Principal Component Analysis of the Biomechanical Factors Associated With Performance During Cutting

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Abstract

Welch, N, Richter, C, Franklyn-Miller, A, and Moran, K. Principal component analysis of the biomechanical factors associated with performance during cutting. *J Strength Cond Res* XX(X): 000–000, 2018—The main aim of the current study was to investigate the relationship between kinematic variables in cutting and performance outcome across different angled cuts through the use of principal component analysis and permutation testing. Twenty-five male intercounty Gaelic football players (23.5 ± 4.2 years, 183 ± 6 cm, and 83 ± 6.9 kg) participated in the study. Three-dimensional motion capture was used to perform a biomechanical analysis of 110 and 45° cutting tasks. Principal component analysis and permutation testing revealed one principal component within the 45° cut ($r = 0.26$) and 2 principal components within the 110° ($r =$ 0.66 and 0.27) cut that consistently correlated with performance outcome. Within the 45° cut, the identified principal component was interpreted as relating to performance cues of maintaining a low center of mass during the concentric phase, using a shorter ground contact time, resisting a reduction in lateral center of mass to ankle and knee distance in the eccentric phase, and using faster and larger extensions of the hip and knee. Within the 110° cut, the first identified principal component was interpreted as relating to performance cues of maintaining a low center of mass during the concentric phase, using a shorter ground contact time, resisting a reduction in lateral center of mass to ankle and knee distance in the eccentric phase, and resisting hip flexion then using hip extension. The second principal component was interpreted as relating to a performance cue of leaning in the direction of the cut.

Key Words biomechanics, change of direction, time

Introduction

The ability to change direction (cut) quickly is an important part of multidirection sports (18), with technique being one important component of performance (21). To aid practitioners in developing training practices that enhance cutting performance, it is necessary to understand the relevant technical factors that contribute to performance. Only 3 other studies seem to have investigated joint-based biomechanical factors in relation to cutting performance (5,12,15).

The technique of a cut is a combination of biomechanical and neuromuscular factors (18). Although a large number of biomechanical variables have been associated with better performance outcomes, their volume and variety makes the interpretation of results, and consequently their implementation into training practices difficult. The variety of significantly correlated examined biomechanical variables is exemplified by the following 2 studies: Marshall et al. (12) found that maximum ankle power ($r = 0.77$; $p < 0.01$), maximum ankle plantarflexor moment ($r = 0.65$; $p < 0.01$), pelvic lateral tilt ($r = -0.54$; $p < 0.01$), maximum thorax rotation angle ($r = 0.51$; $p = 0.01$), and ground contact time ($\mathrm{r} = 20.48$; $\mathrm{p} = 0.01$) during the whole ground contact correlated with enhanced performance outcome in a 110° cutting task. Havens and Sigward (5) found greater peak ankle flexor moment ($r = 0.45$; $p = 0.02$), greater hip sagittal plane hip power ($r = -0.48$; $p = 0.02$), greater hip extensor moment ($r = 0.39$; $p = 0.05$), and greater peak medial-lateral center of mass and center of pressure separation ($r = -0.39$; $p = 0.06$), greater medial lateral impulse ($r = -0.49$; $p = 0.01$), greater hip internal rotation ($r = -0.47$; $p = 0.02$), greater frontal plane hip power ($r = -0.59$; $p = 0.002$), and lower knee extensor moments ($r = 0.50$; $p = 0.02$) during the deceleration phase correlated with enhanced performance outcome in 45 and 90° cuts. In particular, this large number of variables is in contrast to coaching practice where limiting the number of factors for the athlete to focus on is believed to enhance skill acquisition (14,17); therefore, reducing the number of variables may be beneficial.

