SIMULATION SYSTEM FOR IMPROVING TENNIS STROKE MOTION

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The purpose of this study was to construct a system that can simulate tennis stroke motion for competition level enhancement of players. To do so, 10 female tennis club players (19-23 years old) of University of Tsukuba were selected for a biomechanics study using three-dimensional stroke motion analysis method, in a total of 10 trials. Using obtained results on joint angles of the whole body, the best results of university tournament and racket head speed at impact, a database was constructed. Principal component analysis was used to classify the motion patterns into the principal component scores. Based on the principal component score and optimization theory, we generated a simulation system to predict competition level and racket head speed, and thus a new stroke motion, which can be expressed using 3D animations.

KEYWORDS: simulation, stroke motion, competition level, principal component analysis.

INTRODUCTION: There is a need of players who desire to make improvements in motion for competition level enhancement. To meet such a need, biomechanics-based studies are being performed world-wide, and in Japan. However, the research needs to be explained in simple terms to both the players and the coach/staff on the field, as biomechanics data are sometimes difficult to explain. Such explanation was recently developed for baseball study by Ishi and co-workers (2012) who used a new system to predict both the ball-speed and the shoulder injury simulating pitching motion for the high-speed ball and the prevention against injury easily utilizing principal component analysis (PCA) and regression analysis. This system could predict performance data and pitching motion, but could not predict the competition level of the simulated motion. Although the simulation is regularly used in baseball, the simulation of the tennis stroke motion using such a technique has not yet been reported. Thus the purpose of current study was to construct a system that can simulate tennis stroke motion for competition level and racket head speed.

METHODS: To fulfil the objective of the study, we recruited students from the University of Tsukuba tennis club, comprising 14 female tennis club players at various competition levels including a few top-level players. Ten players who satisfied the criteria of a right-handed female tennis player were selected as subjects. The subject's average age was 20.4±1.2 years, average height was 162.3±3.5 cm, and average weight was 55.3±3.9 kg. The following trial was performed by the subjects. Each subject instructed at 100 % of the effort degree hit the tennis ball coming out of a ball machine (Toss machine, Toa sport machine corp., Osaka, Japan) at the right slant ahead towards a forward mark (height: 50 cm, length: 100 cm) on a target mat, placed at 13.88 m from the subjects hitting position. After every hit, each subject was asked about introspection by five phases of evaluations of 1 to 5, had to hit multiple times till they reached introspection more than 4. One trial more than 4 introspection per one subject was selected for current study (10 trials in total). All trials were forehand strokes of the square stance.
Three dimensional trajectories of markers, which were attached to characteristic points of human body, were measured with a motion capture system (VICON-MX, 10-camera, 250 Hz; Vicon Motion Systems, Oxford, UK). The analysis section was based on an impact with all trials, was from 0.8 seconds before impact to 0.3 seconds after impact. We normalized the analysis section in time and divided it into 101 frames (0-100 %). We also calculated joint

angles in the analysis section by using the SIMM (Software for Interactive Musculosketetal Modeling; Motion Analysis Corp., CA, USA) software. The joint angles (29 joints in total) were as follows: right shoulder (3 flexibility: elevation, elevation angle, rotation), right elbow (2 flexibility: flexion, pro supination), left shoulder (3 flexibility: elevation, elevation angle, rotation), left elbow (2 flexibility: flexion, pro supination), left wrist (2 flexibility: flexion, deviation), neck (3 flexibility: pitch, roll, yaw), lumbar (3 flexibility: pitch, roll, yaw), right hip (3 flexibility: add, flexion, rotation), right knee (1 flexibility: flexion), right ankle (2 flexibility: flexion, eversion), left hip (3 flexibility: add, flexion, rotation), left knee (1 flexibility: flexion), and left ankle (2 flexibility: flexion, eversion). We stored these data in a form of the relational database as subjects and variables. There were 2929 variables of 29 (joint flexibility) × 101 (frame) in the stroke motion data. The other data were one variable of competition levels and one variable of racket-head-speed data. Therefore, there were 2931 variables per one subject in total for a database. Table 1 shows an ordinal scale by digitizing the best results of the university tounament, whcih was incorporated in a database.

