EXAMINATION OF EVALUATION INDEX OF TENNIS RACKET SELECTION WITH STROKE MOTION ANALYSIS

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The purpose of this paper is to build a selection index for tennis rackets. Tennis rackets were evaluated using motion indices derived by investigating the effects of rackets on stroke movement. The subjects of this study were three male senior tennis players and two male beginner players. Stroke motion and the three-dimensional information of each part of the human body was measured with 12 motion capture cameras and 6 rackets with different characteristics. By using three-dimensional information, characteristic markers of the tennis strokes were derived. The vertical position of the marker was analyzed, and the change in the stroke motion of each racket was examined. The analysis was performed by comparing the sum of standard deviation and swing speed. As a result, the relationship between the sum of the standard deviation and the swing speed for the stroke motion was shown. It was suggested that a racket suitable for beginners may be presented by presenting the sum of the standard deviation of the z-axis position of the right wrist marker, which has a high correlation with the swing speed, as a racket index.

KEY WORDS: Biomechanics, Tennis, Racket, Human motion, Sum of standard deviation

INTRODUCTION: In sports that use equipment such as rackets, the choice of equipment is largely related to the athlete's skill level. For example, if a player uses a racket that is not suitable for his or her skill level, the load on the body increases and player may not be able to play as anticipated. In sports such as tennis, it is empirically known that when a player uses the most suitable racket, his or her swing speed increases, and the impact and rotation speed of the struck ball increase. However, when selecting equipment, the sensation of swinging a racket or the feel that results from hitting a ball are often judged as good or bad based on the user's subjective opinion. Experts who have long familiarity with the handling characteristics of the equipment used in their sports can readily choose the most suitable types based on their experience, but it is extremely problematic for beginners who have just started participating in a new sport to select proper equipment based on their subjective judgment alone. For this reason, in order to assist beginners in making their equipment choices, an index that can be used to evaluate such equipment objectively is necessary.

In this study, the purpose of this study is to construct an evaluation index for presenting a tennis racket suitable for the user by examining the change of human body movement during stroke movement due to the difference of tennis racket.

METHODS: In this experiment, the movement of the human body during the entire tennis stroke was meatured using 37 markers attached to each part of the body. In the motion measurement, 6 types of rackets are prepared and 12 motion capture cameras (Optitrack, Prime13 and Prime13W) are used to measure tennis stroke motion and racket movement. Table 1 shows the characteristics of the racket. The same grip is used for all rackets. The experimental setup is shown in Figure 1. First, the motion capture cameras are placed, as shown in Figure 1. The test subject strikes a ball that is ejected from the automatic tennis ball machine towards the target as measurements are taken. In this way, 18 data were measured for each racket. By analyzing the meatured movement of the tennis racket, the racket head speed and impact phase were determined. The subjects were three adult men who were skilled tennis players (Sub1,2,3) and two adult men (Sub4,5) who were tennis beginner (Height: 1.74 ± 0.06 m, Weight: 62.0 ± 5.0 kg). This experiment was approved by the Ethics

Committee on Sophia University's "Research for Humans" and all test subjects gave informed consent before participating in our experiments.

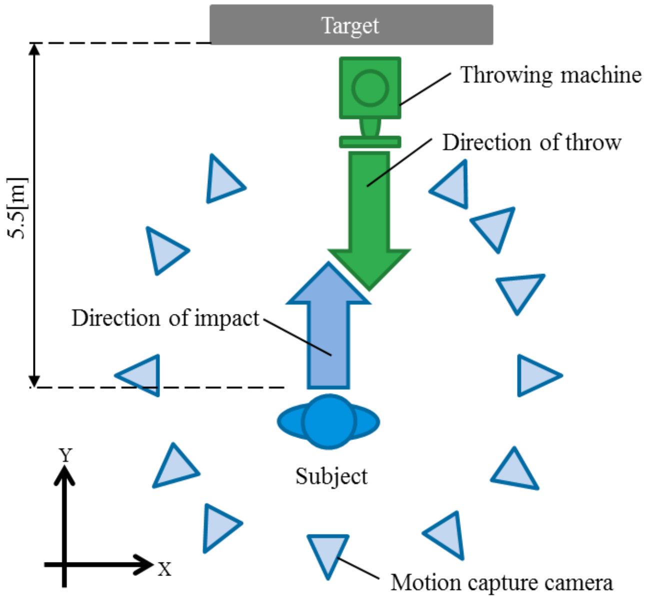

Figure1: Schematic drawing of experiment setup.

