Butler L, Martinez A, Erdman A, et al. Concurrent Validity of The Expanded Cutting Alignment Scoring Tool (E-CAST). *IJSPT*. 2023;18(5):1147-1155. doi:10.26603/001c.87633

Original Research

Concurrent Validity of The Expanded Cutting Alignment Scoring Tool (E-CAST)

Lauren Butler[1,2a], Alexa Martinez[2], Ashley Erdman[3], Dai Sugimoto[4,5], Alex Loewen[3], Eryn Milian[6], Charles Wyatt[3,7], Kristin Hayden[2], Amie DeVerna[2], Kirsten Tulchin-Francis[8], Sophia Ulman[3,7]

[1] Physical Therapy , Florida International University, [2] Rehabilitation, Nicklaus Children's Hospital, [3] Scottish Rite for Children, [4] Waseda University, [5] The Micheli Center for Sports Injury Prevention, [6] University of Miami, [7] University of Texas Southwestern Medical Center, [8] Nationwide Children's Hospital

Keywords: Motion Analysis, Change of Direction, Sidestep Cut

https://doi.org/10.26603/001c.87633

International Journal of Sports Physical Therapy

Vol. 18, Issue 5, 2023

Background

The Expanded Cutting Alignment Scoring Tool (E-CAST) has been previously shown to be reliable when assessing lower extremity alignment during a 45-degree sidestep cut, however, the validity of this tool remains unknown. The purpose of this study was to assess the concurrent validity of the E-CAST by comparing visually identified movement errors from two-dimensional (2D) video with three-dimensional (3D) biomechanical variables collected using motion capture.

Study Design

Cross Sectional

Methods

Sixty female athletes (age 14.1 ± 1.5 years) who regularly participated in cutting/pivoting sports performed a sidestep cut with 2D video and 3D motion capture simultaneously recording. One clinician scored the 2D videos for each limb using the E-CAST criteria. Joint angles and moments captured in 3D were computed for the trunk and knee. Receiver operating characteristic (ROC) curve analyses were performed to determine the accuracy of each E-CAST item and to provide cut-off points for risk factor identification.

Results

ROC analyses identified a cut-off point for all biomechanical variables with sensitivity and specificity ranging from 70-85% and 55-89%, respectively. Across items, the area under the curve ranged from 0.67 to 0.91.

Conclusion

The E-CAST performed with acceptable to outstanding area under the curve values for all variables except static knee valgus.

Level of evidence

3b

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[a] Corresponding Author:
Lauren S. Butler
Florida International University
11200 SW 8th Strett
Miami, FL 33199
United States of America
Telephone: 305-348-3113
Fax: 786-624-5106
Email: Lbutler@fiu.edu

INTRODUCTION

Anterior cruciate ligament (ACL) injuries continue to be a significant concern for the young athlete with rising rates observed in both males and females.[1] Young female athletes who participate in cutting and pivoting sports are of particular concern due to having a higher incidence of both primary ACL injury and contralateral ACL injury after ACL reconstruction surgery.[2,3] Sidestep cutting maneuvers are frequently performed in sports and account for 60-70% of non-contact ACL injuries.[4-7] Previous studies have found an association between high knee abduction moments (KAM) during cutting maneuvers and increased ACL injury risk.[8-10] Furthermore, high KAM during cutting and pivoting movements have been correlated with increased contralateral trunk lean away from the plant leg,[8,11] elevated knee abduction angle,[12,13] knee valgus,[12] increased cutting width,[8,9,13,14] decreased knee flexion,[15] and low/reduced ankle plantar flexion.[13,16] While three-dimensional (3D) motion analysis remains the gold standard method to measure KAM, it poses challenges to clinic and on-field use due to its prohibitive cost and extensive time and training requirements.[17-19] As a result of these limitations, two-dimensional (2D) screening tools to assess sidestep cutting maneuvers have been sought for broader application.

The Expanded Cutting Alignment Scoring Tool (E-CAST) has been reported to have moderate inter-rater and good intra-rater reliability for the assessment of both frontal and sagittal plane trunk and LE alignment during a 45-degree sidestep cut in a group of young female athletes.[20] However, the level of agreement between the E-CAST and 3D biomechanical variables remains unknown. The purpose of this study was to assess the concurrent validity of the E-CAST by comparing visually identified movement errors from two-dimensional (2D) video with three-dimensional (3D) biomechanical variables collected using motion capture. The hypothesis was that all items of E-CAST would perform with acceptable to outstanding sensitivity and specificity values.

