Research on the Biomechanics Analysis of Technical Movement in Fatigue Period for Badminton Athletes

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Abstract — In this paper, we aim at researching the biomechanics analysis of technical movement in fatigue period for badminton athletes. Based on the urgent need to study foot and ankle sports injuries and special badminton biomechanical effects factors, the paper uses the shooting frequency and accuracy higher Qualisys three-dimensional movement infrared acquisition and analysis system with the current state-of-the-art German novel Pedar-X plantar platform to analysis the biomechanical data. An investigation on the prevalence of jumping smash is taken out by using a six video camera system. The experiment data shows that fatigue can lead parameters depreciation of ankle joint movement. In fatigue period, the stability of technical movements of athletes starts to decline and the time for completing the action in the duration of each phase is changing all the time which may lead the failing in the control process of joint. This will greatly increase the possibility of joint injury.

Keywords - biomechanics analysis; goldman technique; fatigue period; technical movement; badminton athletes

I. INTRODUCTION

Badminton is an internationally played sport of which the outcome is determined by a variety of performance determinants. In addition to technical and tactical skills, badminton players need a high level of endurance, strength, speed, power, explosiveness, and agility. The use of smart sensor devices in badminton may provide important information about the physical and physiological loads during practice and competition. Although the movement characteristics of badminton competition have been documented in a small number of time-motion studies, little is known regarding the physical load, with respect to whole body movement, or the associated physiological response to offensive and defensive drills, and game play. Consequently, how these responses contribute to, and impact on the overall practice and/or competition exercise is not well understood.

Biomechanical analysis of human movement has become an important tool for basic research and for clinical management of orthopedic and neurological conditions [1]. Clinical movement analysis is traditionally performed offline by processing of previously recorded raw motion and force data, resulting in a laboratory or gait report to the clinician who makes treatment decisions. Clinically relevant information in the report typically includes the time histories of biomechanical variables such as joint angles (kinematics) and joint moments (kinetics) [2-4]. In recent years, musculoskeletal models have been used to provide additional information about muscle length changes and muscle forces.

A real-time biomechanical analysis, as opposed to a report that is generated during post-processing, would create unique opportunities for both the patient and the therapist to interact in real-time with biomechanical data during patient examination or treatment [5]. Clinicians and physical therapists could benefit from a real-time visualization and quantification of specific motion variables, as well as from having additional information about internal forces and moments which would remain fundamentally invisible [6,7]. Furthermore, such biomechanical data can also be presented to the patient in real-time; to help them perform therapeutic exercises more effectively than could be done with verbal or tactile feedback from a physical therapist.

Jumping and performing a smash is a very popular technique in badminton games. It may contribute to the winning of a point if performed successfully while it may lead the coming into fatigue period for badminton athletes. Thus players strive for a successful smash in order to accumulate points, besides the deceiving skill techniques that occur frequently in the games. Even though previous study has shown that height of jump does not correlate with a high velocity of the shuttlecock, players are overwhelmed with the jump smash [8]. In the jumping smash, the jumping and landing sequence is commonly associated with injury.

The majority of injuries occur in the lower extremity with the ankle and knee joint being particularly vulnerable, with 34 and 29 claims reported respectively [9]. Injuries to the ankle and knee joints are especially important because they are associated with more lost time from sport participation than other injuries cited [10]. Perhaps the most serious knee injury during jumping is the rupture of the anterior cruciate ligament (ACL) while the most serious ankle injury is the calcaneal/Achilles tendon rupture.

It is hypothesized that repeated jumping and the deviations in jumping and landing technique during the games are the primary causes of injury. Furthermore a player puts greater force on the take-off foot in order to propel himself upward with a center of mass vertical velocity. However, no research exists regarding the jumping smash technique and its association with injury in
badminton. Therefore the paper also attends to investigate the jumping smash technique performed by the top ranking international badminton players and to determine the relative frequency of the jumping techniques to avoid early entry into the fatigue period in badminton games.

II. RESEARCH METHODS

Time motion analyses during a badminton game showed that on average 1000 movements were made by badminton players, with an average duration of shorter than 3 seconds. On average, every 2 seconds a different movement was initiated, indicating the importance of agility in badminton. Explosive vertical jumps may be executed up to 50 times per game. Heart rate and blood lactate concentration have been the main focus of investigations into physiological loads. Competition for elite males may elicit maximal heart rate values. More recently, mean heart rates of 171 beats/min or 91% of the maximal heart rate have been recorded during play. Measures of blood lactate concentration indicate that anaerobic metabolism makes a substantial contribution to the supply of energy for muscular contraction. Mean values for male badminton players have been recorded at 8.5±3.1 mmol/L, and 5.7±2.1 mmol/L during international-level female games. However, blood lactate is only a surrogate indicator of anaerobic metabolism, as concentrations may be 1/3 of the muscle concentration, and are influenced by the exercise intensity immediately before sample collection. Heart rate may be a limited indicator of aerobic metabolism during badminton due to rapid movements of upper body segments, cardiovascular drift, or an altered autonomic tone. Despite preliminary efforts to describe some of the physiological aspects of badminton play, the aerobic (VO2) energy loads of competition are unknown.