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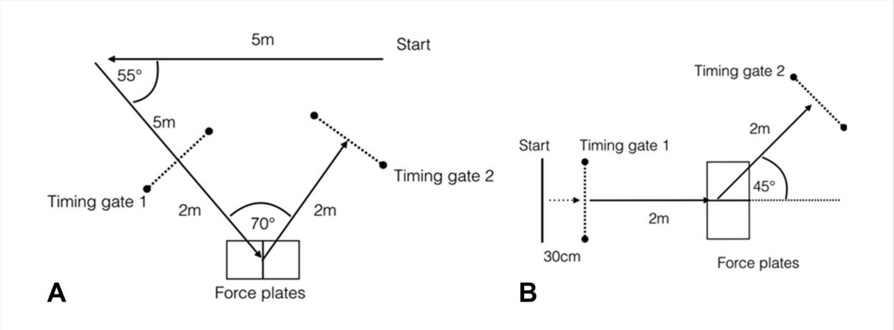

Figure 1. A) The layout for the 110° cut and B) the layout for the 45° cut.

A secondary consideration for enhancing cutting performance is whether the angle of cut affects the joint-based biomechanical variables that contribute to performance. This is important to practitioners who may need to prioritize factors depending on cutting angles for particular sports or playing positions. Only Havens and Sigward (5) have measured joint-based biomechanical variables across different cutting angles with respect to performance. No common variables between the 45 and 90° cuts were found to significantly correlate with performance; however, only the decelerative phase (initial contact to peak knee flexion) of the cut step was considered.

Attempts have been made to reduce the large number of variables into key technical features through the use of qualitative assessment (7). However, quantitative techniques exist that allow for the analysis of more accurate biomechanical data while reducing the large number of variables. A principal component analysis (PCA), a dimension reduction technique, allows for grouping of variables by patterns of common variation to a smaller number of uncorrelated underlying variables, or principal components (9). Although PCA has been used in the domain area of biomechanics, for example in vertical jump (2) and gait (13) analysis, it is yet to be performed on the joint variables in cutting. Grouping of related joint-based biomechanical variables may aid practitioners in identifying the biomechanical factors required to enhance performance outcomes in cutting.

Another possible limitation with the analyses used to date is due to studies only using a mean measurement of a number of trials, thereby potentially removing important captured data and creating a "trial" that does not represent any of the original attempts (4). As such, methods should be considered that allow for analysis of all of the captured data. Permutation testing is a method that takes repeated samples from the captured data (1), allowing for analyses to be performed on greater amounts of captured data rather than the traditional method of creating a mean of the trials.

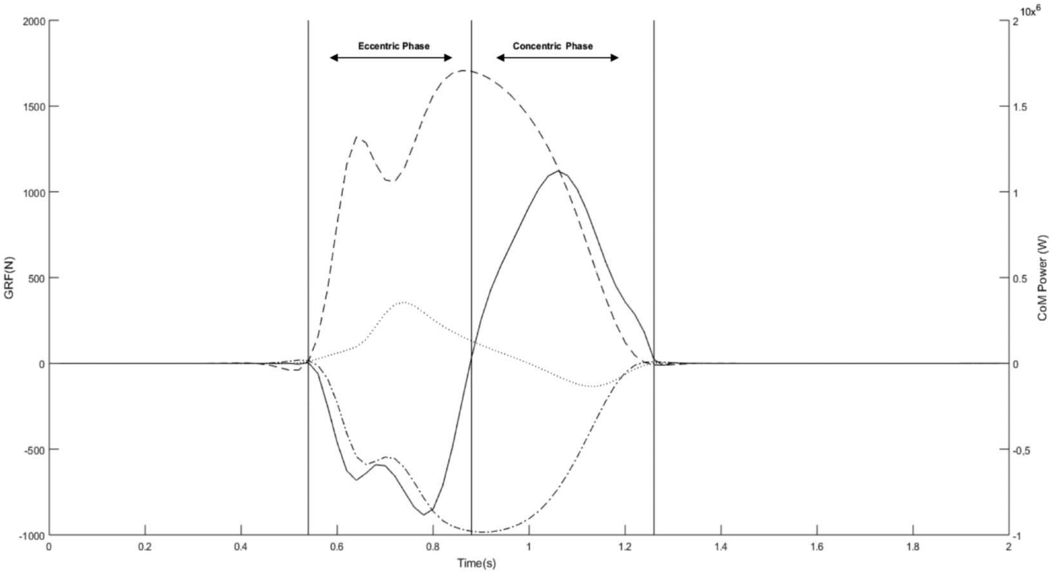

Figure 2. A force-time curve of a 45° cut. Blue line–vertical GRF, green line–lateral GRF, yellow line–anterior/posterior GRF, red line–center of mass power. GRF = ground reaction force; CoM = center of mass.

