A preliminary investigation into a qualitative assessment tool to identify athletes with high knee abduction moments during cutting: Cutting Movement Assessment Score (CMAS).

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Summary

Given the limited accessibility of 3D motion analysis for injury screening of athletes, there is a need to develop a field-based screening tool to identify athletes with ‘at-risk’ cutting mechanics. The aim of this preliminary study was to assess the validity of a qualitative assessment tool for cutting (CMAS) to estimate the magnitude of peak knee abduction moments (KAM) against ‘Gold Standard’ 3D motion analysis. The presented CMAS was able to rank cutting trials based on the magnitude of KAM. Thus, is a potential method to identify athletes who generate high KAM during cutting.

Keywords: Anterior Cruciate Ligament; Knee Abduction Moments; Injury Screening

Introduction

Cutting is an action often associated with non-contact ACL injuries in field and court based sports such as soccer [4] and handball [23]. This is due to the propensity of generating high knee abduction (valgus) and rotational moments when the foot is planted [17], which could lead to increased ACL strain [24, 25]. Whilst the efficacy of screening tests to identify 'at-risk' athletes for specific injuries is debated [1], it is important as strength and conditioning coaches and sports rehabilitators to have a battery of assessments to provide an 'injury profile' of an athlete. If an athlete underachieves in certain related qualities, steps can be taken in training to address these deficiencies to provide an overall more rounded and robust athlete. It is unlikely that one single factor can predict injury alone [1]. Part of such a battery of assessments with regard to non-contact ACL injuries, should include some assessment of movement quality during relevant sports actions. In regard to non-contact ACL injuries, identifying athletes with poor lower limb mechanics in sports where there are large weight acceptance (braking) forces can be considered important.

To date, most literature has examined landing tasks such as the drop jump to identify 'at-risk' athletes despite some sports (i.e., soccer) reporting cutting or changing direction to be the most common action associated with non-contact ACL injury in females[4]. Hewitt *et al*., [6] using 3D motion analysis prospectively found that females who went on to injure their ACL had significantly greater knee abduction angles and moments during a drop jump than non-injured volleyball players. Although more recent research [15] found such an approach was unable to identify at-risk athletes for ACL injury in elite soccer and handball players; which questions the efficacy of the approach to find 'at-risk' athletes, but may also suggest that the screening task needs to reflect the movement demands of the sport. Nevertheless, the accessibility, time and financial costs will limit the widespread application of 3-Dimensional analysis to find athletes with poor movement quality, which has led authors to suggest the use of simplified 2D analysis of drop jumps focusing on estimates of frontal plane knee motion [19, 29]. Moreover, Padua *et al.* [20] have developed and validated a qualitative analysis tool for a drop jump involving 2D video capture in the frontal and sagittal planes. Although, mixed evidence has been reported with regard to the efficacy of the Landing Error Scoring System (LESS) [26, 21] to prospectively predict ACL injury. This may suggest that the use of landing tasks may fail to identify athletes with at-risk cutting mechanics. Furthermore, there is also mixed evidence available to suggest whether examination of landing mechanics could identify athletes with poor cutting mechanics [9,13]. For instance, it is suggested that landing tasks maybe better at identifying athletes with poor knee control during cutting, but the ability to identify athletes with high KAMs during cutting from landing is more difficult due to the differing technical demands of each task [9]. Thus, it is likely that assessment of movement quality of cutting alongside landing mechanics is needed to further develop the injury profile of an athlete in cutting and landing sports.

Field-based measures evaluating cutting mechanics have also relied on 2D estimates of frontal plane knee motion. McLean *et al.* [18] investigated whether a 2D assessment of knee valgus motion relates to knee valgus motion identified from 3D analysis during a 35-60° side-step, side-jump and shuttle-run (180º turn). 2D estimates correlated well with 3D data for the side-step (R^2 = 0.58) and side-jump (R^2 = 0.64), but did not correlate with the shuttle-run, highlighting the difficulty in assessing knee valgus motion 2-dimensionally in the frontal plane with more vigorous horizontal changes of direction. Furthermore, such a method only examines knee valgus motion and does not evaluate the range of technical factors that are associated with high KAM [3, 8,10,11,12, 17, 27]. Hence, a qualitative screening tool that examines many aspects of poor cutting mechanics maybe more informative for practitioners. Therefore, the aim of this preliminary study is to assess the validity of a qualitative screening tool for cutting (Cutting Movement Assessment Score) to estimate the potential magnitude of KAMs against the ‘Gold Standard’ 3D motion analysis.