MATERIALS AND METHODS

STUDY DESIGN AND PARTICIPANTS

This study utilized a cross sectional study design to validate a visual assessment tool for a cutting maneuver. Institutional review board approval was obtained prior to commencement of the study. Specifically, the study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of the University of Texas Southwestern (Protocol Number: 082010-134, Approval Date: 2 February 1993). All participants provided written informed assent, and a parent or legal guardian provided signed consent prior to initiating testing procedures. A convenience sample of female athletes were recruited from local middle school, high school, and club sport teams, and were seen for a single visit in a motion analysis laboratory at a local sports medicine treatment center. Inclusion criteria included 1) age between 12 and 17 years of age, 2) active participation in sports involving cutting and pivoting movements in the prior 12 months, and 3) a level of physical activity between 7 and 10 on the Tegner Activity Scale.[21] The inclusion criteria were developed to provide a sample of female pre-teen and teenage athletes who were actively playing sports that involved cutting and pivoting movements. This population was chosen due to their exposure to cutting movements and their high risk of ACL injury. The following exclusion criteria were used: 1) lower extremity injury within the prior six months, 2) history of lower extremity surgery, 3) a positive response on the Physical Activity Readiness Questionnaire (PAR-Q+), or 4) history of scoliosis. Those with lower extremity injury within the prior six month and a history of lower extremity surgery were excluded to reduce compensatory movement patters that may result from pain, range motion deficits, or strength deficits that are associated with injury recovery. The PAR-Q+ was used to determine the participant's readiness and safety for physical activity. A positive response on the PAR-Q+ indicates the need to seek further advice from a physician prior to engaging in physical activity.[22] Participants with a history of scoliosis were excluded to reduce asymmetries in trunk deviations that may result from structural spinal deformity. For testing, participants were asked to wear comfortable attire and their personal athletic footwear.

DATA COLLECTION

Participants were instrumented with retroreflective markers placed on specific bony landmarks according to a modified Plug-in Gait marker set (OMG Plc, Oxford, UK).[23] A 14-camera motion capture system (Vicon Motion Systems Ltd, Denver, CO, USA) was used to collect 3D kinematic data sampling at 240 Hz while participants performed the sidestep cut task. Kinetic data were collected using AMTI force plates (Advanced Medical Technology Inc., Watertown, MA) that were time-synchronized to the motion capture system and sampled at 2880 Hz. Simultaneously, 2D video data were captured at 60 frames per second with 1080p quality using three cameras (Sony Cyber-shot DSC-Rx10, Tokyo, Japan) adjusted to 36 inches tall. Two cameras were positioned 136 inches from either side of the stance/pivot area (sagittal view), and one camera was positioned 146 inches in front of the stance/pivot area (frontal view).[20]

Following the procedures outlines by Butler et al., all athletes completed a 5-minute warm up on an exercise bike (Matrix Fitness, Cottage Grove, WI) prior to performing the 45-degree sidestep cut task.[20] Participants then practiced the sidestep cut up to three times in each direction or until they felt comfortable with the maneuver.[20] They were instructed to sprint at 80% of their maximum speed in a forward direction toward the "opponent cone" and to pivot, attempting to fake out the "opponent cone" (Figure 1).[20]

Specifically, participants decelerated, planted on their right foot, and performed a sidestep cut, running in the left direction between cones placed along a 45-degree line of progression.[12] Participants completed the procedure in each direction, with three "good" trials per plant leg. A trial was considered "good" if the subject's foot landed within the stance/pivot area necessary for successful completion

