Gender differences in trunk acceleration and related posture during shuttle run cutting

Yasuharu Nagano, Shogo Sasaki, Ayako Higashihara and Hideyuki Ishii

Abstract

Measurements using an accelerometer reflect the impact applied to the trunk. Measurement of trunk acceleration has the possibility of reflecting the typical characteristics of trunk motion during cutting. However, analysis of trunk acceleration data during cutting manoeuvres has not been previously conducted. This study aimed to analyse trunk acceleration during cutting manoeuvres to examine any gender differences or a relationship with posture. All participants (eight male and eight female college soccer athletes) performed a shuttle run cutting task, and trunk accelerations (medio-lateral, vertical, and antero-posterior) were calculated. The peak acceleration (G) and total magnitude during the 200 ms after foot contact were measured, and the forward trunk inclination and femoral angle were calculated from the video images taken using a sagittal plane camera. Peak vertical acceleration (mean, s) was significantly greater among female athletes than among male athletes (−2.18, s = 0.84 G; −1.15, s = 0.45 G, respectively; p < 0.01). Medio-lateral and antero-posterior peak acceleration and the total magnitude in all directions were not significantly different between genders. Moderate negative correlations were found between vertical peak acceleration and trunk forward inclination and femoral inclination (r = −0.57, p < 0.05; r = −0.69, p < 0.01, respectively). The difference in vertical acceleration between genders has the possibility to reflect a stiff cutting movement among female athletes. The acceleration of the upper trunk may be an index for evaluating cutting movements.

Introduction

Anterior cruciate ligament (ACL) injuries occur at a high rate in female athletes (Arendt & Dick 1995; Agel et al. 2005), and often occur in non-contact sport situations, including landing and cutting (Boden et al. 2000). In recent years, the trunk and lower limb positions of female athletes at the time of ACL injury have been described (Boden et al. 2009; Hewett et al. 2009; Sheehan et al. 2012). From the results of these studies, knee abduction (Boden et al. 2009; Hewett et al. 2009), increased hip flexion (Boden et al. 2009), increased trunk lateral motion (Hewett et al. 2009), decreased trunk forward inclination (Sheehan et al. 2012), and extreme posterior position of the centre of mass relative to the base of support (Sheehan et al. 2012) was observed. These studies revealed that female athletes have characteristic lower limb and trunk positions at the time of ACL injury.

The typical characteristics of trunk motion during cutting have recently been described. Nagano et al. (2011) reported that female athletes demonstrated reduced trunk forward inclination, greater lateral inclination opposite to the cutting limb, and a smaller knee flexion angle during shuttle run cutting than male athletes. Others reported that lateral trunk orientation increased during unanticipated tasks involving sidestepping, while the knee abduction moment also increased (Houck et al. 2006). Some studies (Jamison et al. 2012; Frank et al. 2013; Kristianslund et al. 2013) also demonstrated a significant positive association between lateral trunk orientation and peak knee abduction moments during run-to-cut manoeuvres. These results suggest that the trunk position during cutting differs between genders, and these differences may be related to a greater propensity for injury, i.e. ACL injuries, among female athletes than among male athletes.

Several authors (Houck et al. 2006; Nagano et al. 2011; Jamison et al. 2012; Frank et al. 2013; Kristianslund et al. 2013) have recently measured trunk movement during cutting. Unfortunately, the methods used in previous studies to measure trunk movements are costly and require the use of expensive equipment, i.e. a 3D motion capture system.
system. Infrared cameras and measurement systems are expensive and require considerable time for measurement and processing. In addition, the calculation methods were dissimilar among the studies. On the other hand, measurements using an accelerometer are comparatively simple, with the measured acceleration also reflecting the impact applied to the segment. Peak impact accelerations occur for individual body segments as the impact is transmitted through the skeletal system from the leg to the head, and the accelerations of these segments will depend on the geometry of the segments, apparent stiffness of the joints, segment deformations, segment masses, and segment moments of inertia (Derrick 2004). Therefore, acceleration measurements have been used in some motion analysis studies. Moran and Marshall (2006) reported the effects of fatigue on tibial impact acceleration during a drop jump, and Henriksen et al. (2004) showed a high reliability of trunk accelometric data for gait analyses. However, the analysis of trunk acceleration data during cutting manoeuvres has not been reported, although beneficial information could be obtained.