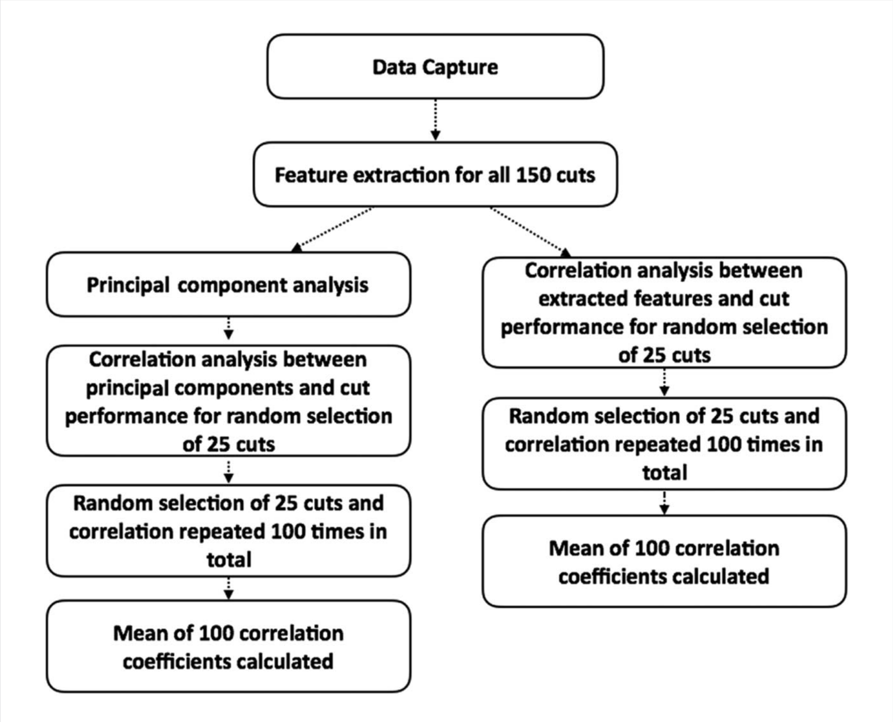

Figure 3. A flow chart of the data analysis performed.

The main aim of the current study was to investigate the relationship between joint-based biomechanical variables in cutting and performance outcome across 2 different angled cuts, using a PCA and permutation testing. It was hypothesized that variables related to movement in the frontal about the hip and related to greater ankle plantarflexion moments would be common across both angles of cut.

METHODS

Experimental Approach to the Problem

This study was an exploratory biomechanical analysis. It used a cross-sectional design whereby performance and biomechanical data were captured during one testing session. Participants were asked to avoid strenuous exercise for 48 hours before testing.

Subjects

Twenty-five male (mean ± *SD*: 23.5 ± 4.2 years, 183 ± 6 cm, 83 ± 6.9 kg), elite Gaelic football players, all of whom train 4–6 times per week, out of an invited 32 participated in the study. Testing was approved by the Sports Surgery Clinic ethics board (ref: 0017) ethics board (ref: 0017), and all participants provided written informed consent before undertaking testing.