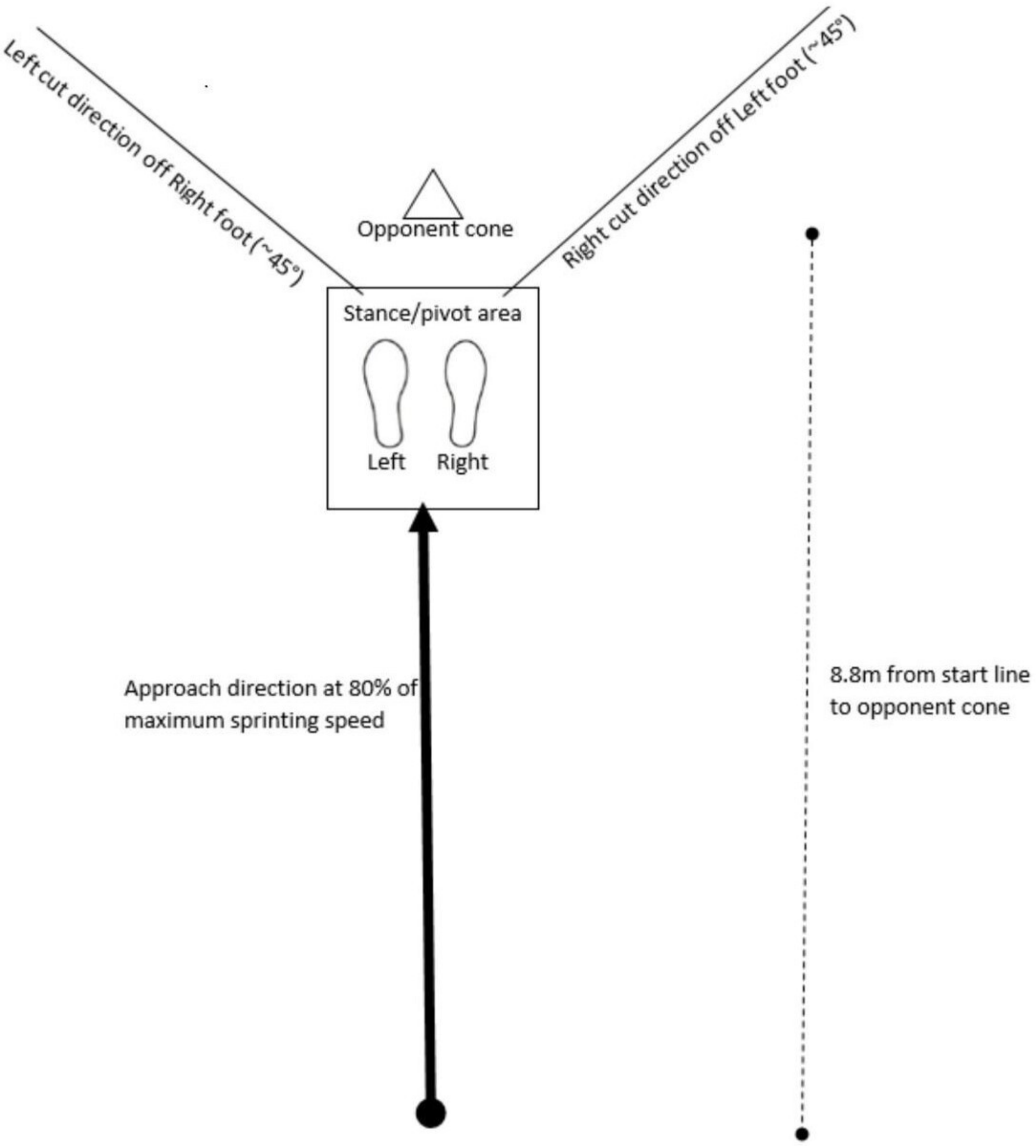

Figure 1. 45-degree sidestep cut task.[20]

of the task. Videos in the frontal and sagittal plane were recorded as each participant performed a total of six cutting maneuvers, with one trial per side randomly selected for analysis.

All videos were slowed by 50% for visual analysis and participants' faces were blurred using Corel VideoStudio (Corel Corporation, Ottawa, ON). In the clinic or on-field setting most practitioners record video using a smart device which allows for playback at slower speeds. The videos in this study were slowed to allow for improved visualization and identification of movement criteria and to replicate the process used by practitioners. A clinically established checklist, E-CAST, was utilized to examine the quality of trunk and lower extremity movement during a 45-degree sidestep cut task based on 2D video.[20] The E-CAST involves a dichotomous rating system, with scoring defined as "1" when a movement fault was present and "0" when optimal movement patterns were observed. The E-CAST evaluates items in the frontal plane (trunk lean, cut width, knee valgus) as well as items in the sagittal plane (plantar flexion and knee flexion). One physical therapist with five years of experience in pediatric sports rehabilitation trained in the scoring criteria, independently scored the 2D video in both planes for each limb using the E-CAST scoring criteria (Table 1).

