Biomechanical Factors Associated With Time to Complete a Change of Direction Cutting Maneuver

Brendan M. Marshall,[1,2,3] Andrew D. Franklyn-Miller,[1,4] Enda A. King,[1]
Kieran A. Moran,[2,3] Siobhán C. Strike,[5] and Éanna C. Falvey[1,4]

[1]*Sports Medicine Department, Sports Surgery Clinic, Santry Demesne, Dublin, Ireland;* [2]*School of Health and Human Performance, Dublin City University, Dublin, Ireland;* [3]*INSIGHT Research Centre, Dublin City University, Dublin, Ireland;* [4]*Centre for Health, Exercise and Sports Medicine, University of Melbourne, Melbourne, Australia; and* [5]*Department of Life Sciences, Roehampton University, London, United Kingdom*

Abstract

Marshall, BM, Franklyn-Miller, AD, King, EA, Moran, KA, Strike, SC, and Falvey, ÉC. Biomechanical factors associated with time to complete a change of direction cutting maneuver. *J Strength Cond Res* 28(10): 2845–2851, 2014—Cutting ability is an important aspect of many team sports, however, the biomechanical determinants of cutting performance are not well understood. This study aimed to address this issue by identifying the kinetic and kinematic factors correlated with the time to complete a cutting maneuver. In addition, an analysis of the test-retest reliability of all biomechanical measures was performed. Fifteen ($n = 15$) elite multidirectional sports players (Gaelic hurling) were recruited, and a 3-dimensional motion capture analysis of a 75° cut was undertaken. The factors associated with cutting time were determined using bivariate Pearson's correlations. Intraclass correlation coefficients (ICCs) were used to examine the test-retest reliability of biomechanical measures. Five biomechanical factors were associated with cutting time (2.28 ± 0.11 seconds): peak ankle power ($r = 0.77$), peak ankle plantar flexor moment ($r = 0.65$), range of pelvis lateral tilt ($r = -0.54$), maximum thorax lateral rotation angle ($r = 0.51$), and total ground contact time ($r = -0.48$). Intraclass correlation coefficient scores for these 5 factors, and indeed for the majority of the other biomechanical measures, ranged from good to excellent (ICC >0.60). Explosive force production about the ankle, pelvic control during single-limb support, and torso rotation toward the desired direction of travel were all key factors associated with cutting time. These findings should assist in the development of more effective training programs aimed at improving similar cutting performances. In addition, test-retest reliability scores were generally strong, therefore, motion capture techniques seem well placed to further investigate the determinants of cutting ability.

Key Words cutting performance, biomechanics and correlation

Introduction

Change of direction (cutting) ability is an important component of many field sports, including soccer (3), rugby (11), and Gaelic games (13). In soccer, for example, players have been found to make approximately 723 turns and swerves per game (3), and cutting ability has been successfully used in talent identification testing batteries to discriminate between elite and subelite players (25). The agility and sprinting demands of Gaelic games (hurling and football) could be broadly described as being similar to soccer, and McIntyre (17) found no significant difference in 15-m sprint speed between soccer and Gaelic games players ($p > 0.05$).

Needs analysis and training exercise specificity are important aspects of training program design that are considered by strength and conditioning professionals when training athletic ability, including cutting (34). In essence, coaches seek to provide training exercises that target specific factors that are limiting performance outcome. Therefore, to assist in the identification of exercises that will be most effective in enhancing cutting performance (i.e., reduce cutting time), it is imperative that the biomechanical factors associated with performance success are identified.To date, the majority of studies examining such factors have relied on field test scores and their correlation with cutting time (6,12,28,30). Chaouachi et al. (6), for example, found that vertical jump peak power and various anthropometrical measures were associated with time to complete a cutting maneuver ($R^2 = 0.48$). However, such field test studies lack the ability to determine the specific kinetic and kinematic factors that are associated with cutting

Address correspondence to Dr. Brendan M. Marshall, brendanmarshall@sportssurgeryclinic.com.