Methods

Participants

With institutional ethical approval, 8 University level team (mean ± SD; age: 20.1 ±1.1 years, height: 1.63 ± 0.09 m, mass: 54.0 ± 6.9 kg) sport female athletes participated in this study. For inclusion in the study, all athletes had played their respective sport for a minimum of 5 years and regularly performed 1 game and 2 structured skill based sessions per week. All players were right leg dominant. All players were free from injury during the course of the study and none of the player’s had suffered prior traumatic knee injury such as anterior cruciate ligament injury. Data collection took place during the players pre-season. Written informed consent was provided by all subjects.

Cutting Movement Assessment Score

Table 1 presents a qualitative technique analysis tool to estimate the magnitude of KAMs during cutting (Cutting Movement Assessment Score - CMAS) based on research pertaining to technique determinants of KAM during 45-90° cutting. If an athlete during cutting exhibits any of the characteristics in Table 1 they are awarded a score. It is hypothesised that the greater the total score the greater the potential magnitude of KAM.

Table 1. A qualitative technique analysis tool to determine the magnitude of knee abduction moments during cutting – Cutting Movement Assessment Score (CMAS).

Variable	Observation	Score
<u>Penultimate contact</u>		
Backward inclination of the trunk	**Y/N**	**Y=0/ N=1**
<u>Final Contact</u>		
Wide lateral leg plant	**Y/N**	**Y=2/N=0**
Hip in an initial internally rotated position	**Y/N**	**Y=1/N=0**
Initial knee 'valgus' position	**Y/N**	**Y=1/N=0**
Inwardly rotated foot position	**Y/N**	**Y=1/N=0**
Frontal plane trunk position relative to intended direction**;** Lateral (L), Upright (U) or Medial (M).	**L/U/M**	**L=2/U = 1/M=0**
Trunk upright or leaning back throughout contact	**Y/N**	**Y=1/N=0**
Limited Knee Flexion during final contact	**Y/N**	**Y=1/N=0**
Excessive Knee 'valgus' motion during contact	**Y/N**	**Y=1/N=0**
	Total Score	**/11**

The CMAS examines both the penultimate and final contact during the cutting tasks. For penultimate contact a 'backward inclination of the trunk relative to the planted foot' is considered in order to increase horizontal braking forces during penultimate contact, based on research [11] that has found an association between average horizontal ground reaction forces (GRF) during penultimate contact and KAMs during final contact. For the final contact, 'wide lateral leg plant' and 'frontal plane trunk position' are considered major determinants of KAMs [3, 8, 12, 10]; and thus, are given a greater weighting. Previous research has found that a wide-lateral foot plant is associated with high KAMs [3, 27, 12, 10] as such a technical characteristic may create a GRF vector acting laterally outside the knee with greater distances of foot plant creating a greater moment arm and thus, KAM. Lateral trunk flexion has also been associated with increasing KAMs during cutting [3, 8, 12, 10], as a laterally flexed trunk towards the planted leg side shifts the athletes weight laterally creating a laterally directed force vector, increasing the moment arm relative to the knee joint and thus, KAMs.

Other considerations for the final foot contact include ‘initial knee valgus position’, which has been found in several studies to be associated with KAMs [17, 12, 10]. An increased knee abduction angle at initial contact has an effect of placing the knee more medial to the resultant GRF vector and thus, increases the lever arm of the resultant GRF vector relative to the knee joint leading to an increased KAM. Furthermore, Sigward and Powers [27] found both initial foot progression angle and initial hip internal rotation angle were significantly related to KAMs, as such a position could lead to a more medially positioned knee in relation to the GRF vector [27] and thus, are both considered within the tool. Finally, overall knee valgus motion during final contact and trunk inclination throughout final contact, with the latter considered to potentially increase the overall knee joint load due an increased lever arm of the trunk relative to the knee.

