edwards et al, 2005; Lidor et al, 2007; Muramatsu, 1996; Tasaka et al, 1998). These quantified indices, however, do not necessarily reflect the accuracy of serves correctly because the way the court is divided or by just a few centimeters of difference in landing point could lead to different evaluation results even for the same sport. These conventional methods struggle to ascertain the actual deviation and variation from target.

When it comes to serves, instruction books even for different sports tend to give similar advice. For instance, an instruction book for volleyball (Japan Volleyball Association, 1988) advises players to aim a serve at the least skilled receiver or hard-to-receive spots while guidebooks for regular and soft tennis (Japan Tennis Association, 2005; Japan Soft Tennis Association, 2004) instruct to place serves on the lines or in hard-to-reach spots for the opponent. Likewise, aiming at the opponent's body or at the lines depending on the type of serve is encouraged in badminton (Nippon Badminton Association, 2001) while aiming serves at hard-to-return spots for the opponent is endorsed in table tennis (Japan Table Tennis Association, 2012). However, the type or degree of accuracy required of athletes may differ from sport to sport, as each sport has a different set of serve rules and different size and shape of service court/box, etc. However, no comparison or analysis of serves in different sports have been made in previous studies, all of which focused only on one sport.

Accordingly, the authors aimed to quantitatively assess the accuracy of serves by measuring the landing points in several different sports that begin with a serve. The analysis also included investigation of factors that may have influence on the accuracy of serves by comparing the deviations from target and variation patterns of different sports.

II. Methods

1. Subjects

Subjects of this study consisted of athletes of W University who are regular players in college league games of five different sports: volleyball,

badminton, regular tennis, soft tennis, and table tennis. More specifically, the subjects comprised eight volleyball players [age: 20.1±1.0 years, experience: 10.5±2.1 years, gender: eight males], six badminton players [age: 19.8±1.5 years, experience: 10.2±2.7 years, gender: six males], seven regular tennis players [age: 20.9±1.2 years, experience: 12.7±2.7 years, gender: seven males], eight soft-tennis players [age 20.6±1.1 years, experience: 10.0±2.7 years, gender: eight males], and nine table-tennis players [age 19.2±1.3 years, experience: 11.2±2.0 years, gender: seven males and two females]. Subjects were explained about the purpose and methods of this study, to which they gave oral consent. Experiments of this study were conducted after applying to (application number: 2011-187) and obtaining approval from the ethics committee concerning research involving personnel of Waseda University.

2. Experimental procedure

Subjects were instructed to execute serves on the court of their respective sports in accordance with their respective rules after a sufficient warm-up and practice of the types of serves to be performed in the trials. Volleyball players were asked to hit overhand or jump serves, soft and regular tennis players to hit overhand serves, badminton players to hit underhand serves, and table-tennis players were told to serve by tossing a ball sufficiently high, while aiming at the targets situated in different locations within the opposing court. The size of each target was defined as a square with each side being the diameter of the ball or shuttle used in each sport. Targets were placed at three specific locations as outlined below relative to the service box/court of each sport (Fig. 1):

Target ①: the intersection of 1/6 lines from end line and side line.
Target ②: the intersection of 1/3 line from end line and 1/2 line from sideline.
Target ③: the intersection of short service line and center line (badminton only)

In all sports, serves were executed in three different trial conditions in the order randomly chosen: a) side, b) center, and c) game, as described below. Each trial session consisted of a total of 20 serves comprising 4 sets of 5 consecutive serves with an appropriate rest period between sets. Serves that touched the net were not counted.

a) side: aim at target ① without regard to serve type and speed.
b) center: aim at target ② without regard to serve type and speed.
c) game: serve as if in an actual game, aiming at target ① (or target ③ in case of badminton).

3. Data collection

Serve landing points were recorded by two high-speed cameras (Casio EX-F1, frame rate: 300 fps, shutter speed: 1/1000 sec) that were arranged according to the shooting environment to capture the target and surrounding area. Prior to trials, four 1-meter poles were placed vertically around the target as reference points and simultaneously shot by the two cameras for calibration.

