Contribution of eccentric strength to cutting performance in female soccer players.

Abstract

The aim of this study was to examine the contribution of eccentric strength to performance of a 70-90° cutting task (CUT) (time to complete: 5 m approach, 70-90° cut, 3 m exit). Nineteen female soccer players (mean ± SD age, height and mass; 21.6 ± 4.4 years, 1.67 ± 0.07 m and 60.5 ± 6.1 kg) from the top two tiers of English women's soccer participated in the study. Each player performed 6 trials of the CUT task whereby three-dimensional motion data from 10 Qualisys pro-reflex cameras (240 Hz) and ground reaction forces from two AMTI force platforms (1200 Hz) were collected. Relative eccentric knee extensor (ECC-KE) and flexor peak moments (ECC-KF) were collected from both limbs at $60°\cdot s^{-1}$ using a Kin Com isokinetic dynamometer. Hierarchical multiple regression revealed that minimum center of mass (CM) and approach velocities (CM velocity at touchdown of penultimate foot contact) could explain 82% (79% adjusted) of the variation in CUT completion time ($F_{(1,16)} = 36.086$, $P < 0.0001$). ECC-KE was significantly ($P < 0.05$) moderately associated ($R \geq 0.610$) with velocities at key instances during the CUT. High (upper 50th percentile) ECC-KE individuals (n = 9) had significantly ($P \leq 0.01$; $d \geq 1.34$) greater velocities at key instances during the CUT. The findings suggest that individuals with higher ECC-KE produce faster CUT performance, by approaching with greater velocity and maintaining a higher velocity during penultimate and final contact, as they are better able to tolerate the larger loads associated with a faster approach.

Key words: Change of direction speed; velocity; kinetics; penultimate contact; deceleration

Introduction

Agility is defined as a rapid and accurate whole-body movement with change of velocity, direction or movement pattern in response to a stimulus (29) and is considered highly important in a number of field and court based sports (39). Change of direction (COD) ability is an underpinning quality for successful agility and is defined as the (pre-planned) ability to decelerate, reverse or change movement direction and accelerate again (22). Enhancement of COD ability is essential to provide the technical and physical foundation to develop agility (27). Numerous studies have examined the physical determinants of COD ability, with associations found to linear sprinting speed (16, 22), vertical jump characteristics (1, 8), eccentric (16, 22, 30), isometric (30, 33), concentric (30), isoinertial (20), and reactive (6, 38) strength. However, findings from these studies have generally been conflicting due to variations in; sample population (i.e. sports student vs. athlete population; combined sexes), COD protocols used (i.e., 505-180° turn vs. 45° "cut" manoeuvre), statistical approaches adopted (i.e., correlational analysis, fast vs. slow group comparisons, inclusion or exclusion of multiple regression analysis), muscle strength quality under investigation and methods of assessing a given muscle strength quality (i.e., isokinetic vs. isoinertial).

A shortcoming of the abovementioned studies is that often the association between COD ability to 'strength' in general is explored, without focusing on the specific role that particular strength qualities have during different COD tasks. For instance, during the final 'plant' foot contact of a COD maneuver, an athlete will require sufficient eccentric strength to reduce velocity in the initial direction of travel during the braking phase, isometric strength during the amortization phase and concentric strength during the propulsion phase to help re-accelerate into the new intended direction of travel (30). Moreover, eccentric strength is considered important to reduce velocity during the final stages of approach during a COD task. In support of this theory, previous research has found an association between eccentric isokinetic knee extensor (R= -0.529) and flexor strength (R= -0.626) and 505 test performance (22) and eccentric isokinetic knee extensor strength (R^2= 42.1%) and performance during a similar 180° turn task (16) both in university sports participants. Jones *et al.* (22) suggested that eccentric knee extensor strength is important to control knee flexion during final contact when the ground reaction forces acting through the lower limb are high, whilst eccentric knee flexor (hamstring) strength is important to help generate hip extensor moment to maintain trunk position during deceleration and assist with knee joint stability.

In addition, Naylor and Greig (26) found eccentric isokinetic hamstring peak moments at $180°\cdot s^{-1}$ and $60°\cdot s^{-1}$ were the best predictors of T-test performance (R^2 = 61%) and a deceleration task (reactive stopping distance from a 10 m sprint) (R^2 = 32%) in 19 male team sport players, respectively. Lastly, Spiteri *et al.* (30) using elite female basketball players investigated the relationships between 505 and T-test performance with a number of lower limb muscle strength qualities, finding eccentric strength (eccentric only back squat) the best predictor of COD performance. Collectively, the findings from these studies suggest an association between eccentric strength and 90° (T-test) to 180° (505 test) COD performance and deceleration ability.

A limitation of these studies is that they have only examined the association between eccentric strength and global COD performance, which does not consider the role specific strength qualities have during specific phases of COD. Jones *et al*. (24) examined the role of eccentric strength during a 180° COD task in female soccer players through examination of a velocity profile during the deceleration phase of the COD task. Large correlations were revealed between COD performance (completion time) and eccentric knee extensor strength (R = -0.674), whilst moderate to large correlations were observed between approach velocity and COD performance (R = -0.484) and eccentric strength (R = 0.724), suggesting that greater eccentric strength is associated with faster 180° COD performance in female soccer players. Furthermore, stronger participants recorded significantly faster approach velocity (4.01 ± 0.18 vs. 3.74 ± 0.24 $m \cdot s^{-1}$, d = 1.28) and greater reduction in velocity (-1.55 ± 0.17 vs.-1.37 ± 0.21 $m \cdot s^{-1}$, d = -0.94) during penultimate contact than weaker subjects. These findings suggest that stronger players are better able to decelerate during penultimate contact from faster approach velocities perhaps due to a 'self-regulation' effect (i.e., a player approaches faster based on the deceleration load they know or feel they can tolerate), which can lead to faster overall COD performance.