Table 1
An ordinal scale by digitizing the best results of university tournament

The best results of university tournament	Competition levels	Order standards
Champion of the world student tournament : Subject A	More than the world student tournament winning prize	10
	More than the world student tournament participation	9
Fifth place in the Japan student tournament : Subject B	More than the Japan student tournament winning prize	8
Japan student tournament participation: Subjects C, and D	More than the Japan student tournament participation	7
	More than the Kanto student tournament participation	6
Kanto student tournament second qualifier participation: Subjects E, F, G, H, and I	More than the Kanto student tournament second qualifier participation	5
Kanto student tournament first qualifier participation: Subject J	More than the Kanto student tournament first qualifier participation	4

Based on these databases, PCA was carried out. A simulation system was constructioned by using R studio (R Studio Inc., Auckland, New Zealand) as the statistics software and Excel (Microsoft Corp., Washington, USA) as the spreadsheet software. We used SIMM for depicting the animation on the computer as viewer software because SIMM model is near a genuine human being than link segment model and one can image real movement more. We compressed reversibly the information in the database, and analysed it using PCA to extract the principal component (PC). The eigenvector line (EL) was calculated using PCA and expressed the data of the individual player as principal component scores (PCS). We set the range that satisfies the number of PC as eigenvalue >1. This is because PC smaller than 1 eigenvalue has less information than an original variable.

Using PCA, PCS of a certain subject can be determined from a certain subject data [motion, competition level, and racket head speed] in the database through EL. Reversibly, a certain subject data [motion, competition level, and racket head speed] in the database can be found from PCS of a certain subject through EL. Using Excel, a calculation sheet was created in order to perform this interactive calculation by this system. Utilizing this calculation sheet, and changing each PCS, we could create new simulation data [motion, competition level, and racket head speed]. In addition, we utilized the Solver Function (SF) programed by Excel to search for the motion to satisfy needs by this system. The SF can directly calculate the value that we want to search for by setting the objective function (competition level etc) within several minutes. The calculation algorithm used a "non-linear GRG". When the combination of PCS was demanded as a result of search, using a calculation sheet mentioned above, we calculated the joint angle data of the whole body through EL from PCS. Furthermore, we input calculated joint angle data into SIMM and allowed one to watch the stroke motion as 3D animation on a computer.

RESULTS AND DIXCUSSION: The average racket head speed was 115.5±8.13 km/h, the maximum velocity was 128.7 km/h, and the minimum velocity was 102.8 km/h. When we analysed the information in the database with using PCA, 2931 variables were compressed reversibly in 10 variables, and the accumulation contribution ratio was 89.89 %. This means that 89.89 % of information in the database was gathered by 10 PC. Each PCS of 10 trials was demanded by this analysis and we were able to make individual data a parameter with 10 numerical value. The axis of the biggest dispersion was defined as the first PC in PCA, the other PC were defined in big order, and each PC axis was at right angles each other. Applying this principle to the stroke motion analysis of current study and trying to interpret it, the dispersion means "unevenness" in a database, and this "unevenness" reflects the characteristic of each subject. For example, it may be said, "There is quick characteristic in racket head speed as for this subject" if the racket head speed data of a certain subject is two-standard deviation far in the plus direction than average. This example pays attention only to one variable that is racket head speed, but can interpret it equally when it is multivariate. There are 2931 variables for the database of this system. First PC means the pattern that most greatly shows the characteristic of data [motion, competition level, and racket head speed]. Second PC means the pattern that secondly shows the characteristic of data [motion, competition level, and racket head speed] and is similar after third PC. Each PC becomes independent then, and each pattern is not affected at all by each other. Zero of all each PCS means that the data [motion, competition level, and racket head speed] are average. In other words, stroke motion of the average is generated when one set all PCS to 0 and is predicted to generate a competition level of the average and racket head speed of the average in the motion. The data [motion, competition level, and racket head speed] changes on the pattern of PC when one change a certain PCS. One point of PCS means one standard deviation. Therefore, statistically approximately impossible data [motion, competition level, and racket head speed] are generated when ranges changing PCS exceed three points. Attention is necessary for the range that PCS changes to perform simulation with the validity.

