INITIAL EXPLORATIONS USING THE KNEE MOMENT VECTOR VERSUS THE KNEE ABDUCTION MOMENT TO IDENTIFY ATHLETES AT RISK OF ACL INJURY

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The knee abduction moment (KM-Y) is a biomechanical risk factor for ACL injury, yet multi-planar loads are known to strain the ACL. The KM-Y alone is often used for injury screening and prediction. This study examined if the KM-Y alone would identify athletes with high knee moments. Forty five female participants performed a bilateral drop jump and single leg drop jump with each leg and their 3D motion characteristics and ground reaction forces were measured. The identification of “at risk” individuals was compared between KM-Y, the non-sagittal resultant moment and the resultant knee moment using a risk threshold of the mean+1.6SD. The KM-Y identified 60 and 70% athletes in each task whereas also using the non-sagittal resultant moment identified 90 and 100%. This suggests that transverse plane moments should not be ignored to identify at risk athletes.

KEYWORDS: Screening, resultant moment, classification, risk threshold

INTRODUCTION: The knee abduction moment has been implicated as an *in vivo* biomechanical risk factor for ACL injury during drop vertical jumping (Hewett et al., 2005). Unfortunately though in more recent prospective studies, the knee abduction moment did not predict ACL injury occurrence (Krosshaug et al., 2016; Leppanen et al., 2017). Although it is generally agreed that high abduction moments are undesirable during dynamic tasks, their weak prediction of ACL injury occurrence has led to suggestions that their use for injury screening is limited (Bahr, 2016).

When the knee is loaded during dynamic sporting activities, the resultant knee moment vector is often resolved into an anatomical reference system to extract the knee abduction moment but comparatively little focus is given to the transverse plane rotation moment. This is perhaps surprising when *in vitro* literature (Markolf et al., 1995) indicates that internal rotation moments increase ACL strain as much or if not more than abduction moments. The *in vivo* literature also supports a multi-planar injury mechanism (Kiapour et al., 2015; Quatman, Quatman-Yates, & Hewett, 2010) and this is further supported *by in silico* research (McLean, Huang, Su, & van den Bogert, 2004; Quatman et al., 2010). The knee abduction moment alone may therefore fail to represent the complexity of the multi-planar loading experienced in dynamic tasks (Robinson et al., 2015). However if the knee abduction moment alone can identify all “at risk” individuals then one might consider the additional moment components redundant in injury screening and classification.

The aim of this study was to evaluate if the knee abduction moment can identify all individuals with high multi-planar knee joint moments. We will address this by comparing the classification of “at risk” individuals using the knee abduction moment alone versus a non-sagittal resultant moment vector and the resultant moment vector.

METHODS: Forty five recreationally active female participants (mean ± SD: age, 22.1 ± 3.7 years; mass, 64.0 ± 10.6 kg) volunteered to participate in the study which was approved by the university’s ethics committee. After familiarisation, each participant completed five trials of a maximal bilateral drop vertical jump (B-DVJ) and five trials of a maximal single-leg drop vertical jump (SL-DVJ) for both legs, all from a height of 30 cm. Two tasks were chosen to test if the results observed were consistent across a bilateral and single-leg task and both legs were used to investigate within participant effects. Adequate rest was given between trials to delay the effects of fatigue. Participants landed on 90x60 cm force platforms sampling at 1500 Hz (Kistler, Winterthur, Switzerland) and their 3D motion characteristics were captured at 250 Hz (10 Oqus Cameras and QTM v.2.14 Qualisys AB, Gothenburg, Sweden) using the coordinates of 44 spherical markers which were used to create geometric models of the trunk, pelvis and lower limbs according to the 6 degrees of freedom LJMU model (Malfait et al., 2014; Vanrenterghem, Gormley, Robinson, & Lees, 2010). This model uses functional knee axes and hip joints. Knee joint moments from both limbs during B-DVJ and for the landing limb during the SL-DVJ were estimated using inverse dynamics. All modelling procedures and estimates of knee moments were calculated in Visual 3D (5.02.30).