The role of different muscle strength qualities is likely to be influenced by the demands of the task, with deceleration demands dependent on the angle of CODs (13). For instance, a 180° COD requires an individual to reduce their horizontal velocity to zero at a 'turning point' before then re-accelerating in the opposite direction, whereas with cutting <90° individuals are not required to reduce horizontal velocity to zero, but are required to shift momentum into a new direction of travel during the final 'plant' step. Hader et al. (19) found that during 45° and 90° COD maneuvers the ability to maintain high velocity during both maneuvers was a major determinant of performance, highlighting the different task demands of cutting ≤90° compared to turning (i.e., 505 test) and thus, the need to gather a greater understanding of the role of eccentric strength within such cutting tasks.

Little is known about what role, if any, eccentric strength may play during 'cutting' maneuvers to help with such task demands. Previous research (11) has shown positive benefits of 10 weeks eccentric training on final 'plant' contact braking force-time characteristics during 60°-side-step and 45°-cross cutting in under 19 male soccer players, suggesting that eccentric strength does indeed assist with deceleration during cutting actions. More research is needed to gather a greater understanding of how greater eccentric strength facilitates cutting maneuvers. Furthermore, it would be prudent to investigate this in female soccer players, given that such maneuvers are commonly associated with non-contact anterior cruciate ligament (ACL) injuries in female soccer (5, 14). Thus, understanding the role of eccentric strength within the deceleration aspect of cutting may have important implications for conditioning with this population of athlete in respect of the demand of tasks regularly performed in soccer. Therefore, the aim of the study was to examine the contribution of eccentric strength during performance of a 70-90° cutting task in female soccer players. To achieve this aim the study had the following objectives: 1) to explore the relationships between cutting performance (completion times), velocities at key instances during the approach, eccentric knee extensor and flexor strength; 2) examine the velocity profile differences during the cutting task between players with 'high' and 'low' eccentric knee extensor strength; and 3) explore the kinetic differences during weight acceptance of penultimate and final contact between players with 'high' and 'low' eccentric knee extensor strength. It was hypothesized that there is an association between eccentric strength, velocities during key instances of approach and cutting performance and that players with higher eccentric knee extensor strength produce faster cutting task completion times, through a faster approach velocity and lower decline in velocity during penultimate and final contacts.

Methods

Experimental Approach to the Problem

This study involved a cross-sectional design whereby 19 participants performed multiple trials of a 70-90° cutting task, whilst collecting three dimensional motion and force data along with an isokinetic assessment of eccentric knee extensor and flexor strength. A minimum of 12 participants was determined from an *a priori* power analysis using G*Power (Version 3.1.9.2, University of Dusseldorf, Germany) (15). This was based upon a previously reported coefficient of determination of 0.45 (COD completion time – eccentric knee extensor strength) (24), a power of 0.8, and type 1 error or alpha level 0.05. Each participant attended the lab on 2 occasions. The first occasion was a familiarization session on the protocols used in the study with data collected in the subsequent session. To test the study hypothesis, Pearson's correlation, co-efficients of determination and hierarchical multiple regression were used to explore relationships between cutting task completion time, velocities at key instances during the cutting task and eccentric knee extensor and flexor strength. Furthermore, using a median-split analysis approach as used previously (31) velocities at key instances during the maneuver and kinetic characteristics were compared between sub-groups of players with 'high' and 'low' eccentric knee extensor strength (upper and lower 50th percentiles, respectively).

Subjects

Nineteen female soccer players (mean ± SD age, height and mass; 21.6 ± 4.4 years, 1.67 ± 0.07 m and 60.5 ± 6.1 kg) participated in the study. All players were outfield players (6 defenders, 7 midfielders, 6 forwards) and played in the top two tiers of English women's soccer at the time of the study. Each player participated in at least two soccer practice sessions and one match each week. Seventeen of the players reported their dominant limb (i.e., favored kicking limb) to be the right leg. All of the players were free of injury at the time of the study. None of the players had suffered any traumatic knee injury (i.e., ACL injury) in the past. Approval for the study was provided by the University's Ethics committee. All participants provided written informed consent and parental assent was attained for any player under the age of 18 prior to participating in the study through signing at institutionally approved consent form.

Procedures

Cutting task

The cutting task involved the subjects running towards 2 force platforms: the first force platform was used to measure ground reaction forces (GRFs) from the penultimate foot contact (PEN), whilst the 2nd force platform was used to measure GRFs from the final (plant) foot contact (FIN) [Figure 1]. Prior to the turn, each subject ran through a set of single-beam timing cells (Brower, Draper, UT) positioned 5 m from the center of the last platform. The subjects then cut within a 70-90^0 path to the left once contacting the second force platform with their right leg and ran through another set of timing cells positioned 3 m away. The timing cells were set at approximate hip height for all subjects as previously recommended (37), to ensure that only one body part broke the beam. Task completion time was used as a global performance measure. Each subject started approximately ≤10 m behind the first set of timing lights. Some flexibility was allowed for the exact starting point for each subject to allow for the subjects' differing stride pattern as they approached the 2 force platforms. Each subject was allowed time prior to data collection to identify their exact starting point to ensure appropriate force platform contacts. During data collection all subjects performed a minimum of 6 trials of the cutting task with the fastest 3 trials used for analysis.

