THE INTER-LABORATORY REPEATABILITY OF UNPLANNED SIDESTEPPING KINEMATICS

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Anterior cruciate ligament (ACL) injury research has received much attention over the past 20 years. In this time, there have been many laboratory based clinical movement protocols developed to help characterise an individual's injury risk in sport. Though many testing procedures exists, there is a paucity of research verifying the inter-lab reliability of these testing protocols. This places practical limitations on the ability to compare or share motion data between testing centres. The aim of this research was to help bridge this gap by assessing the inter-lab repeatability of an established sidestepping protocol. Results showed the inter-lab kinematics of unplanned sidestepping are repeatable (RMSE ≤ 5.02^{O}) verifying this experimental protocol as a dependable between testing centres.

KEY WORDS: reliability; injury; classification; SPM; female; team sport.

INTRODUCTION: For the past 20 years, much research has been spent on the prevention of non-contact anterior cruciate ligament (ACL) injuries in sport (Hewett *et al.*, 1996). With it known that the majority of non-contact ACL injuries occur during sidestepping and landing tasks (Cochrane *et al.*, 2002), laboratories world-wide have developed innovative experimental testing procedures to mimic the internal and external forces related to the injury event. In general, these testing procedures either use a single/double support landing or planned/unplanned sidestepping protocol, with clinically relevant kinematic, kinetic and muscle activation measures to classify an athlete's risk of ACL injury/re-injury in sport (Donnelly *et al.*, 2012a). Though an appropriate research approach, little research has been spent testing the repeatability of these procedures between research centres, placing practical limitations on the shared use and interpretation of motion data collected between different motion capture laboratories.
A study by DiCesare *et al.* (2015) showed that the three-dimensional (3D) lower limb kinematic and kinetic repeatability of a single-leg cross drop landing task presented moderate to good repeatability when tested between three independent testing centres (CMC = 0.647 – 0.956). These results proved in principle that motion capture data can be compared between laboratories when drop landing tasks are performed from fixed heights. It is unknown if similar levels of repeatability can be achieved during more mechanically demanding testing protocols like unplanned sidestepping (Donnelly *et al.*, 2012b; Brown *et al.*, 2014). The purpose of this study was to estimate the inter-laboratory repeatability of time varying, 3D lower limb kinematic estimates through the stance phase of unplanned sidestepping. It is hypothesized no statistical differences in 3D lower kinematics will be observed through the stance phase of unplanned sidestepping, and RMSE will be ≤ 5^{O}, which is an expected level of kinematic measurement uncertainty (Besier *et al.*, 2003).

METHODS: Sixteen athletes were originally recruited from the Australian Women's National Field Hockey team volunteered to participate within this multi-centre, international study between 2013 and 2014. Two testing sessions were performed at the University of Western Australia (UWA), and one at the Liverpool John Moores University (LJMU). Eight athletes (1.68 ± 0.10m, 64.0 ± 9.2 kg) completed the experimental testing procedures at one of the two UWA testing sessions, and once at the LJMU testing session (Figure 1, *left*). The participants unable to complete a re-testing session were due to de-selection, injury or availability.

For all testing sessions, the same experimental laboratory procedures and kinematic modelling protocols were performed. First, the electronic signalling system used to instruct athletes which sporting tasks (i.e., straight-line run, cross-over cut or sidestepping task) and anticipatory condition (i.e., planned vs unplanned) were mapped between testing sites (Donnelly *et al.*, 2012). Second, the same tester applied the same kinematic marker set to all participants during each testing session (Donnelly *et al*., 2012). Third, the same kinematic model, calibration trials and dynamic testing procedures were performed (Donnelly *et al.*, 2012). For the kinematic model calibration trials, participants performed a functional hip and knee protocol (Besier *et al.*, 2003). For the dynamic running and change of direction trials, approach velocities were restricted to 4.5 $m \cdot s^{-1}$ and 5.5 $m \cdot s^{-1}$, and change of direction angles to 45° (Figure 1, *middle and right*).

