INTRODUCTION

Biomechanical data associated with impact situations involving large accelerations can be prone to error due to inadequate data processing (Knudson and Bahamonde, 2001) and sampling rate. For ball kicking, the movement data at or just before initial ball contact can suffer from such problems, which reduce its usefulness in determining both the quality of the impact and the skill of the player.

The purpose of this study was to describe the true kinematics of lower limb motion during ball impact phase of instep kicking by exploring the influence of both sampling rate and smoothing procedures of the acquired motion data on the resulting movement transients.

METHODS

Nine male footballers (age = 27.6 ± 5.6 yrs; height = 175.1 ± 5.5 cm; mass = 74.5 ± 8.2 kg) participated in this study. After a brief warm-up, the subjects performed nine consecutive maximal kicking trials aiming at a wooden target in the middle of a goal which was 9m in front of the subject. They were instructed to kick the ball straight forward as hard as possible at the target with the instep of their foot. Before the trials, reflective spherical markers (9mm diameter) were tightly fixed (using acrylic glue) onto several bony anatomical landmarks including: 5th metatarsal head, lateral side of calcaneus, lateral malleolus, lateral head of fibula and tibial tuberosity (see figure 1). For measurement of ball displacement, a flat, reflective marker (22 mm diameter) was also fixed to the center of the ball which was sprayed with matt black to minimize extraneous reflections. Three-dimensional motion of the foot, shank and ball before, during and after kicking were recorded using a six camera opto-electronic motion analysis system (ProReflex, Qualisys Inc., Sweden) operating at 1000 Hz.

The angular velocity of the leg before, at and during ball contact was determined using the coordinate data after different processing approaches. The displacements were smoothed by a 2nd-order dual low-pass Butterworth digital filter at 200 Hz cut-off (BWF) and also processed using a modified version of the time-frequency filtering algorithm (based on the Wigner representation (WGN)) described by Georgakis et al. (2002). The modifications that enable the automatic selection of the filtering parameters of the present data are as follows:

(a) The time-of-impact can be estimated via the time when the second derivative reaches its peak. The signal is initially filtered (2nd-order duo-pass Butterworth filter, cut-off frequency at 200Hz) and then the second derivative can be easily calculated using finite differences, and its peak is clearly distinguishable.

(b) The process of estimating the highest cut-off frequency during ball impact phase exploits the dependence between the maximum acceleration present in the filtered signal and the cut-off frequency used. Initial investigation showed that in most cases the absolute acceleration peak value of a low-pass filtered version of the signal is rapidly ascending (up to a certain point, where it gradually becomes approximately flat) as the low-pass cut-off increases. The “optimum” value of the filtering parameter occurs in this high cut-off “plateau” region. The algorithm performs iterative calculations of the absolute acceleration peak value around the estimated time-of-impact, using a 3rd-order duo-pass Butterworth filter for incrementing cut-off frequency values. The iteration stops when the rate-of-change falls below a preset level-percentage (in this case 60%) of the initial rate-of-change (at cut-off frequency of 10Hz). This choice for the highest cut-off frequency was made to account for the presence of noise mainly at high frequencies.

Also, the co-ordinates were re-sampled (every four frames) at 250 Hz but not smoothed (RSR) and finally, the re-sampled data were filtered by the same Butterworth digital filter using a 10 Hz cut-off (RSF) to resemble typical sampling and processing conditions used in previous studies.

As shown in Figure 1 panel (a), ankle dorsiflexion/plantar flexion and shank extension/flexion angle were defined and both angles (ankle and shank) were projected on to the axis which was defined by the vector product of the vector from lateral malleolus to lateral head of fibula and from lateral malleolus to 5th metatarsal head to detect more anatomically relevant angular motion of the ankle and shank. The angular velocities and accelerations were computed as their first and second derivatives, respectively. A simple finite (forward) differentiation was used to calculate the derivatives. The ball velocity and acceleration were calculated from non-filtered coordinates also using the forward differentiation method.

![Figure 1](image_url)
The moment of impact was determined from the initial ball acceleration and defined as the frame before there was a clear positive acceleration (above 200 m/s\(^2\)). The end of ball impact was defined as the last frame that demonstrated a positive acceleration. Resultant peak ball velocity was computed as the average of five airborne frames after the end of impact.

Comparisons were made between the variables of the WGN and the other three filtering schemes (BWF, RSR and RSF). Two-way paired Student t-tests were conducted. The criterion for statistical significance was \(p< .05\) for all analysis.

**RESULTS AND DISCUSSION**

The average resultant ball velocity was \(26.3 \pm 3.1\) m/s and the average foot-ball contact time was \(9.1 \pm 0.7\) m/s. Both values were within the range of previously reported and also gave a good agreement with the values measured using ultra-high speed video records (Asai et al, 1995).

The typical changes of ankle and shank angular velocities computed using the four different filtering and sampling schemes (WGN, BWF, RSR and RSF) are shown in Figure 2 and 3. As shown large high frequency movements of the shanks and ankle were detected during kicking in all subjects. These movements were estimated to contain substantial frequency content up to 60 Hz.

The shank was still angularly accelerating during the initial phase of ball contact and reached its peak angular velocity after ball contact (see Figure 2). Meanwhile, the ankle was rapidly forced into plantar flexion by ball impact (Figure 3).