Experimental Procedures

The procedures are similar to the methods of Jones et al. [10] and are summarised here. Prior to data collection, reflective markers (14 mm spheres) were placed on bony landmarks of each athlete [10], along with 4 marker ‘cluster sets’ (lightweight plastic shell) placed on the upper back, both thighs and shanks, which approximated the motion of the segments during dynamic trials.

Following a static trial, each athlete performed 5 trials of a between 60-90° cutting task (Figure 1) which involved sprinting through a set of timing gates (Brower, Draper, UT) positioned at hip height 5 m from the centre of the plate and then after contacting the centre of the force platform with the right foot cut to the left through a second set of timing gates positioned 3 m away. The performance times were used to monitor performance between trials. For each trial, three-dimensional motion data using 10 Qualisys Oqus 7 infrared cameras (240 Hz) operating through Qualisys Track Manager Software v2.8 and ground reaction force (GRF) data from two AMTI force platforms (sampling at 1200 Hz) were collected. This arrangement allowed data to be collected for both penultimate and final contact. Simultaneously, 2 Casio EXF-1 cameras (Casio, Tokyo, Japan) sampling at 30 Hz were positioned 5 m away from the force platforms in frontal and sagittal planes. Greater video sampling rates could not be used as floodlights would have been required to enhance lighting, which would have then impacted on 3D motion data collection. Video footage was subsequently viewed in Quintic Biomechanics v26 (Coventry, UK) for qualitative analysis using the CMAS (Table 1).

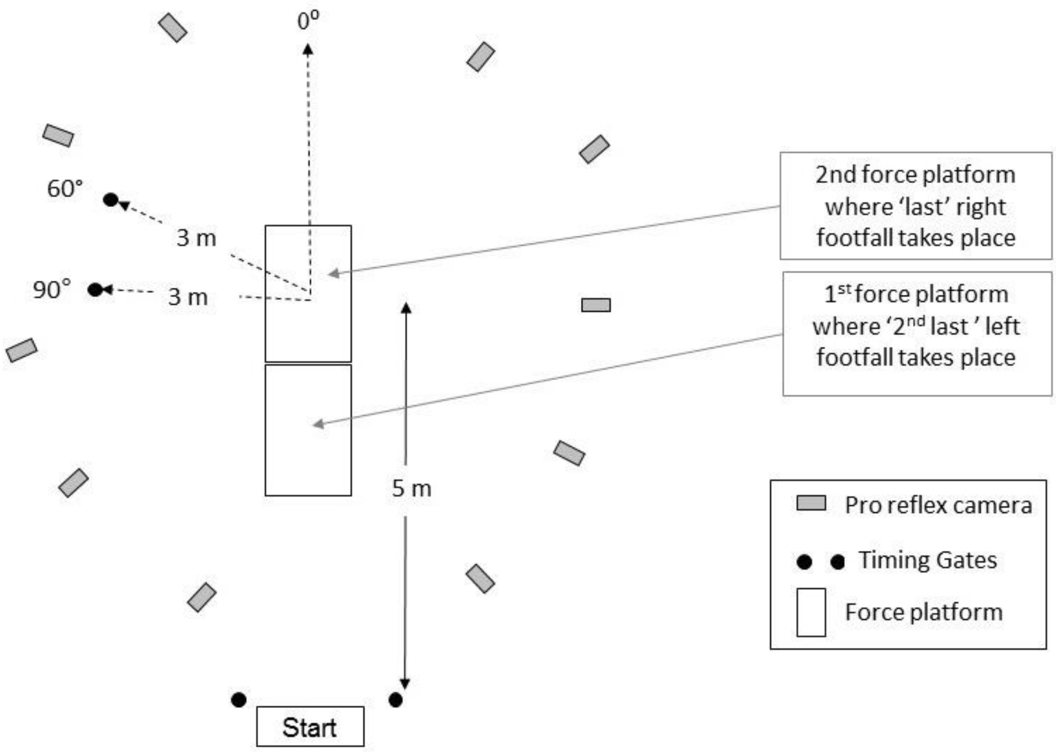

Figure 1. Plan view of the experimental set-up. The task involves subjects approaching 5 m towards a turning point on the 2nd of 2 force platforms. At the turning point, subjects cut to the left between timing cells positioned 3 m away and 60 to 90° from the original direction of travel.