Clarification of the trunk acceleration during cutting manoeuvres might help in the examination of factors related to injury from different points of view, as part of a conservative motion analysis. The purpose of this study was, therefore, to analyse trunk acceleration during cutting manoeuvres and examine any gender-related differences as well as any relationship with posture. We hypothesized that female athletes would demonstrate greater medio-lateral, antero-posterior, and vertical trunk acceleration, and that greater vertical trunk acceleration would be related to less femoral and trunk forward inclination; this is because female athletes may assume a posture at high risk for ACL injury, which can transmit greater acceleration to the upper trunk.

Material and methods

Participants

A total of eight male (mean age, 21.4, s = 0.5 years; body mass, 71.1, s = 4.9 kg; height, 179.0, s = 6.3 cm) and 8 female (mean age, 18.9, s = 0.4 years; body mass, 51.3, s = 7.4 kg; height, 159.3, s = 3.2 cm) athletes (soccer players) were recruited for the experiment. All participants had more than 4 years of experience at the national intercollegiate level. Participants were excluded from the study if they had a history of serious musculoskeletal injury; any musculoskeletal injury within the past six months; or any disorder that interfered with sensory input, musculoskeletal function, or motor function. Prior to participation, all participants provided written, informed consent in accordance with the requirements of the university’s ethical committee (approval number, 17263).

Measures

Measurements were taken during shuttle run cutting, at maximum speed. During this manoeuvre, the participants ran straight ahead for 5 m, planted their cutting foot perpendicular to their initial direction of motion, changed direction 180° from their initial direction of motion, and then ran again straight ahead for 5 m (Nagano et al. 2011). This manoeuvre was conducted on indoor carpet floor surface. To comply with the experimental setting, the participants conducted the cutting manoeuvre using their right limb, and were permitted several preparation trials. The right foot was dominant in all participants. Initially, the manoeuvre was performed at a jogging speed, and the speed was gradually increased. When they achieved sufficient acceleration, but were not off-balance, measurements were taken. If they could not plant their foot perpendicular to their direction of travel or if they slipped during the cutting manoeuvre, the trial was excluded. The time between the start and the achievement of the shuttle run cutting manoeuvre was also measured. If the time was less than the fastest time, by more than 0.2 s, the trial was excluded. Measurements were recorded for three successful trials.

Procedures

The axial direction of the accelerometer was set to be +1 G when it indicated acceleration due to gravity. The acceleration value is the value of the reaction against the moved direction. Linear acceleration in a ±5 G range was measured using a lightweight (35 g), triaxial accelerometer (Logical Product, Fukuoka, Japan). The accelerometer was secured to the spinous processes of the first and second thoracic vertebrae using double-sided and vantage tapes. The three axes of the accelerometer were aligned close to the anatomical axes, i.e. the X-axis was aligned medio-laterally, the Y-axis vertically, and the Z-axis antero-posteriorly (Figure 1). Acceleration data were sampled at a frequency of 200 Hz and saved in the accelerometer’s built-in memory (32 MB). After testing, the accelerometer was connected to a computer, and the raw data were downloaded into a database for later analyses.

From the acceleration data, the peak acceleration and the total magnitude of the acceleration during the 200 ms following foot contact were measured in each direction (medio-laterally, vertically, and antero-posteriorly). The moment of foot contact was determined from synchronized high-speed camera images filmed in the sagittal plane. Synchronization with acceleration data and camera images was performed by a light signal at the time when measurement commenced. Peak accelerations were defined as the maximum acceleration in the medio-lateral
(X) direction, concurrent with minimum accelerations in the vertical (Y) and antero-posterior (Z) directions. The total magnitudes were defined as the differences between the maximum and minimum accelerations during the 200 ms after foot contact.