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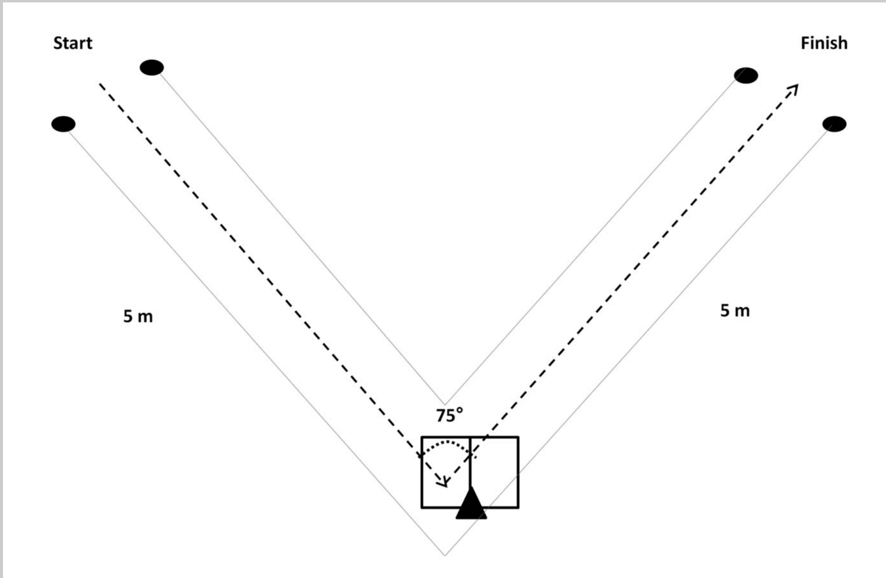

Figure 1. Running cut layout for a right-footed plant and cut left. From a standing start participants accelerated through a "start" gate then ran as fast as possible toward a cone placed next to the force plate, made a single complete foot contact on the force plate, and performed an approximate 75° cut before running maximally through a "finish" gate. Cutting angle was controlled using a 1-m marked runway, and trials were deemed successful if subjects did not step outside the runway.

time. The current authors suggest that it is these specific biomechanical factors that can provide a more powerful insight into the determinants of cutting ability.

To the best of authors' knowledge, only 1 study has examined the biomechanical factors related to cutting performance. Sasaki et al. (27) found that forward inclination of the trunk ($r = 0.61$) and ground contact time during the stance phase ($r = 0.65$) were both related to cutting time ($p \leq 0.05$). Unfortunately, Sasaki et al. (27) did not examine the influence that other body segments or joints have on performance. Such an analysis is warranted, as at present, the biomechanical determinants of cutting performance are poorly understood. Although full-body analyses of cutting biomechanics have been undertaken in the past, these studies have focused on potential injury mechanisms (2) or comparisons of different population groups (11), rather than examining the potential determinants of cutting time.

This study aims to identify the 3-dimensional (3D) biomechanical kinetic and kinematic factors (at the ankle, knee, hip, pelvis, and torso) that are correlated with the time to complete a cutting maneuver. The test-retest reliability of all biomechanical factors will also be examined.

Methods

Experimental Approach to the Problem

Similar to previous studies that have examined the key biomechanical factors of a given task (20,26), the current study used bivariate correlations to identify the key biomechanical factors associated with time to complete a cutting maneuver. A regression analysis was not undertaken because of the likely presence of multicollinearity, that is, when several predictor variables are related to each other. When multicollinearity is present, relevant variables can be excluded from a predictor model (8).

Biomechanical data of the stance phase of the cutting action were collected using standard motion capture techniques (33). Kinetic and kinematic measures were examined at the ankle, knee, and hip joints, whereas kinematic values only were measured at the pelvis and torso segments. Peak values for kinetic variables and range of motion values for joint and segment angles (maximum to minimum) were identified during the phases from initial contact to toe off and from initial contact to peak knee flexion. The phase from initial contact to peak knee flexion was included because it represents the eccentric portion of the cut, which can strongly influence neuromuscular output of the concentric phase in such stretch-shortening cycle activities (19). The significance of eccentric phase variables may be masked in a total ground contact analysis simultaneously considering both eccentric and concentric phases.