Procedures

Participants undertook a standardized warm-up consisting of 2-minute jogging, 5 forward, backward, and lateral lunges on each leg, 8 deep squats, and 5 countermovement jumps. The first test performed was a 110° cut (Figure 1A) followed by a 45° cut (Figure 1B) on both limbs, with the limb testing order randomized but kept consistent across both tests. The 110° cut was selected as it requires a deceleration before the direction change, which differs from the 45° that was selected as an accelerative cut. Two practice attempts were performed on each leg before each cut assessment to allow for familiarization. The 110° cut was as described previously (12) with the addition of timing gates (Fusion Sport Smartspeed, Queensland, Australia) positioned 1.5 m apart at a height of 1.2 m, 2 m before and after the cutting point. For the 45° cut, the same timing gates were also set 2 m before and after the cutting point with participants starting 30 cm behind the timing gates in a staggered stance. The distance of 2 m was chosen as it allowed only one ground contact before the cut to reduce the variety in strategies used during the cut. Participants were asked to repeat a trial if they used a drop step or felt their attempt was not maximum effort. For both cuts, trials were repeated if a full foot contact with the force plates was not achieved. Participants were instructed to complete all trials as quickly as possible.

A 10-camera motion analysis system (Bonita B10; Vicon, Bilston, United Kingdom), synchronized with two 40 × 60 cm force platforms (BP400600; AMTI, Watertown, MA, USA), was used to collect kinetic and kinematic data for all tests. Data were sampled at 200 Hz and the Vicon Plug-in-Gait marker set was used as per Marshall et al. (12). Twenty-four reflective markers were placed on bony landmarks at the lower limb, pelvis, and trunk. Simultaneous kinematic and ground reaction force data (200 and 2,000 Hz) were collected using a software package (Nexus 2; Vicon Motion Systems, Yarnton, United Kingdom). These data were filtered using a fourth-order low-pass Butterworth filter (cutoff frequency: 15 Hz) (11). The Vicon Plug-in-Gait modeling routine (Dynamic Plug-in-Gait) used standard inverse dynamics techniques to calculate segmental and joint kinetics (20).

Variables of interest in all 3 planes were angles, angular velocities, and moments about the ankle, knee, hip, pelvis, and thorax; center of mass distance to the ankle and the knee; and transverse plane foot to pelvis rotation angles. To allow for comparison across cuts, data were time normalized

Table 1. Principal components with positive or negative correlations in ≥95% of the simulated 45° cuts.*

Principal component interpretation	Principal component factors (loadings)	*r* value (confidence interval)
Maintaining a low center of mass during the concentric phase	Vertical CoM to ankle distance change through conc phase (0.16)	0.26 (0.23–0.29)
Shorter ground contact times	Conc phase ground contact time (0.17) and total ground contact time (0.14)	
Faster and larger extensions of the hip and knee	Knee flexion angular velocity at end of ecc phase (0.15), hip flexion angular velocity change through conc phase (−0.15), hip flexion angular velocity at the end of ecc phase (0.14), knee flexion angle change through conc phase (−0.15), hip flexion angles at the end of ecc phase (0.17), and hip flexion angles change through conc phase (−0.17).	
Resisting a reduction in lateral center of mass to ankle and knee distance in the eccentric phase	Lateral CoM to ankle distance at end of ecc phase (0.17), lateral CoM to knee distance change through ecc phase (−0.13), and lateral CoM to ankle distance at impact (0.13)	

*CoM = center of mass; conc = concentric; ecc = eccentric.

to 100 data points. These variables were calculated for each discrete event, which were identified (Figure 2) as impact, the change from the start to the end of the eccentric phase, the end of the eccentric phase, the change from the start to the end of the concentric phase, and toe-off. Impact and toe-off were defined as the first and last points, respectively,

Table 2. Principal components with positive of negative correlations in ≥95% of the simulated 110° cuts.*