For the UWA testing site, kinematic marker data were recorded using a 22-camera Vicon MX/T40 system at 250Hz (Oxford Metrics, Oxford, UK) and ground reaction forces (GRF) with an AMTI force plate at 2,000Hz (AMTI, Watertown, MA). For the LJMU testing site, kinematic marker data was recorded using a 10-camera Qualisys system at 250Hz (Gothenburg, Sweden) and GRFs with a Kistler force plate at 2,000Hz (Kistler, Winterthur, Switzerland). Only the unplanned sidestepping trials were used for analysis. These kinematic data were captured, labelled and low pass filtered (14Hz) in Nexus 2.0 (Oxford Metrics, Oxford, UK) for the UWA site and QTM (Qualisys, Gothenburg, Sweden) for the LJMU site. The stance phase of sidestepping was defined as when the vertical GRF vector was greater than 10N.

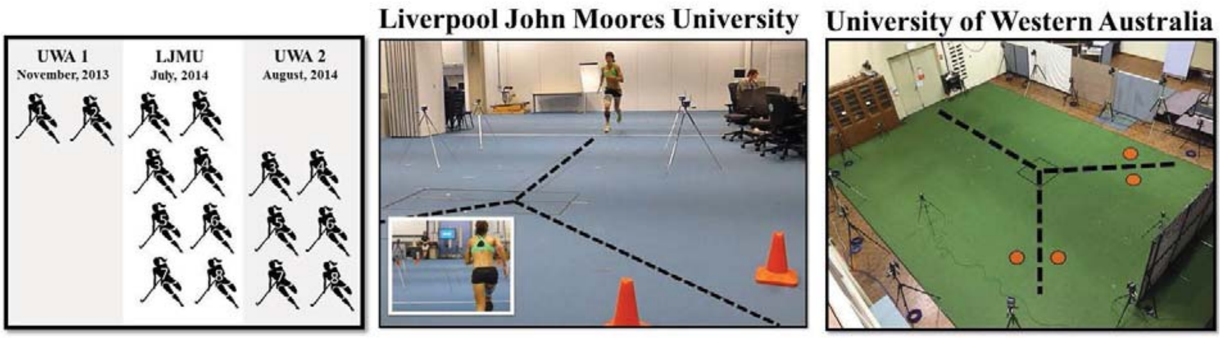

Figure 1: Overview of testing stratification (*left*) as well as LJMU (*middle*) and UWA (*right*) testing sites

All motion capture data from both testing sites were imported into Visual3D for kinematic modelling. Functional hip joint centres and knee axes were calculated in Visual3D as per Robinson & Vanrenterghem (2012). Following ISB recommendations (Wu *et al.*, 2002), the 3D lower limb kinematics of each participant's preferred stance limb were calculated. Flexion/extension, ab/adduction and int/external rotation kinematics at the hip and knee, as well as plantar/dorsi flexion kinematics at the ankle were time normalised to 100% of stance.

The time varying kinematic data collected at both testing centres were compared using SPM1D in Python (Enthought Canopy 1.5.1). A scalar test statistic (SPM {t}) was computed over stance (α = 0.05/7). Independently, RMSE between kinematic waveforms were also calculated.

RESULTS: There were no statistically significant time varying, 3D lower limb kinematic differences between the UWA and LJMU testing centres (Figure 2). The RMSE between the hip, knee and ankle kinematics were all less than or equal to 5.02°.