Table1: Tennis racket specifications.

	Racket A	Racket B	Racket C	Racket D	Racket E	Racket F
Surface [inch^2]	100	97	100	100	97	105
Length [inch]	27	27	27	27	27	27
Weight [kg]	0.30	0.34	0.30	0.28	0.31	0.27
Swing weight [kg • cm^2]	304	319	304	308	314	302
Gravity center position [mm]	320	305	320	335	310	330

RESULTS&DISCUSSION: From the experimental results, it was confirmed that the trajectory of the right wrist marker varied even when the stroke was performed using the same racket (Ae & Fuji, 2002; Miyanishi et al., 1996). In addition, it can be confirmed that even the same subject has different trajectory variations depending on the racket used. Here, it is known that the moment of inertia of the arm affects the motion trajectory of the hand in the articulation of the upper limb (Ito, 2005). From this, it is considered that the difference in the variation of the trajectory of the right wrist in the stroke motion is caused by the difference in the moment of inertia due to the difference in the position of the center of gravity of the racket. In this study, we derive the racket evaluation index by focusing on the variation of stroke motion due to the difference of racket. Kawano have proposed a method for evaluating rackets by comparing the variation in wrist position during badminton smashing with the sum of the standard deviations (Kawano et al., 2017). This method is useful in that rackets can be quantitatively evaluated. In this study, we apply this method and compare the variation of the right wrist marker position with the standard deviation in the stroke motion.

At each time point, the sum of the standard deviation of the right wrist marker position in 10 trials was calculated for each of the x-axis direction, the y-axis direction, and the z-axis direction (Suzuki et al., 2017). Then, the degree of variation of the trajectory of the stroke motion for each racket of each subject was compared. The sum of the standard deviation σ_{sum} was calculated using equation (1) according to the additive nature of the variance.

$$\sigma_{sum} = \sqrt{\sum_{i=1}^{n} \sigma_{t_i}^{2}} = \sqrt{\frac{1}{N-1}\sum_{j=1}^{N}\sum_{i=1}^{n}(p_{(t_i,j)} - \bar{p}_{(t_i)})^2} \quad (1)$$

Here, n is the number of measurement data, ${\sigma_{t_i}}^2$ is the variance of the right wrist marker position in 10 trials at time t_i, N is the total number of trials. $p_{(t_i,j)}$ represents the right wrist marker position of the j trial at time t_i, and $\bar{p}_{(t_i)}$ represents the average of 10 trials of the right wrist marker position at the time t_i.

In this study, the starting point of the section that takes the sum of the standard deviations is 0.45 seconds, and the ending point is the time (peak time) when the racket speed reaches the peak value after impact. By using the end point as the peak value, it was possible to focus on the movement of the section where the rotational movement of the shoulder greatly contributes to the swing speed in the stroke movement of tennis.

Table 2 shows the sum of the standard deviation of the z-axis position of each subject when using each racket. The x-axis and y-axis calculations were also performed, but this paper only shows the z-axis where the results were obtained. Comparing the sum of the standard deviation of the z-axis position for each subject, it was found that the racket that suppressed the variation of each stroke movement of the z-axis position was different depending on the subject. The above results suggest that using the sum of the standard deviations may quantitatively evaluate the characteristics of each subject's swing on each racket. Next, Table 3 shows the average of the swing speed of 10 trials of each subject using each racket. From Tables 2 and 3, focus on the relationship between the sum of the standard deviation of the z-axis position and the swing speed. For subjects 2, 3, 4, and 5, it can be seen that the swing speed is the highest when rackets A, B, C, and E have the smallest sum of the standard deviations of the z-axis position. From these results, it is possible that there is a relationship between the sum of the standard deviation of the z-axis position and the swing speed. Therefore, in order to further investigate the relationship between the sum of the standard deviation of the z-axis position of the right wrist marker and the swing speed, correlation analysis was performed on the sum of the standard deviation of the position of the right wrist marker in the z-axis direction and the swing speed when using the rackets of all the subjects. Here, for subjects 1 and 4, the sum of the standard deviation of the position of the right wrist marker in the z-axis direction and the swing speed when using five rackets except rackets F and B, which were outliers, were used. Figure 2 shows a scatter diagram of the correlation analysis. According to Figure 2, the correlation coefficient is 0.829 and the p-value at this time is $0.00000005 \ll 0.05$. Therefore, there is a high correlation between the sum of the standard deviation of the right wrist marker in the z-axis direction and the swing speed. In other words, it was suggested that the smaller the sum of the standard deviation of the racket in the z-axis direction, the higher the swing speed.