<<INSERT FIGURE 1 HERE>>

The following procedures have been reported previously (23), thus only a brief overview is provided here. Reflective markers (14 mm spheres) were placed on body landmarks (23) of each subject by the same researcher to ensure marker placement consistency. Subjects wore 4-reflective marker 'cluster' sets on the right and left thigh and shin attached using Velcro elasticated wraps to approximate the motion of these segments during dynamic trials. The pelvis and trunk cluster sets were attached onto an elasticated belt and lycra ‘crop top’, respectively.

Three dimensional motions of these markers were collected whilst performing the cutting task using 10 Qualisys ‘Pro reflex’ infrared cameras (240 Hz) operating through Qualisys Track Manager software (version 1.10.282). GRFs were collected from two AMTI force platforms (1200 Hz) embedded into the running track.

From a standing trial, a 6-degree-of-freedom model of the lower extremity and trunk was created for each participant using Visual 3D software (C-motion, v3.90.21). This kinematic model was used to quantify the motion at the hip, knee and ankle joints using Cardan angle sequence (18). The local coordinate system was defined at the proximal joint center for each segment. The static trial position was designated as the subject’s neutral (anatomical zero) alignment, and subsequent kinematic measures were related back to this position. Lower limb joint moments were calculated using an inverse dynamics approach (36) through Visual 3D and are defined as internal moments. Segmental inertial characteristics were estimated for each participant (12). The model utilized a CODA pelvis orientation (3) to define the location of the hip joint center. The knee and ankle joint centers were defined as the mid-point of the line between lateral and medial markers. The trials were time normalized for each subject, with respect to the ground contact time of the COD task. Touchdown and take-off were defined as the instant that the vertical GRF (vGRF) superseded and subsided past 20 N, respectively, for both PEN and FIN. The weight-acceptance phase for both contacts was defined from touchdown to the point of maximum knee flexion as used previously (20, 23). Joint coordinate and force data were smoothed in visual 3D with a Butterworth low pass digital filter with cut-off frequencies of 12 Hz and 25 Hz, respectively. Cut-off frequencies were selected based on a residual analysis (36) and visual inspection of the data.

Trunk and lower limbs center of mass (model CM) was computed as recommended by Vanrenterghem et al. (34) to evaluate velocity. Model CM position was determined from 10 frames prior to PEN to 10 frames after FIN. The first derivative of the model CM position was computed to derive anterior-posterior (x), vertical (z) and medio-lateral (y) velocity over this period. Resultant horizontal plane velocity ($\sqrt{}$ ((CM vel $(x)^2$) + (CM vel $(y)^2$)) was subsequently calculated to provide a 'velocity profile' along the path of the subjects CM during the cutting maneuver. Resultant horizontal plane velocity at touchdown of PEN was determined to represent the 'approach velocity' of the participant for that trial. Values of resultant horizontal plane velocity at take-off of PEN, touchdown of FIN and take-off of FIN were determined for each trial along with the minimum resultant horizontal plane velocity achieved during this period. In addition, to evaluate the change in velocity during the final 2 contacts the following variables were determined; 1) change in velocity from touchdown to take-off of PEN (Δ PEN) and, 2) touchdown to take-off of FIN (Δ FIN). Finally, 'true' cutting angle was determined for each trial at the take-off of FIN using the formula ([CM vel (y)/ CM vel (x)] Tan^{-1}) as used previously (32).

During the weight-acceptance phase of PEN and FIN of the cutting-task, peak and average vertical (Fz) and horizontal (Fx) GRFs were determined along with peak sagittal plane knee and hip moments. Contact times for both PEN and FIN contacts were also determined. Average of individual trials were reported for each variable.

Eccentric Strength Assessment

Gravity-corrected isokinetic eccentric peak moments from 4 trials of the right and left knee extensor and flexor muscle groups at $60°\cdot s^{-1}$ were determined using a Kin Com (Chattanooga Group, Tennessee) isokinetic dynamometer, adopting methods reported previously (17). The subjects were seated with the hip joint at 90°. The axis of rotation of the dynamometer shaft was aligned with the best approximation of the knee joint axis of rotation, midway between the lateral condyles of the femur and tibia. The cuff of the dynamometer lever arm was attached to the ankle, just proximal to the malleoli. Extraneous movement was prevented by straps, positioned at the hip, shoulders and tested thigh. Subjects were instructed to hold onto the handles located underneath the seat. ROM was set as close to 90° as possible (0^0 = full knee extension). Eight sub-maximal concentric knee extension and flexion movements were performed as a warm-up following 3 minutes of stationary cycling (60 rpm) on a cycle ergometer (Wattbike Ltd, Nottingham, UK).

The trial exhibiting the highest peak torque (from the 4 trials) in each mode on each limb was saved and used for further analysis. Data were exported in ASCII format into Microsoft Excel for analysis. Phases of acceleration and deceleration, using a $\pm 1° \cdot s^{-1}$ tolerance, were eliminated from the analysis. Right and left eccentric peak moment values were normalized by body mass for both muscle groups. A paired samples t-test revealed no significant differences ($P > 0.05$; d (ECC-KE) = -0.11; d (ECC-KF) = 0.16) between right and left limbs for eccentric peak moment values for each muscle group. Therefore, right and left eccentric peak moment values were averaged across limbs for both muscle groups (ECC-KE, ECC-KF) and subsequently used for statistical analysis. A-priori test-retest reliability of ECC-KE and ECC-KF peak moments revealed good reliability and low variation (ECC-KE = 0.937, CV = 5.83%; ECC-KF: ICC = 0.952; CV = 4.90%; n = 23) between sessions (17).