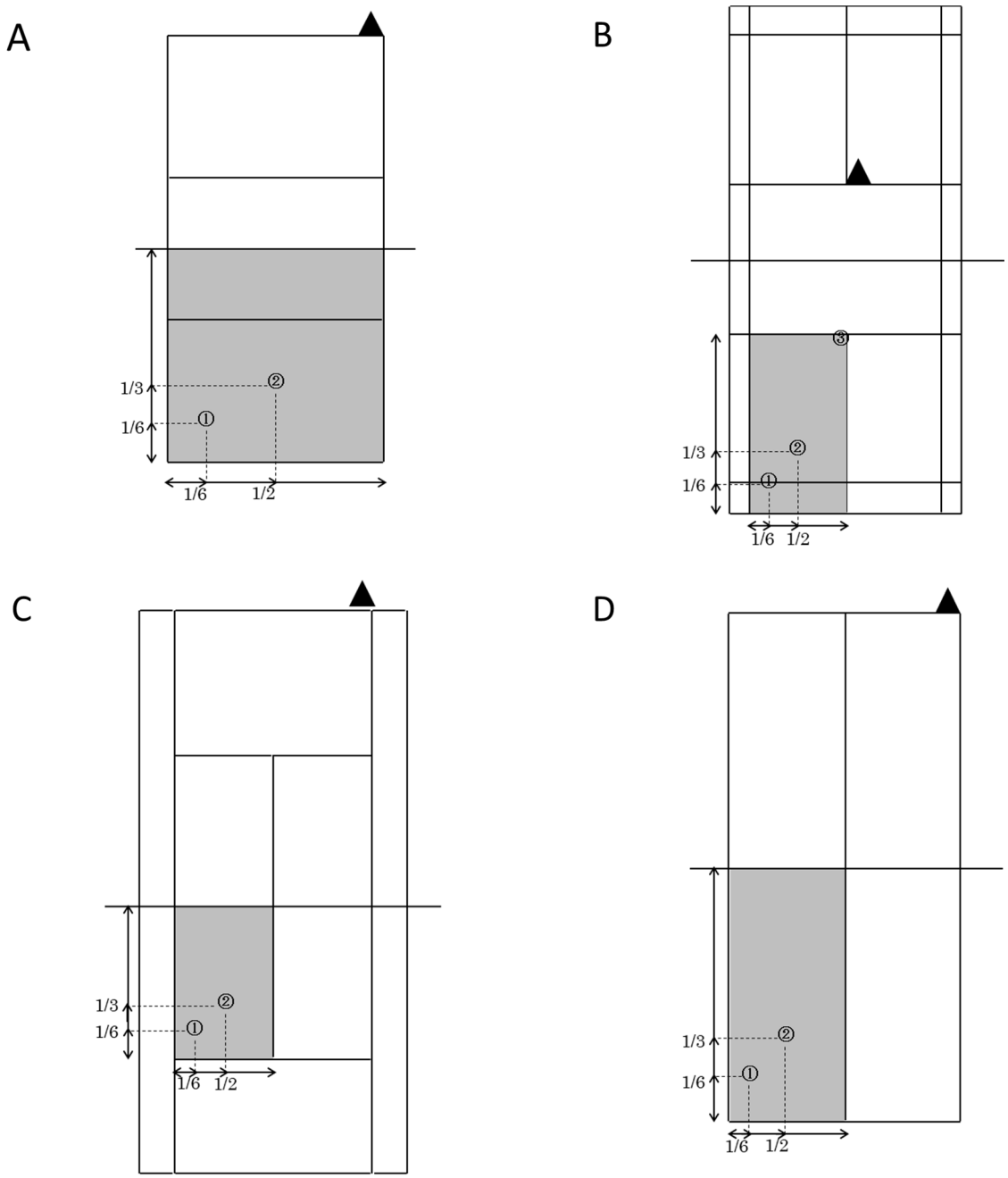

Figure 1. Target positions in each coat (① ・ ② ・ ③)

A: volleyball, B: Badminton, C: tennis/soft tennis, D: table tennis.