Knee moments were obtained during the first landing and the peak external abduction moment (KM-Y) during weight acceptance (Dempsey et al., 2007) was extracted. The peak non-sagittal resultant moment (KM-YZ) and the peak resultant knee moment (KM-XYZ) were also extracted for each trial. These peaks were then averaged across the five trials. To evaluate how each moment variable classified individuals, each moment variable pair were plotted in a scatterplot for each leg separately. A "risk threshold" of the inter-subject mean + 1.6 SD was added to the plots, this was calculated based on injury rate data from Finch, Da Costa, Stevenson, Hamer, and Elliott (2002). Assuming that their sample adequately represented the population, the threshold on the normal distribution curve below which 94.5% of the population fell was the mean +1.6 SD. Any participants above this threshold we subsequently refer to as ''at risk''. As this was an initial exploratory study a descriptive approach was preferred over inferential statistics.

RESULTS: In the B-DVJ, 10 legs exceeded the at risk threshold (figure 1) with two individuals exceeding the threshold with both legs. Classification based on KM-Y found seven at risk individuals and the non-sagittal resultant KM-YZ also classified seven at risk individuals, five of which were classified by both. The resultant knee moment KM-XYZ classified four legs at risk, all of which except one (#80) were classified by either KM-Y or KM-YZ. Therefore in combination, KM-Y and KM-YZ classified 9/10 legs that exceeded the risk threshold.

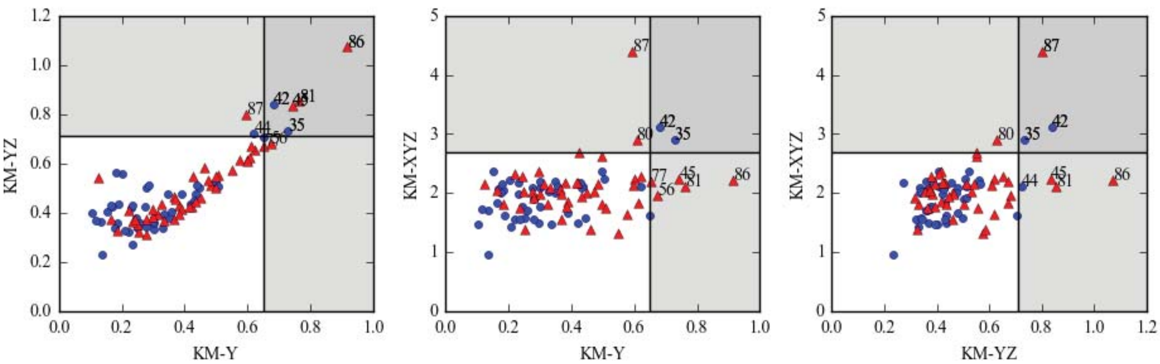

Figure 1. B-DVJ scatterplots of participants left (blue circles) and right (red triangles) peak knee moments (Nm·kg^{-1}). The grey shaded area represents the area greater than the risk threshold (black line) for each moment variable.

In the SL-DVJ task, 10 legs exceeded the risk threshold (figure 2) with three individuals exceeding the threshold with both legs. KM-Y classified five legs at risk and the non-sagittal KM-YZ classified six, one of which was identified by both. The resultant moment KM-XYZ classified four individuals at risk but all of these were also identified by KM-YZ. In combination the KM-Y and KM-YZ moments classified all 10 legs exceeding the risk threshold.