Statistical Analysis

Statistical analysis was performed in SPSS for Windows (version 23, IBM, New York, NY, USA). Normality was confirmed for cutting-task completion time, eccentric strength and velocities during approach via the Shapiro-Wilks test. Within trial reliability and variation for the cutting task was assessed using intraclass correlation coefficients (ICC) and coefficient of variation (%CV) with ICC >0.7 and CV <10% considered to represent good reliability (2, 9). To explore relationships between eccentric strength, velocity at key instances and cutting task completion time Pearson's (R) correlation was performed and co-efficients of determination (R^2 × 100) calculated. Significance for correlations were Bonferroni corrected to reduce likelihood of type 1 error, with statistical significance set as $P < 0.05$ after correction. Correlations were evaluated as follows: negligible (0.0-0.30), low (0.30-0.50), moderate (0.50–0.70), high (0.70–0.90) and very high (>0.90) (25). Hierarchical multiple regression was subsequently used to determine the combined effects of highly correlated variables to cutting task completion time.

Moreover, based on previous approaches used in the literature (31) the sample was divided into the 9 highest and 9 lowest subjects based on ECC-KE (ECC-KF was not considered based on the low mostly non-significant correlations to completion time and velocities at key instances ~ see Table 1). The subject who attained the median value for eccentric knee extensor strength was removed from this analysis. Independent T or Mann-Whitney U tests (non-normally distributed data) were performed to compare differences between groups in terms of completion times, velocities at key instances, contact times, GRF's, knee and hip joint moments. A Levene's test was used to inspect the data for equality of variances with appropriate adjustments (equality of variances not assumed) for violation of this assumption. Effects sizes were calculated using Cohen d (mean strong group - mean weak group/ SD pooled) and interpreted as trivial (<0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), and very large (2.0–4.0) (21).

Results

Good reliability and variation between cutting trials was observed for task completion time (ICC = 0.944; CV = 1.92%) and velocity variables (ICC >0.823; CV <5.32%). Mostly good reliability and variation was observed for joint moments (ICC >0.744; CV <9.74%) and force-time (ICC >0.737; CV <10.59%) characteristics, but higher variation was observed for peak knee extensor moment, peak vertical and horizontal GRF during weight acceptance of FIN and peak hip extensor moment during weight acceptance of PEN (CV = 15.7 - 18.1%).

Relationships between cutting performance, strength and velocities at key instances

Mean ± SD true cutting angle at the point of final plant take-off was 54 ± 6°. Significant ($P < 0.0001$) high correlations were revealed between cutting task completion time and ECC-KE, velocities at key instances during the maneuver and minimum resultant horizontal plane velocity (Table 1). A significant moderate correlation was revealed between cutting task completion time and ECC-KF (Table 1). Significant ($P < 0.001$) moderate correlations were observed between ECC-KE and velocities at key instances during the maneuver and minimum resultant horizontal plane velocity (Table 1). Low (mostly non-significant) correlations were observed between ECC-KF and velocities at key instances (Table 1), thus, comparisons between subjects with 'high' and 'low' ECC-KE strength are provided hereon in. In the hierarchical multiple regression minimal resultant center of mass velocity was entered first and explained 77% (75% adjusted) of the variation in cutting task completion time ($F_{(1,17)} = 55.35$, $P < 0.0001$), approach velocity (CM velocity at touchdown of PEN) was entered second and explained a further 5% (4% adjusted) of the variation ($F_{(1,16)} = 36.086$, $P < 0.0001$). Addition of ECC-KE, average HGRF during FIN and FIN contact time could explain 86% (80% adjusted) of the variation in cutting task completion time, but was not significant ($F_{(1,13)} = 0.586$, $P = 0.458$).

<<INSERT TABLE 1 HERE>>

Velocity profile differences between participants with 'high' and 'low' ECC-KE strength

'High' ECC-KE strength participants (upper 50th percentile) performed significantly ($P < 0.01$) faster cutting task completion times (Table 2). Furthermore, significantly ($P < 0.05$) faster velocities ('large' effect) were observed at key instances during the maneuver (Table 2). 'Low' ECC-KE strength participants (lower 50th percentile) demonstrated slightly greater reductions in velocity during PEN and FIN (Table 2), but these were non-significant ($P > 0.05$) and considered 'small'.

<<INSERT TABLE 2 HERE>>

Kinetic differences between participants with 'high' and 'low' ECC-KE strength

'High' ECC-KE strength participants exhibited significant ($P < 0.05$) moderately greater average horizontal GRF during weight-acceptance of FIN (Table 3). In addition, 'high' ECC-KE strength subjects displayed significantly ($P < 0.05$) shorter PEN and FIN contact times compared to 'low' ECC-KE strength subjects, with moderate and large effect sizes (Table 3), respectively. No other variable revealed significant ($P > 0.05$) differences between 'high' and 'low' (Table 3). 'High' ECC-KE strength subjects exhibited moderately ($d \geq 0.61$; $P > 0.05$) greater; average horizontal GRF and hip extensor moments during weight-acceptance of PEN; average vertical GRF, peak vertical and horizontal GRF during weight-acceptance of FIN than 'low' ECC-KE strength participants (Table 3).