▲ indicates the place from where a subject hit a serve. Gray areas mean service boxes.

Targets were set so that their relative positions in the service box are identical.

4. Data processing

To calculate the positions of serve landing points, images of the moments when the ball/shuttle touched the ground were extracted from the recorded video to digitize the ball/shuttle using a video motion analysis program (Frame DIAS IV, DKH). Using the DLT (Direct Linear Transformation) method, three-dimensional coordinates of the landing points were calculated from the two-dimensional coordinates of eight calibration points. Computed values in the vertically upward direction were checked only to confirm that they were 0mm, as the balls/shuttles were touching the ground. The average margin of

error between the actual two-dimensional coordinates and the estimated values for the static coordinates on the X, Y, and Z axes were all 10 mm or less in all sports.

Based on the calculated three-dimensional values, the serve coordinate system was constructed with each target being the origin, the line connecting the target and the corner of the diagonally opposite service box on the server side being the serve-Y axis, and the line crossing the target and intersecting perpendicularly with the serve-Y axis being the serve-X axis, to calculate two-dimensional coordinates of serve landing points. To ascertain differences in accuracy among the sports selected for this study, the distance between the serve landing point and the target (d) was normalized by dividing it by the distance between the target and the diagonally opposite corner of the server's court (L) (hereinafter referred to as "normalized distance"). The mean and standard deviation of the normalized distance were then analyzed as indices of "deviation" and "variation," respectively. Likewise, the landing point's serve-X component (X_{serve}) representing serve trajectory and serve-Y component (Y_{serve}) representing serve length were divided by the distance (L) to obtain normalized values (normalized serve-X and serve-Y components are hereinafter referred to as "normalized X_{serve}" and "normalized Y_{serve}" respectively). Further, the ratio of normalized X_{serve} to normalized Y_{serve} (hereinafter referred to as "aspect ratio") of each trial session was calculated to represent the distribution pattern of serve landing points.

Normalized distance = d / L × 100 (%)
Normalized X_{serve} = X_{serve} / L × 100 (%)
Normalized Y_{serve} = Y_{serve} / L × 100 (%)
Aspect ratio = Normalized Y_{serve} / Normalized X_{serve}

5. Statistical processing

Using statistical analysis software (IBM SPSS Statistics Ver.21), a two-way ANOVA (5 sports x 3 trial conditions) was performed to ascertain differences in the mean normalized distance and standard deviation among the subjects. For comparison of aspect ratios relative to aspect ratio = 1, a *t*-test (Bonferroni correction) was applied. For statistical processing, the significance level was set at $p<0.05$.

III. Results

Fig. 2 shows the distributions of serve landing points of all subjects in different sports. While landing points are distributed around the target in all trial conditions across different sports, distribution patterns differ from sport to sport. Fig. 3 shows elliptic approximation of landing point distribution and the average aspect ratio of each trial condition of each sport. The aspects ratios of all trial conditions were significantly greater than 1 in regular tennis, (side: 1.92±0.35, center: 1.79±0.50, game: 1.70±0.65; $p<0.01$ for all trial conditions) soft tennis (side: 1.57±0.28, center: 1.44±0.30, game: 1.73±0.28; $p<0.01$ for all trial conditions), and table tennis (side: 1.90±0.93, center: 1.30±0.32, game: 1.67±0.33; $p<0.01$ for all trial conditions) showing an elongated distribution pattern in the longitudinal direction whereas in badminton, the aspect ratio of side trials (0.65±0.18; $p<0.01$) was significantly less than 1, displaying an elongated distribution pattern in the lateral direction.