To assess the between-session reliability of the measures examined, all participants were retested at the same time of day 1 week after their initial testing session. Participants were asked to refrain from any lower extremity training in the 24 hours before both testing sessions. In addition, participants were asked to follow their usual prematch dietary and hydration practices before both testing sessions.

Subjects

Fifteen ($n = 15$) elite multidirectional sports players (Gaelic hurling) (mean ± *SD*: age 24.5 ± 2.8 years; height: 183.7 ± 6.7 cm; mass: 83.5 ± 6.3 kg) were recruited to undergo 3D biomechanical assessment. Both forward ($n = 8$) and back ($n = 7$) players were selected, and all were injury free (self report) at the time of testing. Participants were playing at the elite intercounty level for 4.1 ± 1.7 years and were tested within season before completion of the National Hurling League. This study was approved by the Sport Surgery Clinic Hospital Ethics Committee, and participants completed and signed an informed consent form before taking part.

Table 1. Factors significantly correlated ($p < 0.01$) with time to complete the cut.

	Mean ± *SD*	*r* (*p* value)	Description
Maximum ankle power ($W \cdot Kg^{-1}$)	14.7 ± 2.9	0.77 (<0.01)	Larger ankle power associated with quicker times
Maximum ankle plantar flexor moment ($N \cdot kg^{-1}$)	2.5 ± 0.3	0.65 (<0.01)	Larger ankle plantar flexor moments associated with quicker times
Pelvis lateral tilt range (degrees) (from initial contact to peak knee flexion)	5.2 ± 3.3	−0.54 (<0.01)	Smaller pelvic lateral tilt range associated with quicker times
Maximum thorax lateral rotation angle (degrees)	4.0 ± 10.0	0.51 (<0.01)	Greater lateral turn toward the finish associated with quicker times
Ground contact time (ms)	371 ± 59	−0.48 (0.01)	Smaller ground contact time associated with quicker times

Procedures

A 6-camera 3D motion analysis system (Bonita B10; Vicon, Oxford, United Kingdom), synchronized with two 40 × 60 cm force platforms (BP400600; AMTI, Watertown, MA, USA), was used to collect kinematic and kinetic data. Reflective markers (14 mm diameter) were placed on bony landmarks on the lower limbs, pelvis, and trunk according to the Plug in Gait model (Vicon) as follows: toe, heel, lateral malleolus, shank, knee, thigh, anterior superior iliac spine, posterior superior iliac spine, clavicle, sternum, shoulder, C7, and T10. The following anthropometrical measures were also obtained for entry into the biomechanical model: height, weight, ankle width, knee width, and leg length. Vicon Nexus software (version 1.8.2; Vicon, Oxford, United Kingdom) controlled simultaneous collection of motion and force data at 200 Hz and 1,000 Hz, respectively. Both marker and force data were filtered using a fourth-order Butterworth filter with a cutoff frequency of 15 Hz to avoid impact artifacts (14,15). The Vicon Plug in Gait modeling routine (Dynamic Plug in Gait) defined rigid body segments (foot, shank, thigh, pelvis, and torso) and the joint angles between these segments. The model then used standard inverse dynamics techniques (33) to calculate segmental and joint kinetics.

Table 2. Test-retest reliability of kinematic measures in the cut.*

Joint/segment	Measure	ICC
	Cutting time	0.90
	Ground contact time†	0.76
Torso ROM	Flexion	0.60
	Lateral flexion ROM	0.79
	Lateral rotation ROM†	0.83
Pelvis ROM	Anterior tilt angle	0.83
	Lateral tilt angle†	0.88
	Lateral rotation angle	0.76
Hip ROM	Flexion angle	0.91
	Adductor/abductor angle	0.87
	Internal/external rotation angle	0.88
Knee ROM	Flexion angle	0.90
	Knee varus/valgus angle	0.76
	Internal/external rotation angle	0.89
Ankle ROM	Plantar/dorsi flexion angle	0.79
	Adductor/abductor angle	0.87
	Internal/external rotation angle	0.78
Foot ROM	Rotation angle	0.86

*ICC = intraclass correlation coefficient; ROM = range of motion.
†Correlated with cutting time.