<<INSERT TABLE 3 HERE>>

Discussion

The aim of this study was to examine the contribution of eccentric strength to performance of a 70-90° cutting task in female soccer players. High correlations were found between cutting-task completion times and velocities at key instances (R = -0.838 to -0.875) during the maneuver. Hierarchical multiple regression revealed that minimum CM velocity and approach velocity (CM velocity at touchdown of PEN) explained 82% (79% adjusted) of the variation in cutting task completion time ($p < 0.0001$). ECC-KE was highly (R = -0.75) associated with CUT task completion time and moderately associated ($R \geq 0.610$) with velocities at key instances during the cutting task. Players with higher ECC-KE strength (n = 9) also had significantly ($P \leq 0.01$; *d*: 1.34 – 1.71) greater velocities at key instances and significantly shorter ground contact times ($P \leq 0.05$; *d*: - 1.16 to -1.65) during cutting. Furthermore, although non-significant and small, players with higher ECC-KE strength exhibited slightly lower reduction in velocity during PEN and FIN (*d* = 0.36 & 0.38, respectively) compared to 'low' ECC-KE strength players (n = 9). These findings support the study hypotheses that there is an association between eccentric knee extensor strength and velocities during key instances of a cutting-task. Moreover, players with higher ECC-KE strength produce faster cutting-task completion times, through a faster approach, but higher velocities throughout the maneuver seem to be more important than a lower decline in velocity during PEN and FIN per se.

The findings substantiate previous research for an association between eccentric (knee extensor) strength and COD performance during COD tasks involving 180° turns (16, 22, 24, 30), particularly in female athletes (24, 30). Collectively, this highlights the importance of eccentric strength in COD tasks involving large direction changes (i.e., >45°). Many of the abovementioned studies only examined the association of eccentric strength to global performance time (16, 22, 30). Only one previous study using a similar approach has examined the role of eccentric strength during deceleration of a 180° turn (24); finding that female soccer players with greater eccentric knee extensor strength approached the 180° turn with greater velocity and had a greater reduction in velocity during the penultimate contact leading to faster task completion times. Whilst this study supports the theory that eccentrically stronger athletes achieve faster completion times through establishing a faster approach velocity, in contrast to turning (24) this study highlights faster cutting performance is achieved by maintaining higher velocities throughout the maneuver substantiating previous work (19) and that eccentric strength of the knee extensors plays a role in this velocity maintenance.

Another shortcoming of previous studies (16, 22, 24, 30) is that the findings only relate to tasks involving a 180° turn and thus, the role of eccentric strength in cutting tasks until now has been unknown. For instance, Hader et al. (19) found that during 45° and 90° COD maneuvers the ability to maintain high velocity during both tasks was a major determinant of performance. The results of this study suggest that eccentric knee extensor strength plays a pivotal role with regard to velocity maintenance during cutting tasks. Furthermore, these results along with those of Jones et al. (24) support the idea that eccentrically stronger (knee extensors) players are better able to tolerate the loads associated with a faster approach and thus, can approach with a faster velocity perhaps due to a ‘self-regulation’ effect (i.e., a player approaches faster based on the deceleration load they know or feel they can tolerate), which can lead to faster overall COD performance.

The kinetic comparisons between high ECC-KE and low ECC-KE players revealed moderately greater peak vertical and horizontal GRFs during FIN and significantly greater average horizontal GRFs during FIN, which is likely due to the significantly greater velocities achieved by the stronger group of players. A moderate non-significant difference was revealed for average horizontal GRF during PEN, which is in contrast to findings of Jones et al. (24) and suggests that increasing PEN GRFs is a strategy utilized by stronger athletes to aid deceleration during 180° turns, whereas with cutting tasks the maintenance of velocity is more important, thus, no significant differences in PEN GRFs were observed between the 2 groups. Furthermore, the significant large reductions in PEN and FIN contact times for stronger compared to weaker players suggests that, the braking strategy utilized by weaker players involves prolonged braking duration and lower braking forces leading to small reductions in resultant horizontal plane velocity in contrast to stronger players who maintain higher velocities throughout the cut by virtue of shorter ground contact times.

The present study did find a moderate (d = 0.89) non-significant greater peak internal hip extensor moments during PEN for high ECC-KE compared to low ECC-KE players, suggesting a greater utilization of the hip extensor muscle groups during the deceleration phases of cutting. Previous research into COD has highlighted the importance of generating hip extensor moments during the final ‘plant’ contact for knee injury prevention. Jones et al. (23) found that external hip flexor moments were significantly negatively correlated to peak knee abduction moments during a 180° COD task in female soccer players (R = -0.39). Thus, the results of the present study may suggest that stronger players were better able to engage the hip extensors in order to control the deceleration of the cut in the sagittal plane and maybe one way to alleviate the loads experienced at the knee as a result of a higher approach velocity. Given that non-contact ACL injuries more commonly occur during cutting tasks in female soccer players (5, 14), suggests that developing eccentric hamstring strength to help generate hip extensor moments during the final plant step of cutting may be important for injury mitigation purposes in this population of athlete. Future EMG studies are required to confirm such observations.

The study revealed stronger correlations for ECC-KE with cutting task completion times than ECC-KF substantiating previous research (23). Greater ECC-KF (hamstring) strength may assist in helping to generate hip extensor moments during PEN and FIN to control trunk flexion during these phases and provide hamstring co-contraction to assist with knee joint stability during FIN. ECC-KF strength was only significantly correlated with velocity at take-off of

PEN and was considered low. This suggests that ECC-KF may have a minor role in assisting with deceleration mechanics during cutting and turning. More research is warranted to compare mechanical differences between eccentrically stronger and weaker subjects to confirm the abovementioned observations.