A lower extremity and trunk 6 degrees of freedom kinematic model was created for each participant from the static trial. This model included the trunk, pelvis, thighs, shanks and feet using Visual 3D software (C-motion, version 3.90.21, Gothenburg, Sweden) and is described in more detail elsewhere [10]. The local coordinate system was defined at the proximal joint centre for each segment. The static trial position was designated as the participant's neutral (anatomical zero) alignment, and subsequent kinematic measures were related back to this position. KAMs were calculated using an inverse dynamics approach [30] through Visual3d software (C-motion, version 3.90.21) and represented as external moments.

Trials were disqualified if the subjects slid or missed the force platform that went unnoticed during data collection. This resulted in a total of 36 trials considered acceptable for both 3D and qualitative video analysis. Trials were time normalised for each participant, with respect to ground contact time. Initial contact was defined as the instant after ground contact that the vertical GRF was higher than 20 N and end of contact was defined as the point where the vertical GRF subsided past 20 N. Joint coordinate and force data were smoothed with a Butterworth low pass digital filter with cut-off frequencies of 12Hz and 25Hz, respectively. Cut off frequencies were selected based on a residual analysis [30] and visual inspection of the data.

Statistical Analysis

To determine inter and intra-rater reliability, 8 trials (1 from each subject) were randomly selected by one experimenter. One lead researcher (TD) viewed and graded each trial on two separate occasions and compared (intra-rater reliability), whilst another lead researcher (PJ) viewed and graded each trial once and compared to the other lead researcher (inter-rater reliability). Intra-class correlation co-efficients (ICC) for total score were determined. For each item within the CMAS and total score, percentage agreements

(agreements /agreements + disagreements × 100) and Kappa co-efficients were calculated. Kappa co-efficients were calculated using the formula; K = Pr(a) – Pr(e) / 1 – Pr(e), where Pr(a) = relative observed agreement between raters; Pr(e) = hypothetic probability of chance agreement, using the observed data to calculate the probabilities of each observer randomly saying each category [5]. The kappa co-efficient was interpreted based on the following scale of Landis and Koch [16]: 0.01-0.2 (slight); 0.21-0.4 (fair); 0.41-0.6 (moderate), 0.61-0.8 (good) and 0.81-1.0 (excellent).

The relationship between CMAS and the 'gold standard' determination of peak KAM during the final contact of the cutting task from 3D motion analysis for all available trials was explored using Spearman's rank correlation due to the non-parametric nature of the qualitative data. Correlations were evaluated as follows: trivial (0.0-0.09), small (0.10 – 0.29), moderate (0.30 – 0.49), large (0.50 – 0.69), very large (0.70 – 0.89), nearly perfect (0.90 – 0.99), and perfect (1.0) [7].

Results

Moderate to excellent intra- and inter-rater agreement was observed (Table 2). Excellent intra- and inter-rater ICC for total score was also observed (Intra-rater = 0.922; Inter-rater = 0.913).

Table 2. Intra and inter-rater agreement for CMAS criteria and total score.

Variable/ screening tool criteria	Intra-rater reliability		Inter-rater reliability	
	% Agreement	K	% Agreement	K
Backward inclination of the trunk (penultimate contact)	100	1.00	100	1.00
Wide lateral leg plant	87.5	0.60	100	1.00
Hip in an initial internally rotated position	87.5	0.75	87.5	0.75
Initial knee 'valgus' position	87.5	0.60	100	1.00
Inwardly rotated foot position	100	1.00	100	1.00
Frontal plane trunk position relative to intended direction; Lateral (L), Upright (U) or Medial (M).	75	0.62	62.5	0.40
Trunk upright or leaning back throughout final contact	100	1.00	87.5	0.75
Limited knee flexion during final contact	100	1.00	100	1.00
Excessive knee 'valgus' motion during final contact	100	1.00	87.5	0.71
Total	93	0.87	92	0.85

Figure 2 shows a linear relationship between CMAS and KAM's. Mean ± SD KAM from each trial of all 8 subjects and the respective CMAS were 0.80 ± 0.52 $Nm \cdot kg^{-1}$ and 4.5 ± 2.1, respectively. Spearman's correlation revealed a significant large association between CMAS and KAMs ($\rho = 0.633$; $p < 0.001$).