Before testing, each participant undertook a standardized warm-up consisting of a 3-minute treadmill jog at 8 $km \cdot h^{-1}$ followed by a series of 5 body weight squats, single-leg squats, drop landings, and hurdle hops. Testing involved 3 trials, on the dominant leg, of a cutting maneuver. For the cut, participants ran as fast as possible for 5 m toward a marker placed on the floor, made a single complete foot contact in a 40 × 60 cm area in front of the marker (which ensured their foot was fully in contact with the force plate), and performed an approximate 75° cut before running for another 5 m to the finish (Figure 1). Although there seems to be no studies that have quantified the range of cutting angles used in Gaelic hurling, acute cutting angles in the region of 75° are often used in Gaelic games, particularly when attempting to "lose" an opponent. Cutting angle was controlled using a 1-m marked runway, and trials were deemed successful if subjects did not step outside the runway (24). Participants were instructed to undertake the cut as quickly as possible. Time to completion was measured using timing gates (Smart Speed; Fusion Sport, Brisbane, Australia) placed at the start and end of the 10-m running area. Participants undertook 2 submaximal practice cuts before undertaking their test trials; a rest period of 1 minute was taken between trials.

The floor of the Biomechanics Laboratory is an artificial grass surface (polyethylene mono filament; Condor Grass, Hasselt, the Netherlands), which is permanently and firmly

Table 3. Test-retest reliability of kinetic measures in the cut.*

Joint/segment	Measure	ICC
Whole body	Vertical ground reaction force	0.88
	Medial/lateral ground reaction force	0.66
	Anterior/posterior ground reaction force	0.53
Hip	Concentric power	0.89
	Eccentric power	0.93
	Extensor moment	0.73
	Flexor moment	0.86
	Abductor moment	0.19
	Adductor moment	0.62
	Internal rotation moment	0.77
	External rotation moment	0.69
Knee	Concentric power	0.71
	Eccentric power	0.66
	Extensor moment	0.88
	Flexor moment	0.78
	Valgus moment	0.90
	Varus moment	0.33
	External rotation moment	0.69
	Internal rotation moment	0.56
Ankle	Concentric power†	0.81
	Eccentric power	0.84
	Plantar flexor moment†	0.63
	Abductor moment	0.40
	Internal rotation moment	0.40
	External rotation moment	0.51

*ICC = intraclass correlation coefficient.
†Correlated with cutting time.

fixed to the force plates (Sanctuary Synthetic Adhesive, Naas, Ireland). Participants wore brief shorts and their own molded football boots. The use of artificial grass and the wearing of football boots were aimed at increasing the ecological validity of the study.

Several biomechanical variables of interest were analyzed while the cutting foot was planted on the force plate: whole-body ground reaction force and hip, knee, and ankle powers and moments. Joint moments were examined in the 3 anatomical planes (sagittal, frontal, and transverse) while joint power was a single resultant variable reflecting the overall power at a joint. Three-dimensional knee, hip, pelvis, and torso angles were also measured, as was foot rotation angle in the transverse plane and foot contact time. The mean of each participant's 3 trials was used in all further analysis.

Statistical Analyses

Pearson's product-moment correlations were performed between cutting time and the magnitude of each of the biomechanical variables examined. Visual examination of the scatter plots of each parameter vs. cut time was undertaken to check for the presence of outliers. A significance level of $p < 0.01$ was adopted for all analyses; this more stringent significance level was used to reduce the risk of type 2 errors (1).