PC	Interpretation	Principal component factors (loadings)	*r* value (confidence interval)
1	Maintaining a low center of mass during the concentric phase	Vertical CoM to knee distance change through conc phase (0.13), vertical CoM to ankle distance change through conc phase (0.13), and pelvis abduction angles at toe-off (−0.12),	0.66 (0.65–0.68)
	Resisting hip flexion then using hip extension	Hip flexion angles at end of ecc phase (0.16), hip flexion angles change through ecc phase (0.15), pelvis flexion angles at end of ecc phase (0.12), and hip flexion angles change through conc phase (−0.15),	
	Resisting a reduction in lateral center of mass to ankle and knee distance in the eccentric phase	Lateral CoM to knee distance change through ecc phase (−0.13), lateral CoM to ankle distance at end of ecc phase (−0.13), posterior CoM to ankle distance at end of ecc phase (0.13), and lateral CoM to knee distance at end of ecc phase (−0.15),	
	Shorter ground contact times	Conc phase ground contact time (0.14) and total ground contact time (0.14).	
2	Lean in direction of the cut	Thorax to pelvis abduction angles at toe-off (−0.21), thorax to pelvis abduction angles at impact (−0.18), and thorax to pelvis rotation angular velocity at toe-off (0.18)	0.27 (0.24–0.30)

*CoM = center of mass; conc = concentric; ecc = eccentric.

Table 3. The 10 variables with the strongest correlations to performance during 45° cut grouped by phase of the cut.

Order	Variable	Time point	Range	Mean ± *SD*	*r* value (confidence interval)	Interpretation related to faster times
1	Ankle rotation angles (°)	Change from the start to the end of the eccentric phase	−17.09 to 26.53	0.52 ± 7.70	−0.41 (−0.44 to −0.39)	Less external rotation change
2	Ankle abduction angles (°)	Change from the start to the end of the eccentric phase	−7.00 to 4.89	−0.14 ± 2.04	0.40 (0.37 to 0.43)	Greater abduction change
3	Vertical center of mass to ankle distance (mm)	At toe-off	267.74 to 366.74	325.14 ± 0.02	0.37 (0.34 to 0.39)	Lower distance between center of mass and ankle
4	Ankle abduction angles (°)	Change from the start to the end of the concentric phase	−8.40 to 3.49	−2.90 ± 2.31	−0.37 (0.37 to 0.43)	Smaller change in ankle abduction
5	Thorax to pelvis rotation angles (°)	At the end of eccentric phase	−15.28 to 19.19	−2.43 to 5.41	0.36 (0.34 to 0.39)	Greater contralateral thorax rotation angle
6	Hip abduction angles (°)	Change from the start to the end of the eccentric phase	17.31 to 12.56	−4.63 ± 5.54	0.36 (0.33 to 0.39)	Smaller change in hip abduction
7	Posterior center of mass to knee distance (mm)	Change from the start to the end of the concentric phase	112.87 to 425.88	278.85 ± 55.44	0.35 (0.32 to 0.39)	Smaller change in distance throughout phase
8	Ground contact time (s)	Change from the start to the end of the concentric phase	0.07 to 0.20	0.12 ± 0.02	0.34 (0.31 to 0.37)	Shorter ground contact time
9	Knee rotation angles (°)	Change from the start to the end of the eccentric phase	−22.82 to 15.04	3.71 ± 6.53	0.34 (0.30 to 0.37)	Smaller change in knee rotation
10	Ankle rotation angles (°)	At the end of eccentric phase	−41.2 to 4.5	−20.89 ± 11.07	−0.33 (−0.36 to −0.30)	Straighter foot position

TABLE 4. The 10 variables with the strongest correlations to performance during 110° cut grouped by phase of the cut.