Recently, the development of personal heart rate telemetering systems incorporating predictive software can provide real-time estimates of the VO2 during training and competition. These systems offer great flexibility for team sport practitioners as multiple players can be monitored, and their heart rate and VO2 responses viewed in real time. This methodology offers coaches and support staff the opportunity to modify the intensity (or duration) of a practice session if objectives are not being met. Competition intensity can also be quantified, allowing practice drills of similar intensity to be designed. The Suunto system has shown to be reliable, with a typical error of 0.64 mL/(kg·min) (1.5%) and a coefficient of variation of (6%). This degree of reliability (accuracy) is sufficient in characterizing moderate to larger changes or differences in aerobic capacity (>6%) but not small subtle changes.

Three-axis accelerometers are now available which are relatively unobtrusive for use during team sport training and competition. Accelerometers have been used extensively in the general population as a measure of physical activity level. The physical demands of team sports have been evaluated using Global Positioning System (GPS) technology. GPS may be appropriate in outdoor settings which allow satellite reception, but is unsuitable for indoor sports such as badminton. To our knowledge, only one study has been conducted in badminton and other high intensity team sports that quantified the physical demands by using accelerometer technology. However, the accelerometer used in that study was a uniaxial version, and possibly underestimated the true physical loads as only one plane of movement was measured. To gain further insight into the loads of badminton using accelerometer technology, player movement should be measured in all three planes (three-axis accelerometers). Many offensive and defensive badminton movements are combinations of forward, backward and/or lateral movements. These rapid movements presumably combine to elicit a substantial physical load, and associated physiological load. Given that previous time motion observations predominantly focused on running, the aim of this study was to quantify differences in whole body dynamics (physical load), heart rate and predicted VO2 responses (physiological load) between selected offensive and defensive practice drills, reduced court area competition (fatigue period), and live game play.

Video data were collected on badminton games during the men's singles and doubles semi-final and final events of the Thomas/Uber Cup 2013 competition. Thirteen male players in the single and double competitions were studied. Nine of the players were right-handed and four were left-handed. The motion of a player during the jumping smash stroke is shown in Figure 1. The numbered points represent the shuttlecock and they are marked in accordance with the respective motions: preparation (1), back swing (2-4), forward swing (4-5), contact (5), and follow-through (6-9). The best smash strokes made by each player during the games were selected. The stroke referred to what was perceived, through manual observation, to produce the fastest shuttlecock speed. For each selected player, eight trials for the singles (number of players = 5) and three trials for the doubles (number of players = 8) in the semi-finals, and five trials for doubles during the finals (number of players = 4) were used in the analysis.

The method of literature: This paper grasps the present situation of excellent badminton players from all over the world by referring to the relevant document data, which provides scientific theory evidence for their research.

The Testing method of the valid catching ball rate: Every player carries out multi-ball practice by catching his coach's serve. The serve frequency of each group is 30 balls/min; the break time of each group is 1 min. The valid catching ball rate is calculated by counting how many balls every player successfully caught.

The Testing method of BLA: The player's finger blood is collected respectively when they are not in movement and after they finish the practice, then, every player's BLA value is gained by testing his BLA 1min, 3mins, and 5 mins, respectively. Heart rate test: Heart rate telemetry is carried out during the whole process of the practice.

The method of data analysis: All the acquired data will be calculated, organized in Excel. All the data is shown by X LSD and analyzed by single factor variance analysis within groups.

Instrument: YSL1500 BLA analyzer, PE4000 telemetry cardio tachometer made in Finland.

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Reagent: YSI2357BUFFER made in America (distribution in Beijing).

III. EXPERIMENT AND DATA ANALYSIS

The whole body movements of practice and competition were expressed as the accumulated load. This estimate of physical load combines the instantaneous rate of change in acceleration in three planes of body movement: up/down (z), side/side (y) and forward/backward (x) according to the formula:

\[
\text{Load} = \sqrt{(Ax_n - Ax_{n-1})^2 + (Ay_n - Ay_{n-1})^2 + (Az_n - Az_{n-1})^2}
\] (1)

Where \(Ax\), \(Ay\) and \(Az\) are the orthogonal components of acceleration measured from the triaxial accelerometer directions at 100 Hz. To reduce the value for ease of use, the resultant was multiplied by a scaling factor of 0.01, so it is representative of a 1/100-s summation. This unit of load was highly correlated to heart rate and blood lactate accumulation during 1on1 drills, and 2 on 2 scrimmage play.