Intraclass correlation coefficients (ICCs) were used to examine test-retest (ICC [3, k]) reliability. The ICC classifications of Ford et al. (10) (<0.4 poor, 0.4–0.75 fair to good, >0.75 excellent) were used to describe the range of ICC values. All statistical analyses were performed using IBM SPSS Statistics (version 21; IBM, New York, NY, USA).

Results

The mean ($\pm SD$) time to complete the cutting task was 2.28 ± 0.11 seconds. Five biomechanical factors were significantly correlated ($p < 0.01$) with cutting time: maximum ankle power ($r = 0.77$), maximum ankle plantar flexor moment ($r = 0.65$), pelvis lateral tilt range (from initial contact to peak knee flexion) ($r = -0.54$), maximum thorax lateral rotation ($r = 0.51$), and total ground contact time ($r = -0.48$) (Table 1).

The test-retest ICCs for kinematic measures in the cut are detailed in Table 2, whereas results for kinetic measures are provided in Table 3. The vast majority of kinematic measures (17 of 18) displayed excellent reliability (ICC >0.75) (Table 2). For the kinetic measures, 10 displayed excellent ICC scores (>0.75), 13 were fair to good (0.4–0.75), and 2 were poor (<0.4) (Table 3). The ICC values for the 5 factors correlated with cutting time were good to excellent (range, 0.63–0.88).

Discussion

The biomechanical performance determining factors of cutting are not well understood, therefore, this study aimed to identify the kinetic and kinematic factors associated with performance times in a specific cutting task. Five factors in total were identified as particularly key to cutting performance (2.28 ± 0.11 seconds): peak ankle power, peak ankle plantar flexor moment, range of pelvis lateral tilt (from initial contact to peak knee flexion), maximum thorax lateral rotation angle, and total ground contact time (Table 1). Test-retest reliability scores (ICCs) for these 5 factors ranged from good to excellent (Tables 2 and 3).

Peak concentric ankle power displayed the strongest correlation with time to complete the cutting task ($r = 0.77$). In other words, 59% of the variability in cutting time could be explained by variance in this 1 factor alone. As far as the authors are aware, no other studies have previously investigated specific lower extremity biomechanical factors associated with cutting performance time, however, ankle concentric peak power has been identified as important in other sporting tasks such as straight line sprinting (7) and countermovement jumping (31,19).

Given that power describes the ability to produce force quickly, it is not surprising that peak ankle plantar flexor moment ($r = 0.65$) and shorter ground contact times

($r = -0.48$) were also significantly ($p < 0.01$) correlated with cutting time. Similar to our findings, Sasaki et al. (27) also found ground contact time significantly ($p \leq 0.05$) correlated with cutting time ($r = -0.65$), whereas Morin et al. (20) found an association between shorter ground contact times and straight line sprinting speed ($r = -0.75$). From our findings it would seem appropriate to enhance explosive force production about the ankle in an attempt to improve cutting ability. Although many muscle groups are involved in the multijoint action of cutting, exercising the ability of the muscles contributing to peak ankle plantar flexor power, moment, and shorter ground contact times should be given greater emphasis. Although no research studies seem to have identified the exercise that is best at enhancing these specific qualities while cutting, plyometric exercises may be particularly useful as they have been found to produce relatively large ankle plantar flexor moments, power outputs, and short ground contact times (16).

Meyers et al. (18) suggest that neuromuscular control of the pelvis is important during high-speed multidirectional sports, as it provides the anchor to facilitate dynamic locomotion. The present study provides support for this theory, as reduced pelvic lateral tilt (contralateral drop) during the knee flexion phase of the cut was associated with faster cutting times ($r = -0.54$). Although previous authors have examined the relationship between frontal plane pelvis control and lower extremity injury (9), our study seems to be the first to have identified a relationship between this quality and cutting performance ability. Green et al. (11) suggest that the plant leg must demonstrate significant control under deceleration in a cut to facilitate efficient stretch-shortening cycle utilization. This may explain, at least in part, the relationship between pelvic control and cutting ability.