Three-dimensional biomechanical data were processed using Vicon Nexus software (OMG plc, Oxford, UK). A Woltring filter was applied to the marker trajectories with a predicted mean square error of 10 mm.[2,24] Analog data were filtered using a 4th-order, low-pass Butterworth filter with a cutoff frequency of 16 Hz. Segment and joint angles were computed for the trunk, knee, and ankle in the frontal and sagittal planes using a custom MATLAB (MATLAB 2016a, Natick, MA, USA) model. External knee abduction moments (KAM) were calculated and normalized to the product of height (cm) and weight (kg). An automated custom MATLAB code was used to detect events during the sidestep cut at time points of interest (i.e., initial contact, load acceptance). Additionally, knee flexion and ankle plantar flexion were extracted at initial contact (IC), defined

Table 1. Expanded Cutting Alignment Scoring Tool (E-CAST)

Item	View	Operational Definition
1. Trunk lean to opposite direction of cut	Frontal	At the time point of initial load acceptance if the whole trunk segment appears to be deviated greater than 10 degrees from a horizontal line through the hips (ASIS to ASIS) score 1 (YES). If not, score 0 (NO).
2. Increased cut width	Frontal	At the time point of initial load acceptance, draw a line down from the lateral most aspect of the athlete's stance leg hip, if the line appears to fall more than one shoe width medial to the foot score 1 (YES). If not, score 0 (NO).
3. Knee Valgus at Initial load acceptance (Static Evaluation)	Frontal	At the time point of initial load acceptance, if the weight bearing limb demonstrates valgus (thigh adduction, genu valgum, or knee abduction) score 1 (YES). If the weight bearing limb is in neutral alignment score 0 (NO).
4. Knee Valgus throughout the cutting task (Dynamic Evaluation)	Frontal	During the cutting task if the weight bearing limb demonstrates valgus (thigh adduction, genu valgum or knee abduction) score 1 (YES). If the weight bearing limb is in neutral alignment, score 0 (NO).
5.Decreased knee flexion angle	Sagittal	At the time point of initial contact if the athlete demonstrates a stiff or extended knee position score 1 (YES). If the athlete demonstrates a flexed knee position (Approximately> 30 degrees), score 0 (NO)
6. Decreased plantar flexion angle	Sagittal	At the time point of initial contact if the stance foot lands heel to toe score 1 (YES). If the stands foot lands toe to heel score 0 (NO)

for 3D data analysis as the time point when the vertical ground reaction force exceeded 1% of the subject's bodyweight. Trunk lean, cut width, and knee valgus (static evaluation) variables were extracted across load acceptance, defined for 3D data analysis as the portion of the task between IC and the point of maximum knee flexion. Knee valgus (dynamic evaluation) was evaluated throughout the cutting task, from IC to foot-off of the plant leg.

STATISTICAL ANALYSIS

Mean and standard deviation values were computed for all demographic and sport participation measures. Additionally, the percent of participants identified as exhibiting each risk factor based on the E-CAST scoring criteria were determined and mean and standard deviation values were calculated for each 3D biomechanical variable corresponding to the 2D scoring items. Logistic regression analysis was used to determine whether 3D biomechanical variables were associated with the corresponding 2D scores. Specifically, receiver operating characteristic (ROC) curves were generated to determine cut points for identifying participants who exhibited each risk factor. This point is selected such that the scoring tool correctly identifies the greatest number of participants at risk (true positives, measured via sensitivity) while minimizing the number of participants incorrectly identified for exhibiting risk (false positives, measured via specificity). Subsequently, accuracy was quantified by computing the area under the ROC curve (AUC) as well as the sensitivity and specificity (IBM SPSS Statistics for Windows, version 24.0, Armonk, NY, USA). The approach used is outlined in detail by Kumar & Indrayan (2011).[25]