The results revealed that at take-off of FIN the mean ± SD true cutting angle was 54 ± 6°, which is lower than the intended cutting angle of 70 to 90°. This observation is consistent with several previous studies (4, 7, 10, 28, 32, 35). This observation highlights that such COD tasks are a multi-step action, with the penultimate or more likely in the case of this study (via a cross-over cut performed) on the subsequent step after the final ‘plant’ step assisting with the direction change (13). Furthermore, the velocity changes observed during PEN and FIN revealed greater reductions during PEN, rather than FIN (Table 2) despite minimum velocity occurring during FIN. This highlights the concept that cutting actions are indeed a multi-step action and should be acknowledged when coaching such maneuvers, rather than solely focusing on the plant step. More research is required that examines COD actions as a multi-step action in order to improve practitioners knowledge and understanding.

A limitation of the present study was due to lab constraints cutting tasks were performed with only the right leg acting as the ‘plant’ leg. Whilst the majority of players were right limb dominant and analysis of the dominant limb can be considered important given that this limb is likely favored during match play. Future work should consider analysis of both limbs to explore potential differences with regard to muscle strength asymmetry or limb preference. Furthermore, while the results of the present study highlight the importance of eccentric knee extensor strength for cutting performance, a cause-effect relationships cannot be deduced. Although, De Hoyo et al. (11) investigated the effects of 10 weeks eccentric over-load training (eccentric flywheel device) on kinetic parameters during cross-over (45°) to side-step (60°) cutting in under 19 male soccer players. Between group analysis revealed that eccentric training led to substantial improvements in contact time, time spent braking during side-step cutting, and relative peak braking force and impulse during cross-cutting. Therefore, eccentric strength training may indeed be beneficial in improving cutting performance, specifically related to aspects of deceleration. More research is required to examine the impact of eccentric strength training on performance and deceleration kinematics and kinetics during cutting, as well as the role of other training modalities on other phases of cutting.

To conclude, the findings of this study suggest that female soccer players with greater eccentric knee extensor strength produce faster cutting-task completion times, by approaching with greater velocity and maintaining higher velocities during the final 2 steps prior to accelerating into the new direction. Stronger players seem better able to tolerate the larger loads associated with faster cutting performance due to a 'self-regulation' effect whereby stronger players approach faster based on the load they know or feel they can tolerate leading to faster completion times. The results along with previous research also highlight that the deceleration requirements for COD are angle dependent in that cutting <90° requires athletes to maintain velocity as much as possible during the maneuver, whilst cutting or turning ≥90° requires athletes to reduce velocity (to zero) rapidly, particularly through penultimate foot contact. Future work is required to explore the effects of eccentric training on whole-body COD mechanics to better inform strength training prescription.

Practical Applications

The findings of the present study suggest that to enhance performance (shorter task completion times) during <90° side-step cutting tasks, female soccer players should approach quickly and seek to maintain high center of mass velocity along the path of the change of direction maneuver. In order to achieve this, practitioners working in female soccer should look to develop eccentric knee extensor strength of their players to provide the physical foundation to enable players to tolerate the high braking forces associated with a faster approach, whilst maintaining short penultimate and final ground contact times. Utilizing traditional strength exercises (i.e., back squats, etc.) whilst accentuating the eccentric phase of the lift (i.e., weight release system, spotters or flywheel device) before progressing to higher velocity plyometric/ jump training exercises (i.e., drop holds, drop jumps, etc.) and/ or deceleration drills would be recommended. Although future research is required to explore the efficacy of such eccentric training methods on whole-body COD mechanics, which would enable more effective strength training prescription to enhance COD performance. Finally, given the association of side-step cutting to the incidence of non-contact ACL injury in female soccer (5, 14) development of eccentric knee flexor strength along with knee extensor strength would be recommended to not only assist players in accepting the deceleration load during the final 'plant' foot contact during cutting, but to also enhance knee joint stability and help generate internal hip extensor moments for injury mitigation purposes.

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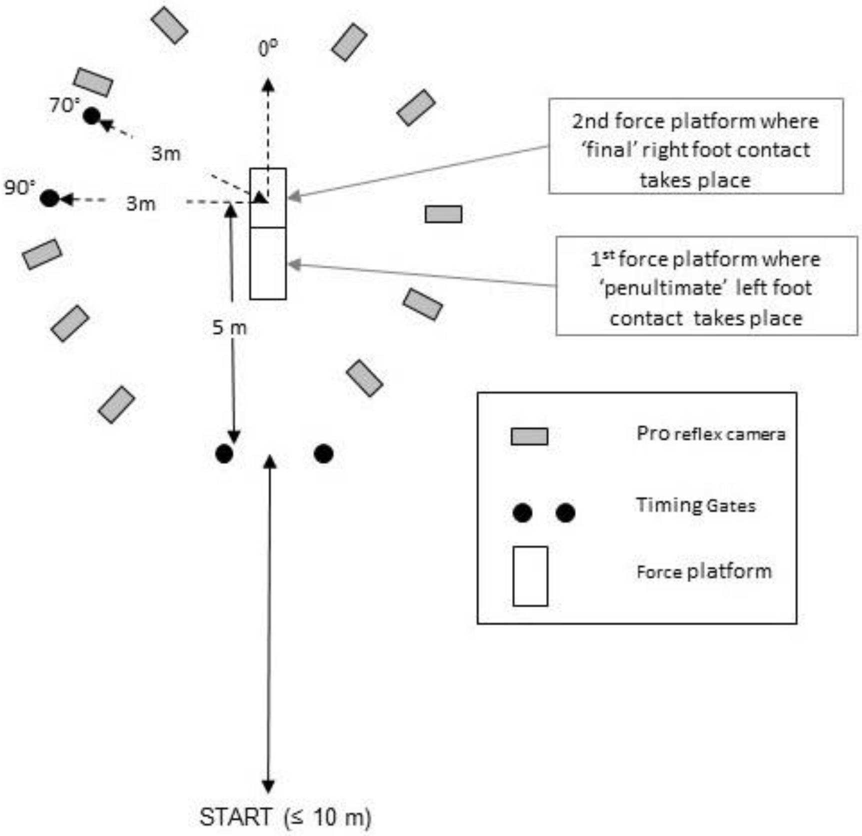
0°
70°
3m
90°
3m
5 m
2nd force platform where 'final' right foot contact takes place
1st force platform where 'penultimate' left foot contact takes place
Pro reflex camera
Timing Gates
Force platform
START (≤ 10 m)

Figure 1.