Forward kinematic equations were generated to express the global 3D position \(\vec{p}(\vec{q})\) of a marker i as a function of the 44 generalized coordinates \(\vec{q}\). Given a set of marker coordinates \(\vec{p}_{i,\text{meas}}\) measured by the motion capture system, the inverse kinematic problem is to find the model pose \(\vec{q}\) that best fits the marker data. This was formulated as a nonlinear least-squares problem:

\[
\vec{q} = \arg \min_{\vec{q}} \sum_{i=1}^{N} \left| \vec{p}(\vec{q}) - \vec{p}_{i,\text{meas}} \right|^2
\] (2)

A full body marker set consisting of \(N = 47\) markers was defined (see “Supplemental Material”) to provide redundancy and robustness against occasional marker dropout which is inevitable in real-time motion capture.

In the inverse dynamics processing step, a vector \(\vec{c}\) of unknown forces and moments, associated with the kinematic degrees of freedom, is solved from the multi-body equations of motion:

\[
\vec{c} = \mathbf{M}(\vec{q})\ddot{\vec{q}} + \mathbf{n}(\vec{q},\dot{\vec{q}}) + \mathbf{B}(\vec{q})\vec{c}_{\text{ext}}
\] (3)

where \(\mathbf{M}\) is a square mass matrix, and \(\mathbf{n}\) are terms related to Coriolis and centrifugal effects and gravity. The final term represents measured external forces (force plate data). Joint power was calculated as the product of joint moment and angular velocity. Separate equations were used to compute the full 6-DOF inter-segmental loads at the knee, and these loads were expressed in the reference frame of the shank.

The overwhelming force of the joint in biomechanical analysis during the fatigue period can be expressed as following:

\[
f^{(\alpha)}(x(0)) = \frac{df(x)}{dx^\alpha}\bigg|_{x(0)}
\] (4)

\[
= \lim_{\Delta t \to 0} \frac{\Delta^\alpha (f(x) - f(x_0))}{(x - x_0)^\alpha}
\] (5)

for \(0 < \alpha \leq 1\) where

\[
\Delta^\alpha (f(x) - f(x_0)) \equiv \Gamma(1 + \alpha) \lim_{\Delta t \to 0} \sum_{j=1}^{N_{tb}} f(t_j)(\Delta t_j)^\alpha
\]

With \(\Delta t_j = t_{j+1} - t_j\) and \(\Delta t = \max \{\Delta t_1, \Delta t_2, \ldots, \Delta t_j, \ldots\}\), where for \(j = 1, 2, \ldots, N - 1, [t_j, t_{j+1}]\) is a partition of the interval \([a, b]\) and \(t_0 = a, t_N = b\).

If \(f(x)\) is defined on the real line \(-\infty < x < \infty\), its fractional function, denoted by \(f_x^{\alpha}(x)\), is defined by

\[
H_x \{f(t)\} = \tilde{f}_x^{\alpha}(x)
\] (7)

Where \(x\) is real and the integral is treated as a Cauchy principal value, that is,

\[
\frac{1}{\Gamma(1 + \alpha)} \int_{(t - x)^{\alpha}} f(t) (dt)^\alpha
\] (8)

To obtain the inverse force, write again Eq. (7) as

\[
\tilde{f}_x^{\alpha}(x) = \frac{1}{\Gamma(1 + \alpha)} \int_{(t - x)^{\alpha}} f(t) (dt)^\alpha
\] (9)

Eight badminton elite players (age of 20 ± 2 years, height of 175 ± 5 cm, weight of 66 ± 6 kg) served as the subjects to perform the standing smash and jumping smash to the ground of the opposite court. Figure 1 showed the...
schematic drawing of the experimental setup. Two Redlake 1000 high-speed digital cameras (250 Hz, Motion Scope, San Diego, USA) were used to record the shuttlecock 3D kinematics data. One Bio-vision wired EMG system (1000 Hz, National Instruments, Austin, TX) was synchronized to collect the EMG signals of seven upper limb muscle groups, which were wrist flexor, wrist extensor, biceps brachii, triceps brachii, middle deltoid, posterior deltoid and pectoralis major. The 3D kinematics data were calculated by Kwon3D system and the surface EMG data were computed by DasyLab system. Raw EMG signals were band-pass filtered (20–400 Hz), full wave was rectified by passed through a linear envelope at 10 Hz. We were interested in analyzing the integrated EMG signal (IEMG) was from the phase of -0.7 second before contact to 0.4 second after contact. The sequence of the surface EMG activities, the EMG amplitude at the shuttlecock contact point, the peak EMG amplitude, the mean IEMG of the movement phase of the upper limb muscle groups were the selected variables. A repeated measures t-test and a Product-Moment Correlation were to test the selected variables of smash and jump smash at .05 significant levels.