Significance level was set to $\alpha = 0.05$, and the AUC was used to classify each model as outstanding (0.90-1.00), excellent (0.80-0.89), acceptable (0.70-0.79), poor (0.51-0.69), or no discrimination (0.50 or less).[26,27] Due to the slightly skewed distribution of the presence of knee valgus observed on 2D video and the limited range of the 3D knee valgus angles recorded, the ROC analysis was unable to define a cut point for the knee valgus scoring items. Therefore, ROC analyses were also performed for the knee valgus scoring items using KAM variables Dynamic knee valgus has been defined as a combination of multiplanar movements, including femoral adduction and internal rotation, anterior tibial translation, external tibia rotation, ankle eversion, and knee valgus.[17,28,29] While knee valgus describes the abnormal biomechanical profile that causes the knee to be in a high-risk position, knee abduction moment indicates the amount of loading acting upon the knee. These valgus forces can increase anterior tibial translation and ultimately the load placed on the ACL by several-fold.[30] Furthermore, both knee valgus angle and knee abduction moment have been reported to be primary predictors of subsequent ACL injury with 78% sensitivity and 73% specificity.[17] Thus, KAM was chosen as a proxy measurement for dynamic knee valgus as it takes into consideration the forces acting on the knee joint.

RESULTS

A total of 60 female athletes who regularly participated in cutting or pivoting sports were recruited for participation in the study. Two athletes were removed from the study due to poor quality videos, leaving a final total of 58 participants (age 14.1 ± 1.6 years, body mass 54.8 ± 10.6 kg, height 162.8 ± 7.7 cm). Athlete's average level of sport participation measured with the Tegner Activity Scale was 9.2 ± 0.8. 2D visual assessment using the E-CAST scoring criteria found that the mean score was 3.9 ± 1.2 out of a maximum score of 6.0 for the 58 athletes (116 limbs). Using the knee valgus E-CAST scores, a KAM cut point of 0.78 Nm/kg was identified throughout the cutting task with 72% of the cohort exhibiting a KAM that surpassed this cut point. Knee valgus for both the static and dynamic E-CAST items were