Table 1. Relationships between cutting task completion time with velocities at key instances of the maneuver and eccentric knee extensor (ECC-KE) and flexor (ECC-KF) strength.

		Relationship to Cutting task completion time		Relationship to ECC-KE		Relationship to ECC-KF	
Variable	Mean (SD)	R	R^2	R	R^2	R	R^2
Cutting task completion time (s)	1.85 (0.17)						
ECC-KE ($Nm \cdot kg^{-1}$)	3.49 (0.53)	-0.750*	56.0%				
ECC-KF ($Nm \cdot kg^{-1}$)	1.69 (0.30)	-0.504#	25.4%				
Velocity at start of PEN[a] ($m \cdot s^{-1}$)	4.43 (0.37)	-0.849*	72.1%	0.633*	40.1%	0.442	19.5%
Velocity at end of PEN[b] ($m \cdot s^{-1}$)	3.40 (0.38)	-0.854*	72.9%	0.641*	41.1%	0.456*	20.8%
Velocity at start of FIN[c] ($m \cdot s^{-1}$)	3.43 (0.37)	-0.838*	70.2%	0.610*	37.2%	0.396	15.7%
Velocity at end of FIN[d] ($m \cdot s^{-1}$)	3.27 (0.40)	-0.872*	76.0%	0.678*	46.0%	0.454	20.6%
Minimum horizontal velocity[e] ($m \cdot s^{-1}$)	2.70 (0.43)	-0.875*	76.6%	0.677*	45.8%	0.352	12.4%

[a-d] Horizontal plane model CM velocity at the start of penultimate (PEN) contact[a], end of PEN[b], start of final (FIN) contact[c] and end of FIN contact[d]. Minimum horizontal plane model CM velocity during the maneuver[e].

ECC-KE = eccentric isokinetic knee extensor peak moment; ECC-KF = eccentric isokinetic knee flexor peak moment;

*$P<0.001$; # $P < 0.05$

Table 2. Differences in cutting task completion time, and velocity profile variables between individuals with ‘High’ (upper 50th Percentile) and ‘Low’ (lower 50th percentile) eccentric knee extensor peak moments.

Variable	**High (n = 9)**	**Low (n = 9)**	**Mean diff (95% CI)**	**P**	**d (95% CI)**	**Descriptor**
Cutting task completion time (s)	1.73 ± 0.11 (95% CI: 1.65 - 1.80)	1.95 ± 0.14 (95% CI: 1.85 - 2.04)	-0.22 (-0.58 – 0.14)	0.003	-1.70 (-2.5 − -0.88)	Large
ECC-KE (Nm·kg^{-1})	3.96 ± 0.34 (95% CI: 4.18 - 3.74)	3.03 ± 0.22 (95% CI: 3.17 - 2.89)	0.93 (0.40 – 1.45)	<0.0001	3.27 (2.18 – 4.37)	Very Large
Velocity at TD of PEN[a] (m·s^{-1})	4.65 ± 0.30 (95% CI: 4.85 - 4.45)	4.24 ± 0.31 (95% CI: 4.44 - 4.04)	0.41 (-0.14 – 0.96)	0.012	1.34 (0.34 – 2.34)	Large
Velocity at TO of PEN[b] (m·s^{-1})	3.67 ± 0.25 (95% CI: 3.83 - 3.51)	3.19 ± 0.32 (95% CI: 3.39 - 2.98)	0.48 (-0.05 – 1.01)	0.002	1.71 (0.70 – 2.73)	Large
Velocity at TD of FIN[c] (m·s^{-1})	3.67 ± 0.27 (95% CI: 3.85 - 3.50)	3.23 ± 0.30 (95% CI: 3.43 – 3.04)	0.44 (-0.09 – 0.98)	0.005	1.54 (0.53 – 2.55)	Large
Velocity at TO of FIN[d] (m·s^{-1})	3.54 ± 0.34 (95% CI: 3.77 - 3.32)	3.03 ± 0.29 (95% CI: 3.22 – 2.84)	0.51 (-0.05 – 1.07)	0.003	1.61 (0.60 – 2.63)	Large
Minimum velocity (m·s^{-1})	2.97 ± 0.30 (95% CI: 3.17 – 2.77)	2.46 ± 0.41 (95% CI: 2.73 – 2.20)	0.51 (-0.09 – 1.10)	0.009	1.41 (0.41 – 2.41)	Large
Δ PEN[e] (m·s^{-1})	-0.98 ± 0.20 (95% CI: -1.11 - -0.85)	-1.06 ± 0.21 (95% CI: -1.20 - -0.92)	0.07 (-0.38 – 0.53)	0.455	0.36 (-0.58 – 1.31)	Small
Δ FIN[f] (m·s^{-1})	-0.13 ± 0.21 (95% CI: -0.27 – 0.00)	-0.20 ± 0.16 (95% CI: -0.10 - -0.30)	0.07 (-0.36 – 0.50)	0.440	0.38 (-0.57 – 1.33)	Small

diff = difference; CI = confidence interval; ECC-KE = eccentric knee extensor peak moment; PEN = penultimate, FIN = final; TD = touchdown; TO = Take-off.