Table 1: Raw values for accumulated load (ACC LOAD), peak heart rate (HR), oxygen use (VO₂) during various forms of badminton practice and competition

<table>
<thead>
<tr>
<th>Drill</th>
<th>Acc load (a.u./min)</th>
<th>Peak HR (beats/min)</th>
<th>VO₂ mL/(kg⋅min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Validation trial</td>
<td>62 ± 10</td>
<td>166 ± 14</td>
<td>42.9 ± 5.5</td>
</tr>
<tr>
<td>Defense</td>
<td>58 ± 26</td>
<td>170 ± 7</td>
<td>45.1 ± 3.6</td>
</tr>
<tr>
<td>Offense</td>
<td>55 ± 15</td>
<td>165 ± 6</td>
<td>42.3 ± 3.0</td>
</tr>
<tr>
<td>Game AVG</td>
<td>171 ± 84</td>
<td>171 ± 12</td>
<td>40.2 ± 7.1</td>
</tr>
<tr>
<td>Fatigue period</td>
<td>279 ± 58</td>
<td>173 ± 6</td>
<td>51.2 ± 3.4</td>
</tr>
</tbody>
</table>

Table 2: Differences in the estimates of physical and physiological load between defensive and offensive drills, and fatigue period and live competition

<table>
<thead>
<tr>
<th>Effect size (±90% CL)</th>
<th>Difference (±90% CL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulated load</td>
<td>0.26 (±1.08)</td>
</tr>
<tr>
<td>Peak heart rate</td>
<td>-0.20 (±0.77)</td>
</tr>
<tr>
<td>Mean heart rate</td>
<td>-0.51 (±0.88)</td>
</tr>
<tr>
<td>Mean estimated VO₂</td>
<td>-0.69 (±1.02)</td>
</tr>
</tbody>
</table>

Figure 1. The schematic of the experimental setup.

Figure 2. The accumulated physical load for badminton practice drills and competition after being normalized for time in each condition.

Errors due to time limits in the iterative solvers are shown in Fig. 3. At real-time speed settings, the errors due to premature termination of the iteration process were < 0.01 degrees for kinematics and < 5 % for muscle forces. Fig. 5 can be used to determine how these errors would change when the code is executed on faster or slower computer hardware, or when time limits are adjusted to a different frame rate for the streaming raw data.
Table 3 shows the kinematical data of the smash and jump smash strokes. There were no significant differences between the smash (68.93 m/s) and jump smash (70.98 m/s) in shuttle initial velocity. The contact duration time was 0.004 second in both smashes. The kinematics results of shuttle initial velocity and contact duration time were similar. The Figure 6 and Figure 7 show the rectified surface EMG signal patterns of smash and jump smash strokes from -0.7 second before contact to 0.4 second after contact point. The EMG patterns of smash and jump smash were looked very similar.

### Table III: The Kinematics Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Smash</th>
<th>Jump Smash</th>
<th>t</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle Velocity (m/s)</td>
<td>68.93</td>
<td>70.98</td>
<td>0.000</td>
<td>0.999</td>
</tr>
<tr>
<td>Time of Contact (sec)</td>
<td>0.004</td>
<td>0.004</td>
<td>0.000</td>
<td>0.999</td>
</tr>
</tbody>
</table>

IV. **Conclusion**

Badminton is the mixed energy supply mainly energized by anaerobic metabolism. Players' physical agility and skills can be remarkably improved by arranging training according to the characteristic of its energy supply and principle. The use of video analysis system for image analysis, and using the method of literature, video analysis, statistics and other research methods, for they completed backcourt backhand the lofty ball moves kinematic parameters were analyzed, in order to fine-tune their backhand forehand clear technical details, improve stroke quality in fatigue period, at the same time as the trainer provide some data parameters, enhanced on adolescent significance both in theory and in practice in fatigue period.
In swing the racket and hit the ball stage, the tested four player’s body weight arc to front right direction and up and down is not obvious in fatigue period. Four players angle of shoulder arc maximum in the whole process and velocity of each joint point was some timing, but different are force parts in hitting time in fatigue period.

The experiment shows that the fatigue can lead parameters depreciation of ankle joint movement. In fatigue period, the stability of technical movements of athletes starts to decline and the time for completing the action in the duration of each phase is changing all the time which may lead the failing in the control process of joint. This will greatly increase the possibility of joint injury.

REFERENCES