Order	Variable	Time point	Range	Mean ± *SD*	*r* value (confidence interval)	Interpretation related to faster times
1	Pelvis abduction angles (°)	At toe-off	−0.46 to 40.6	23.30 ± 6.54	−0.66 (−0.69 to −0.64)	Greater pelvis abduction angles
2	Lateral center of mass to ankle orientation (mm)	End of the eccentric phase	267.90 to 625.23	453.23 ± 67.27	−0.65 (−0.67 to −0.63)	Greater distance between the ankle and center of mass
4	Lateral center of mass to knee orientation (mm)	End of eccentric phase	129.34 to 406.18	247.40 ± 52.71	−0.63 (−0.64 to −0.61)	Greater lateral distance between knee and center of mass
3	Posterior center of mass to ankle orientation (mm)	At toe-off	215.63 to 380.94	298.47 ± 27.17	0.62 (0.60 to 0.64)	Lower posterior distance between ankle and center of mass
5	Ground contact time (s)	At toe-off	0.24 to 0.49	0.30 ± 0.03	0.60 (0.58 to 0.62)	Shorter ground contact time
6	Hip flexion angles	Change from the start to the end of the eccentric phase	−33.90 to 20.46	−5.09 ± 11.44	0.59 (0.57 to 0.60)	Less hip flexion change
7	Time (s)	Change from the start to the end of the concentric phase	0.06 to 0.31	0.20 ± 0.05	0.58 (0.56 to 0.60)	Shorter concentric ground contact time
8	Lateral center of mass to knee orientation (mm)	Change from the start to the end of the eccentric phase	−92.26 to 132.48	18.44 ± 40.75	−0.56 (−0.58 to −0.53)	Greater change in distance
9	Hip flexion angles (°)	End of the eccentric phase	7.66 to 86.79	−53.73 ± 15.06	0.54 (0.52 to 0.56)	Greater hip extension
10	Thorax to pelvis flexion angles (°)	End of the eccentric phase	−59.13 to 4.47	−32.08 ± 10.04	0.53 (0.51 to 0.55)	Less thorax to pelvis flexion

where ground reaction force reached 20 N. The end of the eccentric phase was defined as the point at which center of mass power reached zero. The eccentric phase was identified therefore as the period from impact to the end of the eccentric phase, and the concentric phase was the period from the end of the eccentric phase to toe-off. These events were identified for all the cut trials for each participant before further analysis and resulted in a total of 200 variables.

Statistical Analyses

Analysis comprised 2 aspects: a PCA and a common correlation analysis using the discrete measures (Figure 3). A PCA was used to identify patterns of variation within the cutting data. Before performing the PCA, features within the cutting data were centered (subtraction of mean) and normalized (division of SD) to account for unit differences across the features within the data (10). All PCA loadings below 75% of the absolute maximum were zeroed to ensure variables that had the greatest contribution to the pattern were examined (19). Although this approach removed the orthogonal nature between principal components, it simplifies the interpretation and results in that only the effects of the features that have a large effect on the pattern of variation are included. Principal component scores were then calculated as the inner product between the principal component and the subject feature vector. After the PCA, a permutation-based resampling approach was then used in the analysis of the identified principal components. A sample of 25 cuts, out of all the cuts captured, was selected at random and a Pearson product-moment correlation was used to test the relationship between the identified principal component and cutting performance outcome. Thresholds used to judge the effect of a measure were 0.1, 0.3, and 0.5 for small, moderate, and large correlations, respectively (8). The cuts were selected from both limbs because it is necessary for athletes to cut off both legs and the assumption was made that the same biomechanical variables should be relevant to performance on each limb. The permutation testing was performed by completing this random selection of 25 cuts with a Pearson product-moment correlation a total of 100 times. The factors within the relevant principal components were considered and grouped if they were deemed to be similar. These were then assigned a performance cue to describe those factors, for example if (a) "lower vertical center of mass to foot distance" and (b) "lower center of mass to knee distance" were observed within a principal component, they were interpreted as "maintaining a lower center of mass."

A standard correlation analysis using the discrete measures was then performed to allow for comparison with previous studies investigating the relationship between joint-based biomechanical variables and cutting performance outcome, all of which have used this approach. In addition, due to the emphasis on variation and the 75% cutoff for loadings within the PCA, there was potential for missed relevant variables with lower levels of variation, which is why a standard correlation analysis using the discrete measures was also used. Using the same methodology as with the PCA, a sample of 25 cuts, out of all the cuts captured, was selected at random and a Pearson product-moment correlation was used to test the relationship between discrete measures and cutting performance outcome. The same permutation testing was then also completed 100 times. For both the principal components and the standard correlation analysis, an association to performance was considered to be relevant when a correlation measure seemed either positive or negative for greater than or equal to 95% of the random permutations. Variables from the standard correlation analysis were ranked based on their mean correlation to identify the variables with the strongest effect on time to complete the cut. In a related study in this journal (reference on publication, Welch et al., kinetic determinants of cutting), the authors set a cutoff correlation of 0.4 for variables to be considered relevant. It was decided not to use the 0.4 cutoff in the current study because post hoc analysis revealed that only one principal component, related to the 110° cut, would have been discussed. To allow insight into both angles of cut, it was decided to use the current approach.