A high-speed camera (210 Hz, EX-FH20, Casio, Shibuya, Japan) was used to record the trunk and lower limb movements. The camera was placed along the sagittal planes at a distance of 3.5 m from the foot-plant point and 0.4 m above the running surface (Figure 2). Eight plastic tape markers (diameter, 16 mm) were secured on each subject. The markers were placed on the right acromion, right greater trochanter, and right lateral knee joint. The captured images were imported into digitizing software program (Pixel Runner G, PixelGate, Shibuya, Japan). In the sagittal plane, the forward trunk inclination and femoral angles were calculated (Figure 3). The angle formed by the lines from the marker on the right acromion to the right greater trochanter, and the vertical line was recorded as the trunk forward inclination angle. The angle formed by the lines from the marker on the right great trochanter to the right lateral knee joint, and the vertical line was recorded as the femoral inclination angle. All variables were measured at the time points of foot contact.

**Statistical analysis**

Comparisons between male and female athletes were performed using Student’s *t*-test. The 95% confidence intervals for the minimally detectable changes (MDC95) were also calculated to determine the consistency of the measurements. MDC95 were calculated using the following formula: 

\[ MDC_{95} = SEM \times \sqrt{2} \times 1.96. \]

The associations between trunk accelerations and trunk and lower limb positions were analysed using Pearson’s product-moment correlation coefficients. Significance was set at *p* < 0.05.

**Results**

MDC95 values are shown in Table 1. The time to perform the shuttle run cutting manoeuvre was 2.52 s = 0.05 s for male athletes and 2.83 s = 0.11 s for female athletes. The time for males was significantly faster than that of the females. Figure 4 illustrates the mean time course comparisons between the genders for the three measured accelerations (medio-lateral, vertical, and antero-posterior). The results demonstrated leftward, upward, and rearward accelerations after foot contact. The comparisons between male and female athletes are shown in Table 2. Peak vertical acceleration was significantly greater in female athletes than in male athletes (*p* < 0.01), but peak acceleration in the medio-lateral and antero-posterior directions and the total magnitude in all directions were not significantly different between the genders.

Table 3 presents the correlation (*r*) values between trunk accelerations and trunk and lower limb posture. Because of video imaging problems, one female subject was excluded from the analysis of correlation. Moderate negative correlations were found between vertical peak...
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have the greatest deceleration and acceleration. Therefore, we selected shuttle run cutting as an experimental task for evaluating trunk acceleration in athletes.

The results of this study showed that female athletes had greater trunk vertical (upward) acceleration during cutting. One of the factors that influences trunk vertical acceleration is ground reaction force. A previous study reported acceleration output correlated positively with ground reaction force (Rowlands & Stiles 2012). Some previous studies reported the absence of gender-related differences in vertical ground reaction forces during single-leg (Lephart et al. 2002) or double-leg landings (Decker et al. 2003), but others reported greater vertical ground reaction forces in females during these athletic tasks (Kernozelek et al. 2005; Schmitz et al. 2007). The results of the present study were supported by previous reports (Kernozelek et al. 2005; Schmitz et al. 2007), with female athletes showing greater vertical acceleration during cutting manouevres. Additionally, greater ground reaction force is one of the characteristics of athletes who injure their ACLs (Hewett et al. 2005). Therefore, it is suggested that greater trunk vertical acceleration for females reflected the greater ground reaction force during cutting. This was regarded as a risk factor for ACL injury.

The results of this study also demonstrated relationships between trunk vertical acceleration and posture. Those who had greater trunk and femoral inclination showed decreased trunk vertical acceleration. Vertical acceleration of the upper trunk also is influenced by how ground reaction force is transmitted to the upper trunk, with attenuation of impact by the lower limbs and trunk. The attenuation of impact is affected by the individual’s posture at the time of foot contact (Derrick 2004). Derrick (2004) reported that the attenuation of the impact increased when the knee was flexed. This result suggested that greater flexion of the lower limb joint and trunk increases the attenuation of the impact by joint rotation, stretching of elastic components of the muscle tendon complex, and muscular energy absorption (Derrick 2004). In the present study, greater trunk forward inclination reflects hip flexion and greater femoral inclination reflects knee flexion. Therefore, the results of the present study show that a more flexed posture increased attenuation of each joint and decreased the impact transmitted to the upper trunk, which is supported by a previous study (Derrick 2004). These postures are emphasized in a prevention programme for ACL injury (Myklebust et al. 2003; Mandelbaum et al. 2005), and are far from the position of ACL injury (Sheehan et al. 2012).