The final biomechanical factor significantly related to cutting time ($p < 0.01$) was peak lateral torso rotation; that is, individuals who had a greater rotation of their torso in the transverse plane toward the direction of the finish line tended to have quicker cutting times. In an attempt to explain this finding, we examined the correlation between torso rotation and the other key factors identified in Table 1. A significant ($p < 0.01$) positive correlation was found between peak torso rotation and peak ankle plantar flexor power ($r = 0.65$). It could be suggested therefore that individuals with a trunk rotated more toward the desired direction of travel were in a more appropriate body orientation to produce greater power output about the ankle. This finding highlights the importance of technical coaching when training individuals to improve their cutting performance. In contrast to the findings of Sasaki et al. (27), we did not find a correlation between torso flexion and cutting time. This may be explained by the different angles of the cut examined in both studies; a 180° cut was used by Sasaki et al. (27), whereas a 75° cut was used in the current study.

In general, test-retest reliability scores (ICC values) for kinematic measures in the cut were very strong–all were greater than 0.75, except torso flexion, which was 0.60 but still considered fair to good. The majority of kinetic measures (23/25) displayed excellent or fair-to-good reliability in the cut (Table 3) leaving only 2 measures (hip abductor and knee varus moment) with poorer reliability scores. The support moment theory of Winter (32) may explain, at least in part, why these measures displayed poor reliability. The support moment theory suggests that once the algebraic sum of moments at the lower extremity joints is sufficient for the activity in question, individual joint moments can vary largely. This would be particularly true of moments in the same plane of movement, as is the case with hip abductor and knee varus moments (both frontal plane moments).

A limitation of the current study is that an acute testing session was used to examine the relationships between biomechanical factors and cutting time. It is therefore necessary to explore the findings of our study using a training intervention to examine whether the magnitude of improvement in these factors is directly related to the magnitude of improvement in cutting time. In general, the good test-retest reliability scores found in the present study indicate that similar methodologies to those described herein may be used to assess the effects of training interventions on both cutting time and cutting biomechanics. Future studies should also investigate the effect of different cutting angles on the biomechanical determinants of cutting ability.

In conclusion, several biomechanical factors are related to performance time in a specific cutting maneuver: peak ankle plantar flexor moment and power, ground contact time, pelvic frontal plane control, and thorax rotation toward the desired direction of travel. These findings suggest that the ability to produce explosive force about the ankle, maintain good pelvic control, and exhibit effective torso rotation were all related to performance ability. These findings should assist in the development of more effective training programs aimed at improving cutting performance.

Practical Applications

In light of the biomechanical factors associated with success in the cutting task examined in the current study, it is proposed that plyometric training, pelvic control work, and cutting technique training may all be particularly useful in enhancing performance outcome. Plyometric training could be prescribed in an attempt to improve explosive force production at the ankle and reduce ground contact time while cutting. A bounce style drop jump may be especially suited to this purpose. Marshall and Moran (16) and Bobbert et al. (4) found that a bounce drop jump (where athletes are cued to use a small countermovement amplitude) displayed significantly greater peak ankle plantar flexor moments and powers, and a significantly shorter ground contact time, than both a countermovement drop jump and a vertical countermovement jump. Hurdle jump drills may also be useful; Cappa and Behm (5) found that gastrocnemius muscles (ankle plantar flexors) are overloaded more, and ground contact times are shorter, in hurdle jumps than in drop jumps.

Pelvic control exercises should be prescribed in an effort to enhance frontal plane pelvic control during eccentric loading. Frontal plane control of the pelvis in single-limb stance is determined, at least in part, by the neuromuscular ability of the gluteal muscles, and in particular gluteus medius (23). Common exercises to train the gluteals include bridging and resisted side steps (29), as well as more sport-specific exercises such as single-leg squats and single-leg landings (21).

To encourage athletes to rotate their trunk in the desired direction of travel while cutting, augmented technique feedback (e.g., video playback combined with coaching advice) may be particularly useful. Myer et al. (22) found that augmented feedback on deficits identified in a drop jump assessment resulted in a significant improvement in jumping technique.

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