RESULTS

Within the 45° cut, the PCA revealed that only one principal component demonstrated consistent correlations in one direction ($r = 0.26$) with performance outcome in greater than or equal to 95% of the permutations analyzed (Table 1). This component was made up of 12 variables: eccentric lateral center of mass to knee distance change, lateral center of mass to ankle distance at impact and end of eccentric phase, concentric vertical center of mass to ankle distance, concentric knee flexion angle change, hip flexion angles at end of eccentric and change in through concentric phase, knee flexion angular velocity at end of eccentric phase, hip flexion angular velocity at the end of eccentric phase and change through concentric phase, and total and concentric ground contact times.

Within the 110° cut, the PCA revealed only 2 principal components that demonstrated consistent correlations in one direction with performance outcome in greater than or equal to 95% of the permutations performed (Table 2). The first principal component ($r = 0.66$) was made up of 13 variables: lateral center of mass to knee distance at end of and change through eccentric phase, concentric vertical center of mass to knee distance change, lateral center of mass to ankle distance at end of eccentric phase, posterior center of mass to ankle distance at end of eccentric phase, concentric vertical center of mass to ankle distance change, hip flexion angles at end of eccentric phase and concentric and eccentric change, pelvis abduction angles at toe-off, pelvis flexion angles at end of eccentric phase, and total and concentric ground contact times. The second principal component ($r = 0.27$) was made up of 3 variables: thorax to pelvis abduction angles at impact and toe-off and thorax to pelvis rotation angular velocity at toe-off.

In relation to the standard correlation analysis, the 10 strongest individual correlations between kinematic variables within the 45° cuts and performance outcome are listed in Table 3 and placed in order of correlation strength. The correlations with performance outcome are all moderate ($r = -0.41$ to -0.33 and 0.34–0.40). Four variables relate to the ankle (rows 1, 2, 4, and 10), 2 variables relate to horizontal movements (rows 6 and 7), one variable relates to staying low during the concentric phase (row 3), one variable relates to ground contact time (row 8), one variable relates to knee rotation (row 9), and one variable relates to rotating the torso in the direction of the cut (row 5) (Table 3).

The 10 strongest correlations between kinematic variables within the 110° cuts and performance outcome are listed in Table 4 and placed in order of correlation strength. The correlations with performance outcome are all strong ($r = -0.66$ to -0.56 and 0.53–0.62). Three of the variables relate to maintaining lateral ankle and knee distances through the eccentric phase (rows 2, 4, and 8), 3 are related to resisting sagittal plane flexion movements during the eccentric phase (rows 6, 9, and 10), 2 are related to shorter ground contact times (rows 5 and 7), and 2 are related to a toe-off position with greater pelvis abduction and less distance between the center of mass and the ankle posteriorly (rows 1 and 3) (Table 4).

DISCUSSION

The main aim of the current study was to investigate the relationship between joint-based biomechanical variables in cutting and performance outcome across different angled cuts. A PCA was used to reduce the volume of variables by grouping them through common patterns of variation. This is the first study to take this approach with respect to joint-based biomechanics of cutting. One principal component was identified as being relevant to describe performance outcome within the 45° cut. This principal component was interpreted as being composed of 4 performance cues: maintaining a low center of mass during the concentric phase, using a shorter ground contact time, resisting a reduction in lateral center of mass to ankle and knee distance in the eccentric phase, and using faster and larger concentric extensions of the hip and knee (Table 1). Two principal components were identified as being relevant to describe performance outcome within the 110° cut. The first principal component was interpreted as being composed of 4 performance cues: maintaining a low center of mass during the concentric phase, using a shorter ground contact time, resisting a reduction in lateral center of mass to ankle and knee distance in the eccentric phase, and resisting hip flexion then using hip extension (Table 2). The second principal component was interpreted as represented by one performance cue: leaning in the direction of the cut.