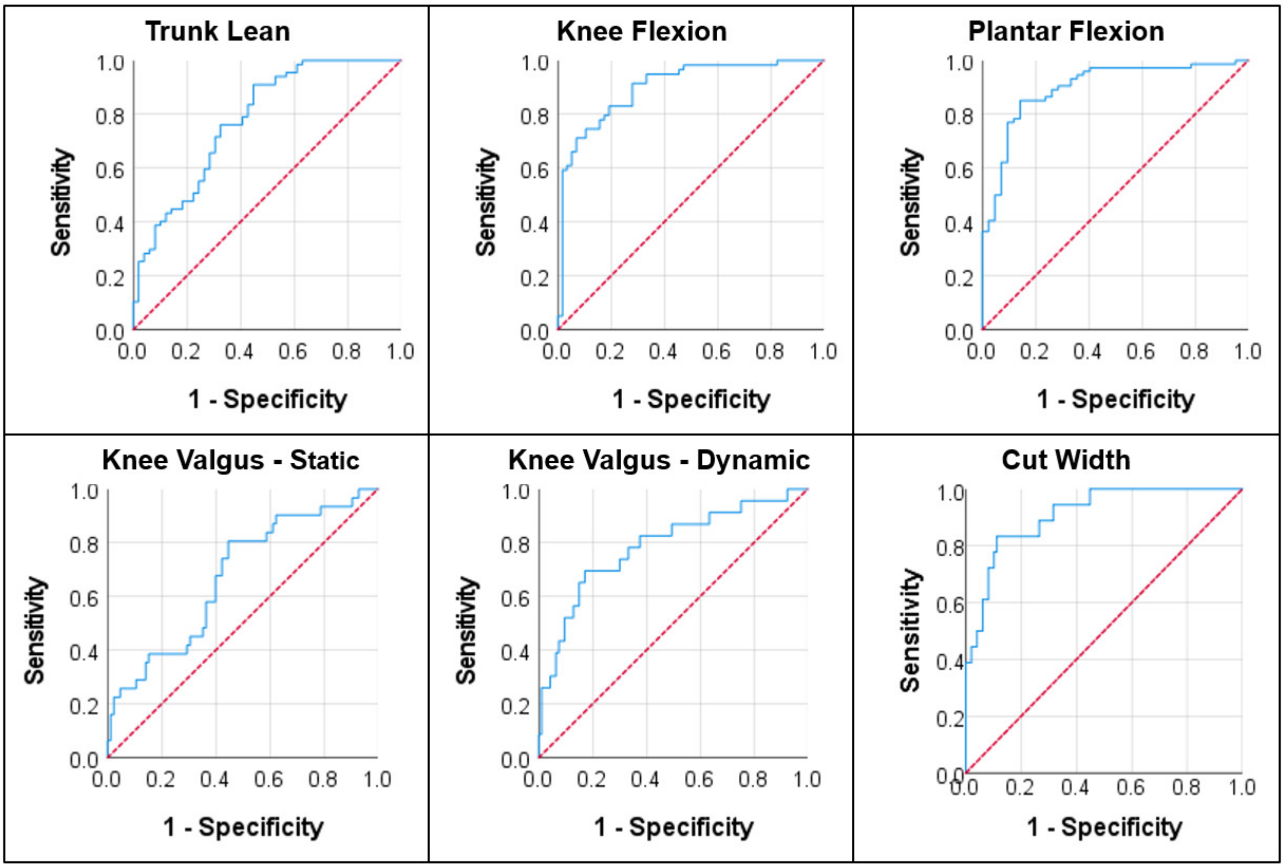

Figure 2. ROC curves for trunk lean, knee flexion, plantar flexion, knee valgus – static, knee valgus – dynamic, and cut width.

Table 2. Prevalence of E-CAST items, mean (SD) 3D measures, and ROC curve analysis results.

E-CAST Item	*2D (%)*	*3D Measure*	*Cut Point*	*Sensitivity (%)*	*Specificity (%)*	*AUC*
Trunk Lean (°)	42%	5.0 (6.8)	6.1	76%	67%	0.78
Cut Width (mm)	85%	63.5 (51.2)	28.4	83%	89%	0.91
Knee Valgus Static (Nm/kg)	73%	0.67 (0.52)	0.74	81%	55%	0.67
Knee Valgus Dynamic (Nm/kg)	80%	1.09 (0.47)	0.78	70%	83%	0.79
Knee Flexion (°)	49%	25.7 (12.1)	24.2	83%	81%	0.90
Plantar Flexion (°)	64%	7.2 (13.2)	8.6	85%	86%	0.90

Note: Positive 3D trunk lean value indicates lean towards cut limb; KAM values (Nm/kg) are reported for Knee Valgus items.

scored visually as present in 73% and 80% of limbs, respectively. Decreased plantar flexion angle was present in 64% of limbs, and decreased knee flexion angle was present in 49% of the limbs. Increased cut width was visually identified in 85% of limbs and trunk lean to the opposite direction of the cut was identified in 42% of the cohort. The prevalence of each 2D E-CAST scoring item and the corresponding mean 3D measures are presented in Table 2. A cut point was identified for all biomechanical variables with sensitivity and specificity ranging from 70-85% and 55-89%, respectively (Figure 2, Table 2). Across scoring items, the AUC ranged from 0.67 to 0.91.

DISCUSSION

The purpose of this study was to assess the concurrent validity of the E-CAST by comparing visually identified movement errors from 2D video using the E-CAST scoring tool with 3D biomechanical variables collected using motion capture technology. Variables of plantar flexion, knee flexion, and cut width had the highest sensitivity and specificity and thus performed with outstanding AUC values. These findings indicate that the sagittal plane items of the E-CAST scoring tool performed the best when compared to 3D biomechanical variables. Alternatively, dynamic knee valgus and trunk lean items were found to be acceptable

(AUC = 0.79 and 0.78, respectively), while static knee valgus performed poorly as indicated by an AUC of 0.67.

Outstanding performance exhibited by plantar flexion, knee flexion, and cut width might be a result of the simplicity and explicit nature of the language used in the E-CAST definition of these items. For example, the plantar flexion definition requires the clinician to determine if the stance foot lands "heel to toe" or "toe to heel" and the knee flexion definition references a flexed knee position greater than thirty degrees to be classified as not present. Sagittal plane measures from 2D visual assessment have been found to allow for more valid interpretation of range-of-motion.[31] This is likely a result of the larger range of motion associated with sagittal plane movements, compared to the frontal plane, which may make movement criteria identification easier as the viewer has a larger range of motion to consider. Additionally, the definition of cut width involves drawing a line down from the lateral aspect of the athlete's hip and determining if that line is greater than one shoe width medial to the foot. This type of spatial reference in the frontal plane may be easier to visually identify compared to evaluating frontal plane joint angles across multiple joints.