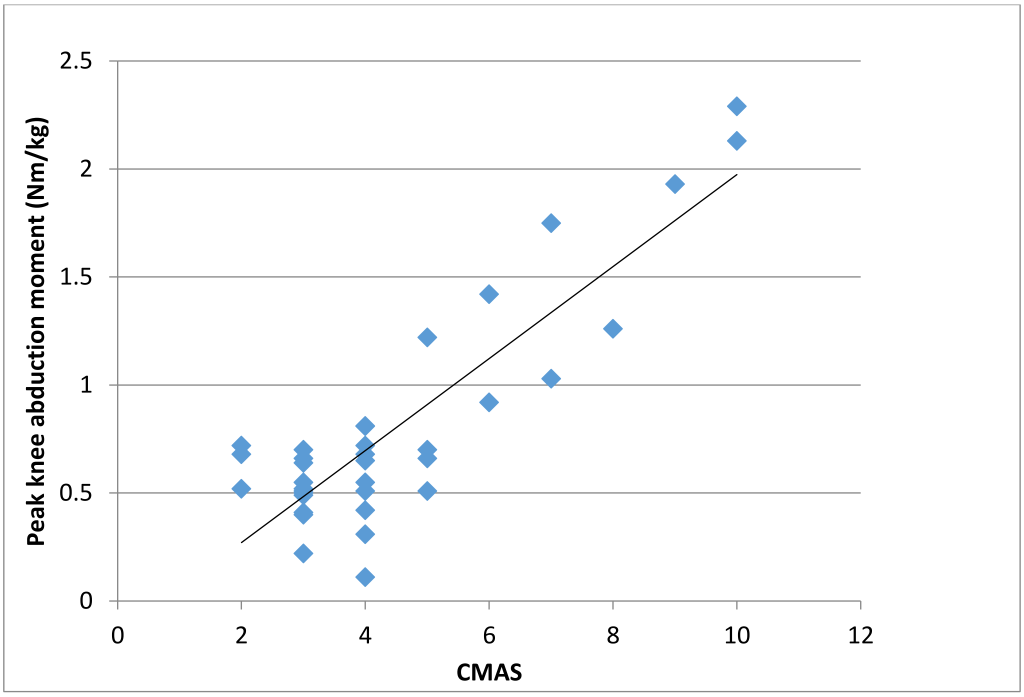

Figure 2. Scatter plot for the relationship between CMAS with peak knee abduction moments.

Discussion

The aim of this preliminary study was to assess the validity of a qualitative movement assessment tool for cutting (CMAS) to estimate the potential magnitude of KAMs against the 'Gold Standard' 3D motion analysis. The preliminary results suggest that the presented CMAS was able to rank cutting trials based on the magnitude of KAM. Thus, the CMAS can be considered a potential method to identify 'at-risk' athletes who generate high KAM during cutting and could be used in a battery of assessments for an athlete from 'cutting' sports to develop an injury profile of the athlete. The CMAS also demonstrated excellent inter and intra-rater reliability and agreement.

The efficacy and efficiency of injury prevention protocols could be improved considerably if they are designed specifically for predetermined at-risk athletes, with defined neuromuscular control deficits. Whilst screening for specific injury is difficult [1], practitioners require a battery of tests to develop an athlete profile that provides an assessment of risk factors that could inform training prescription. Central to such a battery of tests is an assessment of movement quality that relates to common actions in the sport associated with non-contact injury. Mixed evidence has been reported regarding the efficacy of using 3D motion analysis of drop jumping [6,15] to prospectively predict ACL injured athletes and may be partly explained by the need to assess athletes performing common actions that are associated with injury and occur frequently in change of directions sports, rather than just purely focus on landing tasks. Furthermore, 3D motion analysis is difficult to apply for widespread evaluation of athletes. Whilst relationships have been found with regard to knee motion between landing and changing direction [9, 13], when considering knee joint loads, lower or absent relationships have been observed [9, 13]; highlighting the need for field-based assessments of cutting or change of direction mechanics. Current field-based measures evaluating change of direction mechanics from 2D video analysis can approximate frontal plane knee motion for shallow angles of direction change only and have not been shown to predict knee joint loads [18]. The results of the present study suggest that the CMAS has potential to identify athletes with ‘at-risk’ cutting mechanics and could be used in a battery of assessments for an athlete from ‘cutting’ sports to develop an injury profile of the athlete. The use of the CMAS can specifically identify biomechanical or neuromuscular control deficits in athletes, which can then be targeted via appropriate training and conditioning.