Three performance cues were common across both the 45 and 110° angles of cut: maintaining a low center of mass during the concentric phase, resisting a reduction in lateral center of mass to ankle and knee distance in the eccentric phase, and using a shorter ground contact time. Findings from previous studies that used standard correlation analyses corroborate the findings in the current study where the performance cue of shorter ground contact times was correlated with better cutting performance outcomes (3,12,15). Also, the performance cue of maintaining lateral center of mass to ankle and knee distance in the eccentric phase observed in the current study suggests similarities with the findings of Havens and Sigward (5) who found that greater peak lateral separation between center of mass and foot placement during the deceleration phase was significantly correlated ($r = -0.47$) with cut performance outcome in a 45° cut. Finally, similar to the current findings, Shimokochi et al. (16) observed that maintaining a lower center of mass at both initial contact and at the end of the eccentric phase correlated with a higher cutting index, which they used as a performance measure, during a lateral cutting task.

Although there is commonality in findings across the 2 cuts, it was also observed that with each cut angle, one performance cue was not shared: resisting hip flexion then using hip extension in the 110° cut and using faster and larger concentric extensions of the hip and knee in the 45° cut. This is likely due to the differing demands of the task. Findings in the 110° cut highlighted that it is required to resist hip flexion movements before using greater hip extension. This is potentially due to the greater decelerative demands of cuts with a greater direction change angle (6). A greater change of direction angle requires greater braking impulses than shallower angled cuts and therefore greater concentric impulse to reverse it and resulted in a strategy dependent on greater force generation from the hip. A 45° cut requires less deceleration (6), which allowed for the utilization of an alternative strategy through faster and larger concentric hip and knee extensions. Although a degree of commonality exists in the performance-determining biomechanical factors between the cuts of different angles, task-specific demands/factors are also apparent.

The PCA was used to reduce a large number of variables to a smaller group of variables that explained performance; the performance cues were used to further interpret the principal components for the practitioner. However, it is not possible to state that all the discussed performance cues have the same level of importance or that they are exclusive of each other. For example, it is possible that using a shorter ground contact time to enhance performance is achieved by maintaining a low center of mass during the concentric phase with faster and larger hip and knee extensions and resisting a reduction in lateral center of mass to ankle and knee distance in the eccentric phase. This raises the question of whether one of these performance cues can elicit a greater effect on cutting performance than the others. A further body of work is required to determine the relationship that exists between these performance cues and to determine whether training to enhance any one of them is more effective at enhancing performance than the others.

It is worth noting that the principal components were only able to explain 43% of the variance within the 110° cut and 7% of the variance in the 45° cut. It is likely therefore that other factors, such as neuromuscular capacity, help to explain the remaining variance in performance. It is also possible that the task demands of the 45° cut used in this study, with having only one step before the cut, meant that joint-based biomechanical factors played a smaller role and neuromuscular capacity was more important for performance than was observed in the 110° cut. Finally, the performance cues selected and used were an interpretation by the authors of the observed variables and it is possible that they could be interpreted in other ways not considered in the current study.

Practical Applications

Of importance for the practitioner is that common factors exist between cuts of larger and shallower angles. Using technical and physical training that seeks to develop the abilities and capacity to use shorter ground contact times, to maintain a low center of mass during the concentric phase, and to resist a reduction in lateral center of mass to ankle and knee distance in the eccentric phase should be considered. Coaches should also note, however, that relationships likely exist between these performance cues and that by addressing one, all of them may be affected, but further work is required to understand this interaction.

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