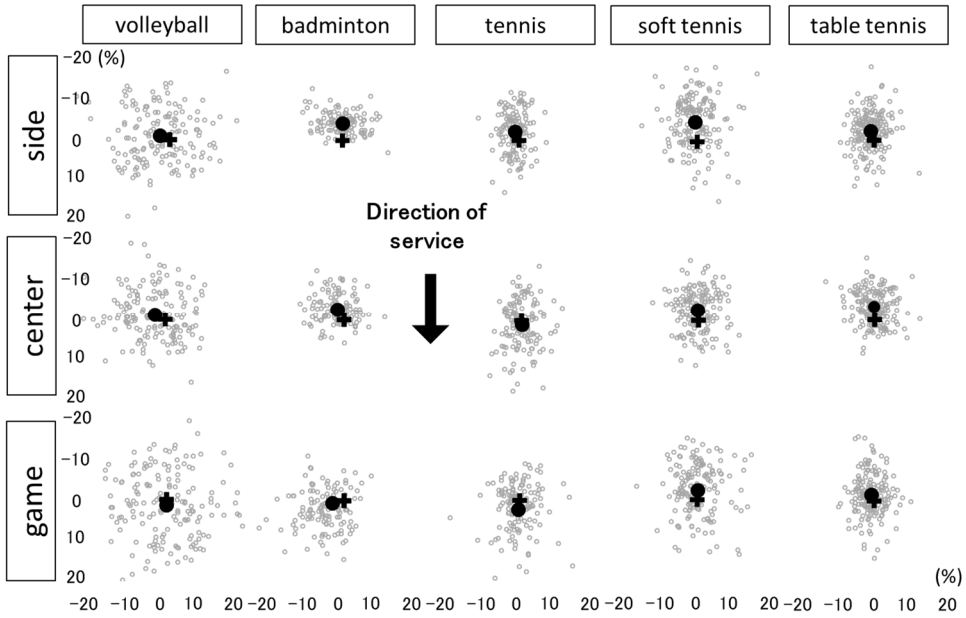

Figure 2. Distributions of serve landing points of all subjects in different sports, expressed in normalized distance.
＋ and ● indicate targets and mean landing points, respectively.

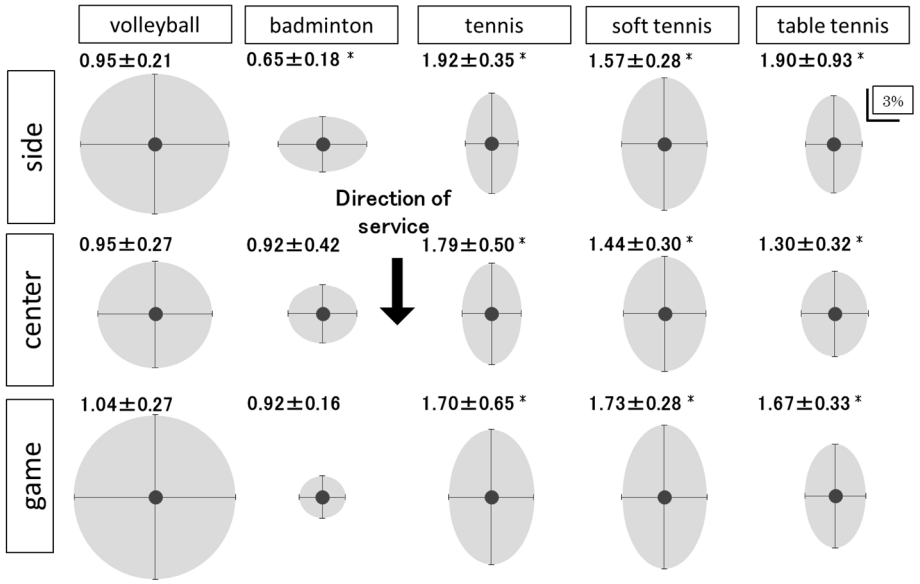

Figure 3. Elliptic approximation of landing point distribution and the average aspect ratio of each trial condition of each sport.
The ration significantly greater than 1 means an elongated distribution pattern in the longitudinal direction, whereas the ratio significantly less than 1 means an elongated distribution pattern in the lateral direction. ＊：$p<0.01$.