Table2: Sum of the standard deviation (z -axis direction).

Subject	Racket A	Racket B	Racket C	Racket D	Racket E	Racket F
1 (skilled)	0.214	0.100	0.081	0.077	0.070	0.062
2 (skilled)	0.083	0.123	0.112	0.135	0.083	0.108
3 (skilled)	0.096	0.071	0.082	0.087	0.079	0.112
4 (beginner)	0.406	0.105	0.094	0.160	0.271	0.151
5 (beginner)	0.182	0.196	0.200	0.148	0.126	0.234

Table3: Average of swing speed of each racket (km/h).

Subject	Racket A	Racket B	Racket C	Racket D	Racket E	Racket F
1 (skilled)	101.0	104.6	105.9	106.3	105.8	101.1
2 (skilled)	113.7	111.6	112.7	111.1	113.2	111.0

3 (skilled)	117.2	121.4	117.5	118.7	120.9	116.9
4 (beginner)	70.9	69.7	74.0	73.8	73.2	72.4
5 (beginner)	82.4	82.5	83.1	83.3	86.1	82.8

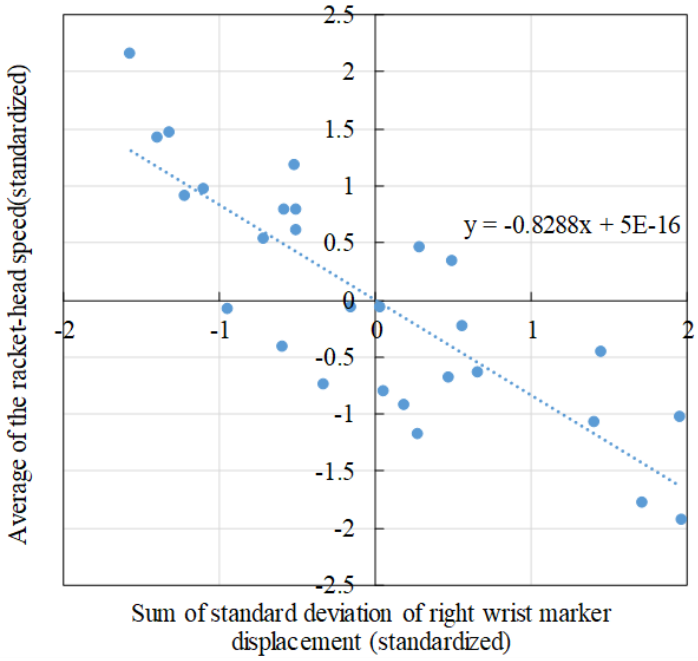

Figure2: The result of the correlation analysis without outliers (All Subjects).

CONCLUSION: In this study, the purpose of this study was to construct an evaluation index for presenting a tennis racket suitable for the user. In the motion measurement experiment, motion capture cameras were used and stroke motion was measured when using multiple rackets. In the analysis of the measurement results, the effect of the difference of the racket on human body movement was examined. As a result, it was suggested that the racket suitable for each subject could be quantitatively evaluated by using the sum of the standard deviations. Furthermore, the swing speed was compared with the sum of the standard deviations to investigate the relationship between the difference in stroke motion due to racket differences and swing speed. The results showed that there was a high correlation between the sum of the standard deviation of the right wrist marker's z-axis position and the swing speed, and that the smaller the sum of the standard deviations, the higher the swing speed.

Therefore, it is suggested that a racket suitable for beginners may be presented by presenting the sum of the standard deviation of the z-axis position of the right wrist marker, which has a high correlation with the swing speed.

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