One benefit of CMAS proposed in this study is that it evaluates an action (cutting) that is common in many sports such as soccer [2] and netball [28], whereas the drop jump is seldom performed in isolation during sport, as this action is effectively an assessment of an athlete’s reactive strength. Furthermore, cutting and change of direction actions have been associated with non-contact ACL injuries in soccer [4] and handball [23], whereas bilateral landings are associated with non-contact ACL injury in basketball [14]. Thus, the CMAS proposed in this study may serve well for athlete assessment in sports where cutting and change of direction actions are common. Further work is required to develop the CMAS particularly with a greater sample of athletes to determine whether the tool is capable of discriminating between athletes exhibiting poor to excellent cutting technique. Previous research using the LESS [21] found that 5 was an optimal cut-off score to identify at-risk athletes for non-contact ACL injury with 86% sensitivity and 64% specificity. Therefore, a longitudinal study is required to identify a potential cut-off score for the CMAS to identify 'at-risk' athletes and whether the tool can subsequently predict injury.

The present study involved team sport athletes with a range of ability levels, therefore, research is required to establish whether the tool can discriminate between athletes of different ability levels. In terms of the method of data collection, the intra- and inter-rater agreements revealed lower percentage agreements for frontal plane trunk position. This was partially due to the difficulty in viewing this variable in the frontal plane when athletes have a slightly rotated trunk or pelvis into the intended direction of travel. The authors recommend placing an additional camera 45° to the original direction of travel in order to improve the view of variables in the frontal plane when some level of rotation prior to or at initial contact of final footfall takes place. A further limitation of this study was that due to the need for additional lighting and to avoid this impacting the 3D motion capture only 30 Hz video recordings were gathered. Use of greater sampling rates (>100 Hz) would enable more precise identification of key instances during cutting manoeuvres and therefore, further enhance validity and reliability of the CMAS. The authors recommend using greater sampling frequencies (if available) in practice.

Finally, another limitation of the present study is that the intra- and inter-rater reliability and agreements were based on Biomechanics researchers carrying out the investigation. Further work is required to quantify intra- and inter-rater reliability with a range of applied practitioners such as strength and conditioning coaches, sports rehabilitators and physiotherapists to be able to apply the CMAS in the field.

Practical Applications for Strength & Conditioning

The large association between KAMs from 3D motion analysis and CMAS found in the present study support the association of the technique characteristics identified in the CMAS (Table 1) to KAMs during cutting, and therefore, could also act as a guide for technique development for athletes where the goal is for injury prevention. A unique aspect of this study is that technical guidelines for safer cutting are provided where currently there are no guidelines available on how to safely cut. This tool offers a template to enable practitioners to coach safer cutting technique. However, it should be highlighted that some of these technique aspects may be detrimental to performance. For instance, a wide lateral foot plant may facilitate the direction change by helping to generate medial GRF's, but would result in an initial increase in KAM. Further research is required to better understand the conflict between performance and injury risk for cutting, which may further inform the CMAS presented here.

A note of caution in using the CMAS is that practitioners should not only focus on total score but the actual criteria where the athlete scored points. A low score doesn't necessarily mean that a player has perfect and safe technique. For example, an athlete may only score two points on the CMAS, however, this score maybe for lateral trunk flexion, which has been stated as one of the theories of increased risk of ACL injury [22], as such this deficit in trunk control displayed by an athlete should not be ignored and the athlete should still receive specific training and conditioning.

Acknowledgements

The authors would like to thank Laura Smith and Natasha Brown for assistance with data collection for this study.

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