The mean normalized distance (deviation) from target in each sport is shown in Fig. 4. As the two-way ANOVA revealed a significant correlation ($p<0.05$) between sport type and trial condition, the simple main effect of each variable was next analyzed, and significant differences among different trial conditions were found in all sports (side: $p<0.01$, center: $p<0.01$, game: $p<0.01$). Multiple comparison testing found significant differences ($p<0.01$) in side trials among volleyball (8.57±1.96), badminton (5.26±0.90), regular tennis (4.93±4.89), and table tennis

(4.87±0.78). In center trials, significant differences ($p<0.01$) were found among volleyball (7.78±0.88), badminton (4.73±1.21), and table tennis (5.07±0.65) whereas in game trials, significant differences ($p<0.01$) were found among volleyball (9.99±1.12), regular tennis (6.43±1.80), and table tennis (4.82±0.97).

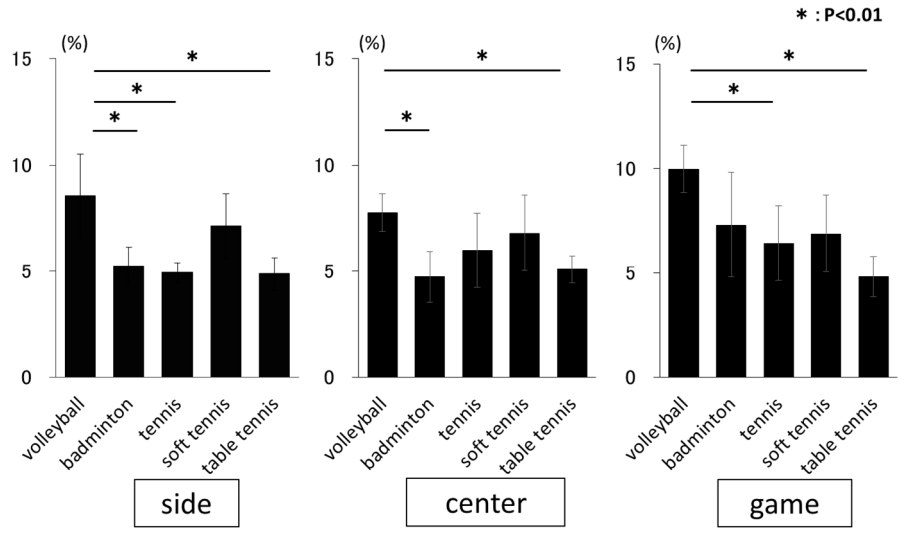

Figure 4. Mean normalized distance (deviation) from target in each sport ＊：$p<0.01$.

Fig. 5 shows the standard deviation (variation) of normalized distance from the target in each sport. A two-way ANOVA found no correlation between factors ($p=0.09$) while revealing a significant main effect for sport type and trial condition (sport type: $p<0.01$; trial condition: $p<0.01$). With respect to sport type, there were significant differences ($p<0.01$) among volleyball, badminton and table tennis. With respect to trial condition, significant differences were found between side and game trials ($p<0.05$) and between center and game trials ($p<0.01$). The standard deviation of each sport and condition revealed a 2 – 4% variation.