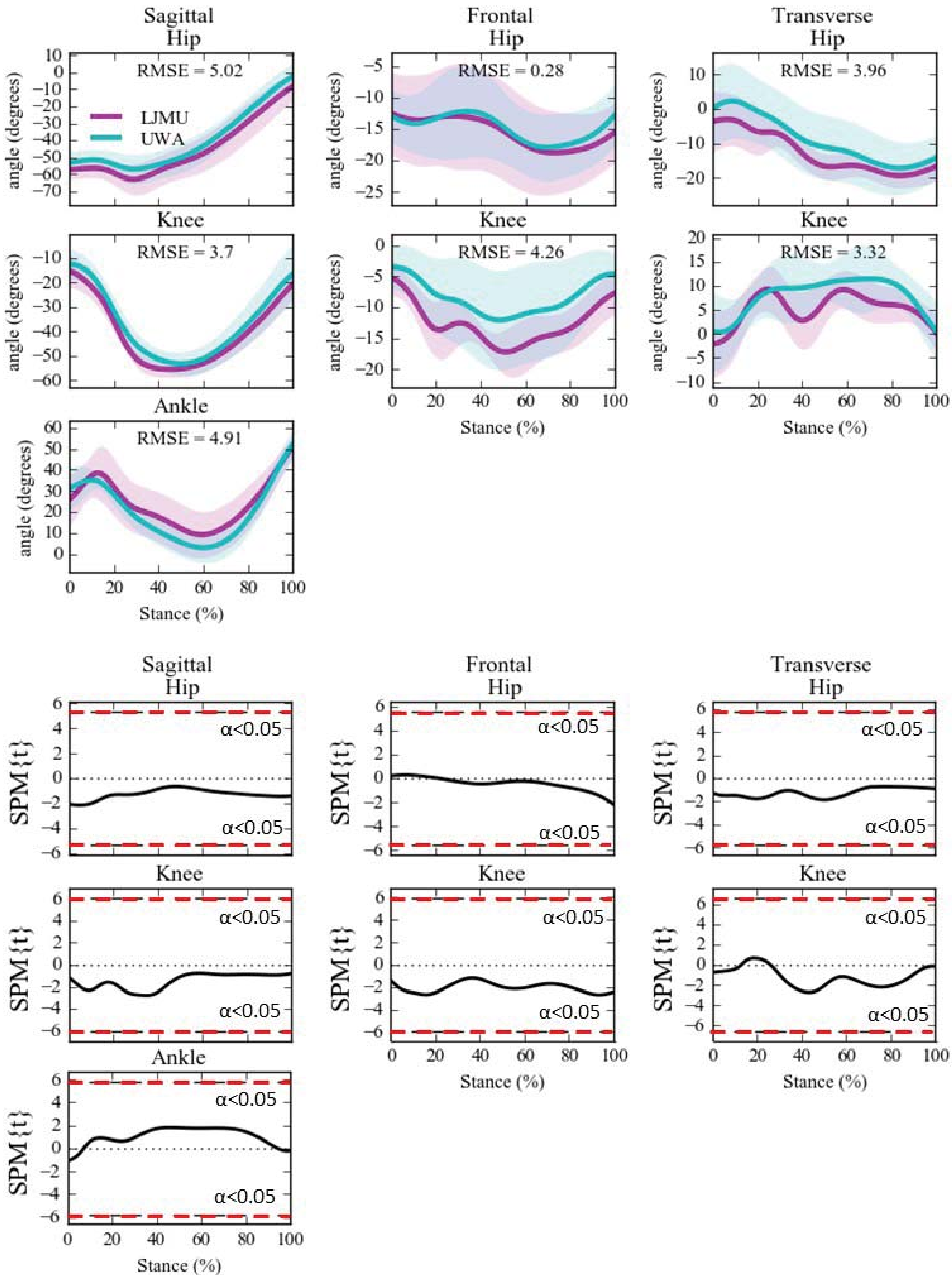

Figure 2: Time varying, 3D lower limb sidestepping kinematics during the stance phase of unplanned sidestepping (*above*) and time varying SPM{t} statistical analysis (*below*). RMSE imbedded (*above*).

DISCUSSION: In general, results agreed with our hypothesis that time varying, 3D unplanned sidestepping lower limb kinematics can be repeatedly obtained between testing centres. By showing unplanned sidestepping kinematics can be consistently obtained between centres, sport scientists can compare and share data with greater confidence. With the field of biomechanics moving towards '*big data*', these results show that we have the ability to build cloud based data repositories to start answering machine learning type research questions within the ACL injury field. These, and previous results (DiCesare *et al.*, 2015) also provide evidence for the potential of multi-centre clinical trials. This is an important factor for researchers attempting to link large volume prospective injury data to the underlying mechanics sidestepping sporting that are predictive of a non-contact ACL injury events.
As with all research studies, there are some notable limitations. First, the sample size was low, with only eight athletes completing testing sessions at both the UWA and LJMU sites. Though a noted limitation, our low RMSE kinematic measurement uncertainty (i.e., 5°) aligns with previous repeatability studies (Besier *et al.*, 2003). Second, this study was conducted on a sample of elite athletes whose motor patterns may be more automated than adolescent or sub-elite populations. Future research is recommended to assess the repeatability of this testing protocol among heterogeneous groups of team sport athletes. Lastly, only lower limb kinematic data was reported, limiting the application of findings in the context of ACL injury risk classification. We are currently analysing three dimensional knee moment data, which will be published at a future date.

CONCLUSION: The time varying unplanned sidestepping kinematics are repeatable when collected between two independent testing centres (RMSE, generally ≤ 5°) and deemed appropriate for use within multi-centre trials.

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