After the WGN and BWF processing the angular velocity curves followed well the rapid changes during ball contact seen in the raw, unsmoothed 1000Hz data (see Figure 2 and 3). As expected, the RSR data did not trace the sudden raw changes for the ankle and shank angular velocity during ball impact phase. Peak shank extension angular velocity and peak ankle plantar flexion angular velocity were significantly underestimated than those of the WGN case (see Table 1).

As shown in Figures, the RSR case still roughly traces the original unsmoothed changes but lost the peaks after ball impact. When the conventional filtering at 10 Hz cut-off was applied on the re-sampled data (the RSF case), totally different curves which removed completely the high frequency movement transients were created. The shank was apparently decreased in its angular velocity before ball impact and the rapid ankle plantar flexion motion was completely erased. In the RSR and RSF cases, their peak shank extension and ankle plantar flexion angular velocities were significantly underestimated than those of the WGN case.

Knudson and Bahamonde (2002) though they used a tennis impact, showed if the angular data were smoothed through impact using conventional Butterworth filtering approach, a false peak before ball impact was introduced by over-smoothing. Probably similar distortion was produced in the RSF case. Both the insufficient sampling rate (250 Hz) and over-smoothing (10 Hz) may account for this. However, as the RSR case roughly traces the raw change, distortion by the smoothing may a more crucial factor.

![Figure 2](image2.png) **Figure 2:** Typical change of shank angular velocity (thick line) in four different filtering and sampling conditions (WGN, BWF, RSR and RSF). Each change was shown against the original raw change (thin line).

![Figure 3](image3.png) **Figure 3:** Typical change of ankle angular velocity (thick line) in four different filtering and sampling conditions (WGN, BWF, RSR and RSF). Each change was shown against the original raw change (thin line).

Although the BWF case with enough high cut off frequency seemed to trace the rapid change, its pre-contact base line (lower frequency motion phase) was still noisy. Figure 4 shows the detailed pre-impact changes of shank angular velocity of the WGN and BWF cases. As shown, the pre-impact motion phase of the BWF case was considerably noisy than the WGN case. This caused a slight but significant overestimation of the peak shank angular velocity (31.5 ± 5.0 rad/s vs. 31.8 ± 5.1 rad/s) (see Table1). Meanwhile, the signal of WGN removed the noise from the base line, yet maintained the peak of the rapid change, thereby showing the advantage of the time frequency filtering technique. The results of the present study clearly show that the conventional Butterworth filtering even have an enough high cut-off frequency is
Table 1. Selected angular velocity values in four different filtering and sampling conditions (WGN, BWF, RSR and RSF).

<table>
<thead>
<tr>
<th></th>
<th>WGN</th>
<th>BWF</th>
<th>RSR</th>
<th>RSF</th>
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<tbody>
<tr>
<td>Shank extension</td>
<td>31.4 ± 5.2</td>
<td>31.8 ± 5.3 *</td>
<td>31.2 ± 5.2 *</td>
<td>23.7 ± 5.0 *</td>
</tr>
<tr>
<td>Ankle plantar flexion</td>
<td>-42.8 ± 12.4</td>
<td>-44.7 ± 12.4</td>
<td>-35.8 ± 5.3 *</td>
<td>-2.5 ± 3.8 *</td>
</tr>
</tbody>
</table>

* shows significant differences against the WGN case.

Figure 4: Enlarged changes of shank angular velocity of the original raw (thin line), WGN case (thick line) and BWF case (broken line)

Apparent decrease in speed of the shank before ball impact has been consistently observed in the literature related to kicking (Barfield, 1995; Dörge et al., 2002). This nature of kicking led to a proposed accuracy enhancing strategy during the final phase of kicking (Teixeira, 1999). As described above, the apparent decrease in angular velocity was mostly due to distortion by over smoothing as seen in the RSF case.

Practically, coaches often made several advices to players for kicking practices like 'kicking through the ball'. However, no evidence has been shown to support this type of instruction from a biomechanical point of view. The present study is the first study that strongly supports the above practical advice of kicking by showing the relevant information of the distal segment motion including ball impact phase.

The rigidity of the ankle has been proposed as a major factor assessing the quality of ball impact. Asami and Nolte (1976) and Asai et al. (1995) tried to quantify the foot deformation during ball impact process. Ben-Sira (1980) in his dissertation, found that forced plantar flexion of the ankle joint has been shown to occur even in a skilled population. The present study confirmed the plantar flexion of ankle joint among mature level of soccer players by (see Figure 2). This implies that a high-speed plantar flexion motion occurs not only for less skilled player but also for skilled footballers who can produce a high ball speed. As this motion was occurred very shortly and observed from the moment of ball contact, it is reasonable to consider that this motion was totally forced to occur by the reaction force from ball. Also it would be assumed that the ankle joint is suffering a transient but high stress from the ball in each instep kicking. Immobility of ankle joint is commonly observed for footballers and kicking is without doubt, the most particular and repetitious skill in soccer practice. Thus, the ankle immobility often observed for footballers is most likely due to the repetitive transient stress of the instep kicking. Unfortunately, the present study is insufficient to quantify the actual stress exposed to ankle joint by the instep kicking; however, the new time-frequency filtering method succeeded to capture the accurate ankle motion at least will be a significant help for further investigations which try to measure the actual ankle stress during the transient motion.

SUMMARY

The present study proposes a new time-frequency filtering technique as a better way to smooth signals whose frequency content varies dramatically with time, by which the movement transients during impacts such as ball kicking can be characterized more accurately.

REFERENCES