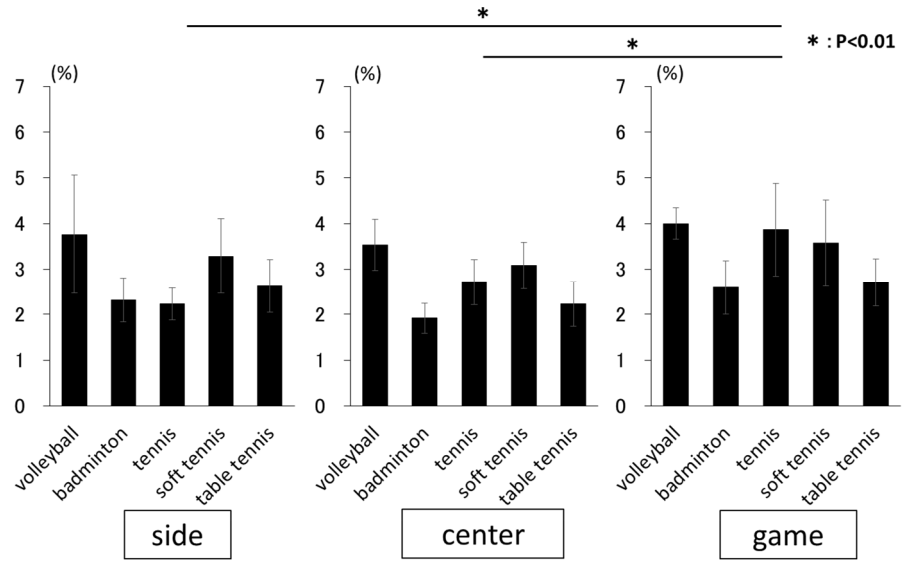

Figure 5. Standard deviation (variation) of normalized distance from the target in each sport ＊：$p<0.01$.

IV. Discussion

This study compared and analyzed several different sports that start with hitting a serve by quantifying the accuracy of serves in terms of deviation and variation from target. The subjects who participated in the experiment are top-level college athletes competing in national leagues, etc. The results show that even athletes of this caliber cannot hit the target 100% of the time, and the landing points of their serves were more or less varied and deviating from the target. Such deviation and variation are most likely occurring even among higher-level elite athletes, albeit to less degrees, as this much deviation and variation inevitably occur in all human movements, including those of everyday life. Messier et al (2003) conducted an experiment, where subjects were asked to make reaching movements towards four targets placed approximately 40 – 60 cm in front of them at different speeds without vision during the movement, and reported a deviation of about 10 cm and a variation of about 5 cm regardless of the movement speed and the distance from the target. Reynolds and Day (2005) conducted an experiment, in which subjects made steps onto two targets in front at two different speeds with vision randomly occluded in 50% of trials, and reported greater deviation and variation of approximately 1 cm and 1.2 cm, respectively, when visual information was not available than when it was available. As evidenced by these studies, deviation and variation tend to occur when it is difficult to use visual feedback to coordinate movement, which applies not only to serves but also other high-speed motions in sports in general.

As for the aspect ratio of serve landing points, only badminton showed a tendency to deviate in the lateral direction in side trials, which is assumed to be related to the serve rules of badminton. Of the sports analyzed in this study, only badminton rules require that the service must be delivered underhand by hitting the shuttle below the waist. Due to its shape, the shuttle is susceptible to air resistance and thus quickly loses momentum and begins to fall vertically. Accordingly, badminton players are taught to take these shuttle properties into account and hit a serve in such a way that it will land on the short or long service line. In addition, the target for side trials was placed on the doubles long service line, which is assumed to have contributed to decreased distribution in the longitudinal direction.

Regular tennis, soft tennis, and table tennis all showed distribution patterns that are elongated in the longitudinal direction in all trial conditions. One of the common serve rules that apply to these three sports is that the receiver is required to allow the ball to bounce before hitting it back. In table tennis, unlike regular and soft tennis, a served ball must touch the server's court first. However, this difference appears to have little influence, as the three sports showed similar distribution patterns. Another commonality among these sports is a strategy, in which a server aims at the opponent's body or the farthest end of the opposing court to disrupt the opponent's reception to gain an upper-hand in the third stroke. In other words, it is possible that players tend to focus on hitting the ball straight at the target and to some degree refrain from serving left or right. Volleyball, on the other hand, showed evenly distributed circular patterns in all trial conditions. This may be due to a broader range of serve options in volleyball, where an effective serve can be aimed at the least-skilled receiver, exposed zones, or anywhere in the opposing court that is relatively large and square shaped. Badminton showed similar well-rounded distributions in center and game trials. In these two sports, points are awarded to a team/player whenever the ball/shuttle touches the ground on the opposing side. This encourages a server to use the opposing court maximally by making the opponent move forward and back and left and right as much as possible to gain advantage in the game.