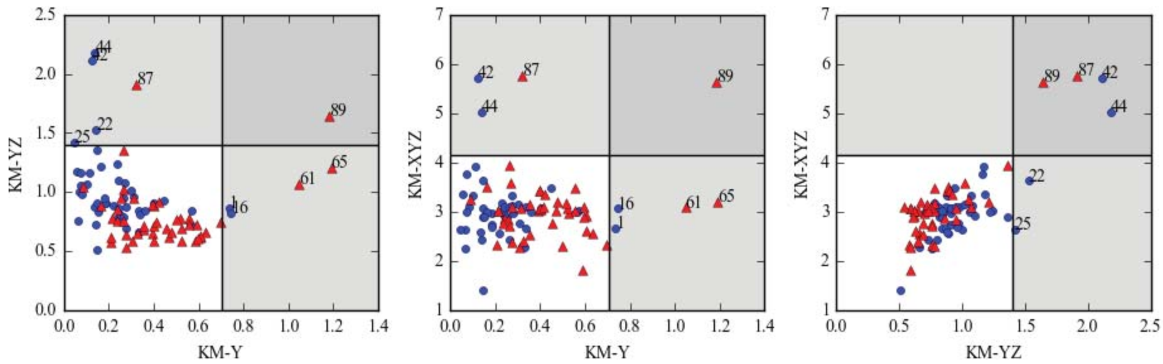

Figure 2. SL-DVJ scatterplots of participants left (blue circles) and right (red triangles) peak knee moments (Nm·kg^{-1}). The grey shaded area represents the area greater than the risk threshold (black line) for each moment variable.

Each task tended to identify different legs at risk, which is similar to previous results across a wide variety of tasks (Sharir, Vanrenterghem, Robinson, & George, 2017). However there was one individual who exceeded the risk threshold for both the B-DVJ and the SL-DVJ tasks with both legs.

DISCUSSION: The aim of this study was to evaluate if the knee abduction moment can identify all individuals with high multi-planar knee joint moments. Classification of "at risk" legs using a KM-Y risk threshold only identified 50 and 70% of legs across both tasks. KM-YZ was slightly better and identified 60 and 70% of at risk individuals due to better SL-DVJ classification. In combination, the KM-Y and KM-YZ identified 90 and 100% of at risk legs.
Identifying athletes "at risk" of ACL injury is a challenge given that recent evidence shows that prospectively identified biomechanical risk factors do not predict ACL injuries (Krosshaug et al., 2016) and classify individuals differently in different tasks (Sharir et al., 2017). This exploratory study has shown that the knee abduction moment (KM-Y) alone is unlikely to identify all individuals that have high multi-planar loading. This is perhaps to be expected given (1) the reliability of the knee abduction moment is questionable (Malfait et al, 2014; Sankey et al., 2015), (2) there is likely to be cross-talk between moment components, and clearly (1) and (2) interact. Furthermore, given the number of at risk legs identified by the KM-YZ not identified by KM-Y, there would appear to be unique and relevant information about individuals with high multi-planar moments that is not always captured if classifying individuals using KM-Y alone. This provides some initial evidence to suggest that the KM-YZ may be as valuable, if not more valuable than KM-Y to identify at risk individuals. The KM-XYZ identified only one additional high risk individual above KM-Y and KM-YZ which suggests that the sagittal plane moment, whilst essential to execute the tasks, contributes little additional information to identify individuals with high multi-planar moments.
There are a number of additional observations that are worth mentioning. Firstly, KM-YZ did not identify all individuals identified as high by KM-Y. This is perhaps counterintuitive but is explained by the magnitude of the transverse plane moment; those individuals identified by KM-Y but not KM-YZ would have had smaller transverse plane (Z) moments. Secondly, the relationship between KM-Y and KM-YZ appeared to be different between the two tasks with the SL-DVJ appearing less linear. This could be due to a wider variability in the SL-DVJ task, but this requires further study.
This study has a number of limitations including the somewhat arbitrary selection of the "at risk" threshold. In future a sensitivity analysis across a range of at risk thresholds will evaluate how robust these findings are to the threshold used. Unfortunately these data cannot be mapped to actual ACL injury occurrence and so it is unknown if KM-YZ may be a better predictor of ACL injuries than KM-Y. Future prospective studies and appropriate statistical analysis would need to confirm the ability of KM-YZ to predict actual injury occurrence. Finally, these exploratory results are specific to this cohort, tasks and protocol and require further verification in independent cohorts and laboratories.

CONCLUSION: The knee abduction moment did not identify all individuals with high multi-planar knee joint moments. The non-sagittal resultant moment in combination with the abduction moment identified 90 and 100% of at risk individuals in the BL-DVJ and SL-DVJ respectively. For screening purposes practitioners might wish to consider the importance of transverse plane knee joint loads in addition to frontal plane loading.

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