Static and dynamic knee valgus items exhibited poor and acceptable performance in classifying the presence of 3D variables (AUC = 0.67 and 0.79, respectively). While static valgus performed with a sensitivity of 81%, specificity was only 55%. Thus, the current item definition performs well in classifying athletes who do not exhibit the 3D variable but fails to successfully recognize when the 3D variable of static knee valgus is present. Alternatively, dynamic knee valgus performed with greater specificity (83%) than sensitivity (70%), however, the gap between classification performance measures was smaller. Both knee valgus items use a multicomponent definition requiring the clinician to identify whether thigh adduction, genu valgum, or knee abduction are present and does not provide a reference degree. Dynamic knee valgus likely performed better than static knee valgus given that movement faults were more evident throughout the cutting task than at initial load acceptance. It is possible that using a definition that requires the viewer to consider movement at multiple joints may make visual assessment more challenging. Furthermore, knee valgus is a multiplanar motion which presents additional challenges for 2D video-based assessment. Specifically, knee valgus identified via 2D methods has not been found to correlate well with 3D biomechanics during single leg squatting and landing tasks.[31-34] In a study by Ulman et al., no agreement was found between 2D identification of knee valgus and 3D knee biomechanical assessment during a single leg squat or a single leg drop landing, while remaining variables, including trunk flexion and lean, were found to exhibit moderate to excellent percent agreement.[34] This suggests the need for more explicit and comprehensive definitions of knee valgus for 2D visual assessments.

To achieve agreement for the knee valgus items, one option explored was taking into consideration the forces acting on the knee joint (i.e., kinetics). Given that the logistic regression analysis indicated agreement between 2D scores and KAM, this may suggest that visual identification of risk at the knee may still be possible when considering the loading forces acting on the knee alongside full lower extremity kinematics rather than just knee angle. A total of 72% of limbs in this study surpassed the cut point for KAM throughout the cutting task. The authors would consider this high risk for ACL injury based on the E-CAST checklist definitions. Furthermore, Dos Santos et al. found that athletes with higher scores on the CMAS (poorer cutting mechanics) demonstrated greater multiplanar knee joint loads. Specifically, these athletes performed a 90-degree sidestep cut with greater knee abduction angles, lateral foot plant distances, internal foot progression angles, and lower knee flexion range of motion and with greater knee flexion, abduction, and internal rotation moments. They also found a positive relationship between the CMAS total score and peak KAM.[35] Therefore, when screening for high knee joint loads, the cumulative effect of multiple joint movements may be more important than the assessment of one joint alone. For example, assessments of knee valgus in isolation may be less effective than assessments that include evaluation of multiple joints and positions resulting in a cumulative "risk" score.

Trunk lean performed with acceptable AUC, with sensitivity (76%) slightly greater than specificity (67%). Although the trunk lean definition includes explicit language and provides a degree reference, participants demonstrated movement variability at the trunk across multiple planes (e.g., trunk flexion, lateral flexion, and rotation) which may have made the visual identification of frontal plane trunk lean more challenging. This suggests that when assessing for movement faults at the trunk, multiple planes of motion need to be considered both individually and together in combination.

LIMITATIONS

Limitations relating to the use of 2D video-based assessments need to be acknowledged. When using 2D video, participant rotation may result in the loss of a fully perpendicular frontal plane and sagittal plane view which can lead to error during movement assessment. Furthermore, this study utilized a planned 45-degree sidestep cut. Planned cutting tasks have been shown to result in lower knee joint loads compared to unplanned cutting tasks.[36] However, unplanned cutting tasks are more challenging to capture using 2D video, requiring more cameras and greater complexity of set up. Moreover, video assessment in this study was performed by a physical therapist. This may present concerns relating to the tool's generalizability for use by coaching staff. Lastly, a power analysis was not performed prior to commencement of the current study.

CONCLUSION

In conclusion, the E-CAST performed with acceptable to outstanding AUC values for all variables except static knee valgus. These findings suggest that the E-CAST individual scores have moderate to good evidence of concurrent validity with 3D variables during a 45-degree sidestep cut. Future studies should aim to improve knee valgus criteria definitions to better align with 3D kinematics and kinetics.

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DISCLOSURE STATEMENT

The authors report there are no competing interests to declare.

Submitted: January 12, 2023 CDT, Accepted: August 28, 2023 CDT

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