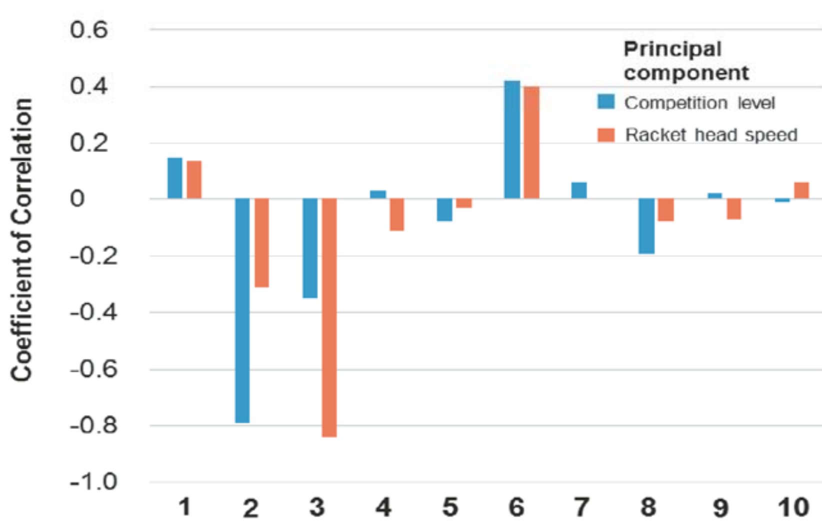

Figure 1: Correlation of each principal component, competition level and racket head speed.

We investigated a coefficient of correlation with each PCS, competition level and racket head speed to push forward the interpretation of the extracted the pattern of PC. The result is shown in Figure 1.

The PC in the high correlation with competition levels was second PC. The PC in the high correlation with racket head speed was third PC. Therefore, second PC is interpreted as a pattern that has a second big characteristic in stroke motion, a strong correlation with a competition level and a weak correlation with racket head speed. Similarly, third PC is interpreted as a pattern that has third big characteristic in stroke motion, a strong correlation with a racket head speed and a weak correlation with a competition level. Thus high competition level not always have as same characteristic as high racket head speed has. The simulated results are shown in Figure 2. Using SF, we simulated stroke motion of competition level 4 and competition level 8 with racket head speed. We visualized the results as 3D animation on the computer by SIMM. Figure 2 shows a stroke posture of foot contact with a still image at the time of stepping forward foot grounding from the animation.

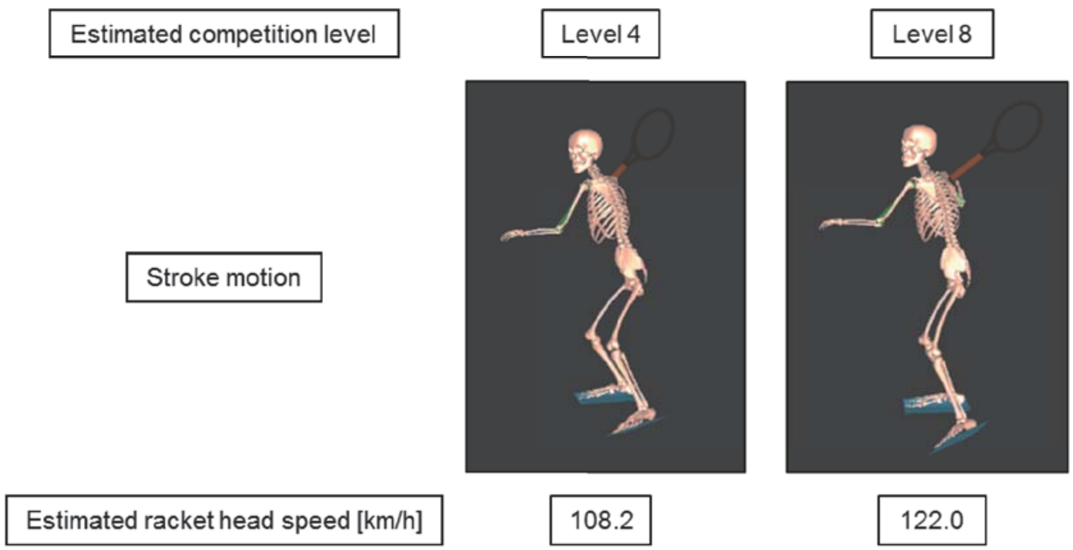

Figure 2: The simulation of stroke motion, competition level and racket head speed.

CONCLUSION: The results are summarized as follows:

(1) We could construct system that can create new simulation data [stroke motion, competition level, and racket head speed].
(2) Using this system, one can search for the stroke motion depending on various objective function within several minutes.
(3) We believe that it is easy for a player and the coach/staff on the field to understand motion characteristic because simulated motion can be depicted as 3D animation by SIMM.

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