The varied distribution patterns may be reflecting these differences in serve rules, tactics, and required skills among different sports.

The analysis of deviation in this study revealed that volleyball has a significant difference from (a greater deviation than) two or more other sports in all trial conditions due to a broader range of serve options as discussed above, as well as a larger target size when aiming at the whole body of a particular receiver. Ishigaki et al (2003) conducted trials, in which the participants threw a ball at small-, medium-, and large-sized targets, and observed increased accuracy when the target size is small and decreased accuracy with larger targets. In the aforementioned study, accuracy was represented by the distance between the hit point and the target, which corresponds to the definition of deviation in this study. The target size of volleyball serve is relatively large when it is aimed at a receiver, which means that precision is less required and training for improving accuracy less emphasized, which may have contributed to the relatively large deviation.

With respect to variation, a significant difference was found between side/center and game trials. The difference is assumed to be caused by the difference in serve speed, as the subjects were instructed to “hit a serve as if in an actual game” in the game trials whereas greater emphasis was placed on accuracy in the other two trial conditions. It is known that the faster the motion, the less the accuracy (Fitts 1954). Although the serve speed was unfortunately not measured during the trials of this study, participants from volleyball, regular tennis, and soft tennis clearly hit the serves at faster speed during the game trials than during the other trials, resulting in decreased accuracy, as is the case with daily life movements such as reaching and stepping (Messier et al. 2003, Reynolds et al. 2005).

Of the five sports studied, only in volleyball the players handle the ball with bare hands without using a racquet. However, volleyball showed greater variation than badminton and table tennis. Iriki (2004) observed and reported that monkeys could use tools to obtain otherwise unreachable food with a smooth motion, appearing to be efficiently controlling the arm- tool from the shoulder to the tip of the tool, and that the monkeys were perceiving the tools as an extension of their arms or “body images” and incorporating the tools into their body schemata. Another report (Hihara 2003) states that repeated use of tools will make movement trajectories more compact and improve time and success rate of a task. It is assumed that the subjects of this study in racquet sports have incorporated the racquet into their body schemata through many years of repetitive use, thus gaining greater accuracy even with a tool than in volleyball without a tool.

In all sports, a variation of around 3% was found, which may be less for higher-level elite athletes as mentioned earlier. However, this much variation may be inevitable for an open-loop movement like a serve that involves multiple joints and muscles. In future, conducting similar analyses on various movements may lead to new insight into limiting the variation in human movement.

Previous studies on the accuracy of serves have used such methods as dividing the court or assigning scores arbitrarily by establishing target zones in the opposing court or levels of difficulty based on the experience of coaches (Blackwell et al. 2002, Edwards et al. 2005, Lidor et al. 2007, Muramatsu 1996, Tasaka et al. 1998). Incorporating the sport-specific variation patterns revealed by this study is expected to enable

analysis of serves at competitive level with higher precision.

V. Conclusions

This study was conducted with an aim to quantitatively assess the accuracy of serves in various sports to compare differences among them, as well as to identify factors having influence on accuracy. The results revealed a variation of around 3% in service accuracy represented by normalized distance even among highly competitive athletes. The results also showed varied distribution patterns of serve landing points among different sports, implying a possibility that accuracy was affected by the serve rules and service box/court size that are different from sport to sport. However, no significant difference was found among different sports, except volleyball, indicating that rules and other characteristics unique to each sport do not have much influence on accuracy. Further analysis of racquet and body movement during serve is expected to identify more detailed factors that contribute to different distribution patterns of serve placement that are characteristic of different sports.

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