Discussion

The primary purpose of this study was to analyse trunk acceleration during shuttle run cutting. We selected shuttle run cutting as an experimental task based on a previous study (Nagano et al. 2011). Shuttle run cutting includes deceleration as well as turning, stopping, and acceleration; the manouevre requires adequate trunk control because of the directional changes required during the task. During the stopping phase, the trunk is assumed to

acceleration and trunk forward inclination and femoral inclination ($r = −0.57, p < 0.05; r = −0.69, p < 0.01$, respectively) (Figure 5). When the genders were considered separately, there was no significant correlation between vertical peak acceleration and trunk forward inclination in either males or females. However, a high negative correlation was found between vertical peak acceleration and femoral inclination only in females ($r = −0.83, p < 0.05$). Moderate negative correlations were found between the vertical magnitude acceleration and femoral inclination ($r = −0.67, p < 0.01$).

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It may be possible to evaluate a subject's ability to avoid the posture that causes ACL injury by measuring his or her trunk acceleration.

We examined the relationship between acceleration and posture in all subjects. The reason for these examinations is that the number of those whose movements put them at high risk for ACL injury is even in males and females. Additionally, the movement characteristics could overlap between males and females. In our previous study (Nagano et al. 2011), the relationships between trunk and knee kinematics were also examined with all (male and female) subjects, which showed that decreased trunk forward inclination was associated with greater tibial rotation. Therefore, the results of the present study suggest that greater vertical acceleration is related to greater tibial rotation and puts athletes at risk for ACL injury. However, it is also beneficial to consider males and females and their risk factors separately. The results of this study demonstrated that vertical acceleration was related to femoral inclination angle only in females. Femoral inclination angle is thought to reflect the knee flexion angle. It is suggested that females buffer the vertical impact through knee flexion while males do not. Because the number of male and female subjects was too small to examine this correlation, a detailed examination should be done in a future study.

The results of the present study demonstrated peak lateral and posterior acceleration of the upper trunk after foot-ground contact. These changes in acceleration may cause trunk motion during cutting. Based on a previous study (Nagano et al. 2011) that reported gender differences in trunk forward and lateral inclination during cutting, we hypothesized that there are gender differences in the medio-lateral and antero-posterior accelerations. However, in the present study, gender differences in medio-lateral and antero-posterior accelerations were not evident. Moreover, the antero-posterior acceleration was not related to trunk and lower limb posture, which may indicate that upper trunk antero-posterior acceleration is influenced by muscular energy absorption, not by posture. Medio-lateral acceleration was also not related to trunk and lower limb posture, but we only examined sagittal posture in the present study because of the difficulty associated with measuring medio-lateral posture from frontal plane camera images. Future studies should examine the relationship between medio-lateral acceleration and medio-lateral posture during cutting.

The present study had some limitations. First, we only collected acceleration data using an accelerometer. Theoretically, we could calculate the position and angle of the trunk using the integrated acceleration data. However, in our system, position and angle accuracy were not established, and we measured trunk forward inclination and

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**Figure 4.** Acceleration comparisons. Notes: Data are presented for the medio-lateral (a), vertical (b), and antero-posterior (c) accelerations.
Conclusion

We analysed trunk acceleration during cutting manoeuvres and examined gender differences in the collected data. Peak vertical acceleration was greater in female athletes than in male athletes, whereas the peak acceleration in the medio-lateral and antero-posterior directions, and the total acceleration magnitude in all directions, were not significantly different between genders. The results reflect the comparatively stiff movements of female athletes. The results also suggest that upper trunk acceleration may be an index for evaluating cutting movements.

Disclosure statement

No potential conflict of interest was reported by the authors.

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