[a-d] Resultant Horizontal plane model CM velocity at touchdown[a] and take-off [b] of penultimate (PEN) contact, and touchdown[c] and take-off[d] of final (FIN) contact

[e] Change in horizontal plane velocity from touchdown to take-off of penultimate contact

[f] Change in horizontal plane velocity from touchdown to take-off of final contact

Table 3. Differences in kinetic characteristics during cutting between individuals with ‘High’ (upper 50th Percentile) and ‘Low’ (lower 50th percentile) eccentric knee extensor peak moments.

Variable	**High (n = 9)**	**Low (n = 9)**	**Mean diff (95% CI)**	**P**	**d (95% CI)**	**Descriptor**
Ground Contact Times						
Penultimate contact time (s)	0.164 ± 0.017 (95% CI: 0.175 – 0.153)	0.202 ± 0.027 (95% CI: 0.220 – 0.184)	-0.038 (-0.186 – 0.110)	0.003*	-1.65 (-2.47 – -0.83)	Large
Final contact time (s)	0.228 ± 0.027 (95% CI: 0.246 – 0.210)	0.281 ± 0.059 (95% CI: 0.320 – 0.243)	-0.053 (-0.260 – 0.154)	0.03*	-1.16 (-2.014 – - 0.306)	Moderate
Ground Reaction Forces						
Peak vGRF during weight acceptance of penultimate contact (bw)	3.06 ± 0.51 (95% CI: 3.39 – 2.73)	3.10 ± 0.96 (95% CI: 3.72 - 2.47)	-0.04 (-0.89 – 0.82)	0.918	-0.05 (-0.97 – 0.87)	Trivial
Average vGRF during weight acceptance of penultimate contact (bw)	1.03 ± 0.12 (95% CI: 1.11 – 0.95)	1.01 ± 0.18 (95% CI: 1.13 – 0.90)	0.02 (-0.37 – 0.41)	0.761	0.13 (-0.80 – 1.06)	Trivial
Peak hGRF during weight acceptance of penultimate contact (bw)	-1.74 ± 0.36 (95% CI: -1.98 – -1.51)	-1.68 ± 0.57 (95% CI: -2.06 – -1.31)	-0.06 (-0.75 – 0.62)	0.795	-0.13 (-1.04 – 0.79)	Trivial
Average hGRF during weight acceptance of penultimate contact (bw)	-0.61 ± 0.11 (95% CI: -0.69 – -0.54)	-0.53 ± 0.15 (95% CI: -0.63 – -0.44)	-0.08 (-0.44 – 0.28)	0.194	-0.64 (-1.53 – 0.25)	Moderate
Peak vGRF during weight acceptance final contact (bw)	3.09 ± 0.35 (95% CI: 3.32 – 2.86)	2.73 ± 0.54 (95% CI: 3.08 – 2.37)	0.36 (-0.31 – 1.03)	0.113	0.79 (-0.18 – 1.76)	Moderate
Average vGRF during weight acceptance final contact (bw)	1.74 ± 0.16 (95% CI: 1.84 – 1.64)	1.60 ± 0.27 (95% CI: 1.78 – 1.43)	0.14 (-0.33 – 0.60)	0.214	0.61 (-0.34 – 1.57)	Moderate
Peak hGRF during weight acceptance final contact (bw)	-1.52 ± 0.24 (95% CI: -1.68 – -1.36)	-1.33 ± 0.21 (95% CI: -1.46 – -1.20)	-0.19 (-0.66 – 0.28)	0.091	-0.86 (-1.73 – 0.02)	Moderate
Average hGRF during weight acceptance of final contact (bw)	-0.93 ± 0.14 (95% CI: -1.02 – -0.84)	-0.77 ± 0.14 (95% CI: -0.88 – -0.67)	-0.16 (-0.54 – 0.21)	0.026*	-1.15 (-2.00 – -0.30)	Moderate
Joint Moments						
Penultimate contact peak hip ext mom (Nm·kg^{-1})	3.45 ± 0.68 (95% CI: 3.90 - 3.01)	2.77 ± 0.85 (95% CI: 3.32 – 2.21)	-0.68 (-1.56 – 0.19)	0.079	-0.89 (-1.76 – -0.02)	Moderate
Penultimate contact peak knee ext mom (Nm·kg^{-1})	2.97 ± 0.52 (95% CI: 3.31 – 2.63)	3.07 ± 0.47 (95% CI: 3.38-2.76)	-0.10 (-0.80 – 0.61)	0.691	-0.20 (-1.11 – 0.72)	Small
Final contact peak hip ext mom (Nm·kg^{-1})	3.49 ±1.10 (95% CI: 4.21 – 2.78)	2.90 ± 1.22 (95% CI: 3.69 – 2.10)	-0.60 (-1.67 – 0.48)	0.291	-0.51 (-1.41 – 0.38)	Small
Final contact peak knee ext mom (Nm·kg^{-1})	2.98 ± 0.48 (95% CI: 3.30 – 2.66)	2.86 ± 0.44 (95% CI: 3.15 – 2.57)	0.12 (-0.56 – 0.80)	0.589	0.26 (-0.68 – 1.20)	Small

diff = difference; CI = confidence interval; vGRF = vertical ground reaction force; hGRF = horizontal ground reaction force; ext = extensor; mom = moment.

*P < 0.05