CASE STUDY OF AN ACCIDENTAL ANKLE TWIST: A KINEMATIC ANALYSIS USING FUNCTIONAL DATA ANALYSIS

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This study examined an accidental ankle twist occurring during a single-participant study of the effects of traction on ankle biomechanics. One male participant performed a series of randomly distributed side-cuts and turns. In the 11th trial, the participant twisted his ankle during a side-cut. As no injury occurred, another 24 side-cut trials were recorded. Functional Data Analysis (FDA) demonstrated that the ankle twist trial was characterised by a sudden increase in inversion and internal rotation along with rapid transition from plantarflexion to dorsiflexion. Velocities showed a two-step increase in internal rotation and inversion, exceeding a 300 °/s safety threshold. The shift to dorsiflexion is indicative of an unloading mechanism that likely prevented the injury. FDA revealed variations between the ankle twist and the control that could inform stud design to prevent injuries.

KEYWORDS: injury, ankle, Functional Data Analysis

INTRODUCTION High-intensity movements and changes of direction in sports are known to cause non-contact injuries in athletes. Ankle injuries are among the most common injuries in football (Woods et at., 2003). These may result in high costs to the teams due to treatment and rehabilitation, hindering the success of the teams during the season. Some understanding of the causes of non-contact ankle injuries has been obtained from the analysis of accidental injuries that occurred during laboratory testing. These studies offer essential insights into the mechanisms of injury, but authors have focussed on subjectively describing how the injury trial differs from control/reference trials (Fong et al., 2009; Kristianslund et al., 2011; Mok et al., 2011). Functional Data Analysis (FDA) offers a more comprehensive exploration of injury-related movements relative to normal analysis, given that FDA considers the movements as a whole (expressed in the form of a functional observation), rather than selected discrete points. Additionally, functional principal components analysis (fPCA) adds to the description of movement patterns by assigning a weight to the different forms of variability present in the data to be further analysed by statistical methods and confidence intervals. fPCA reduces a series of curves into patterns of variation called functional Principal Components (fPCs). These fPCs can be interpreted through further analysis of their fPC scores. fPC scores have the potential to descriptively examine individual data and indicate changes in movement behaviour related to injury. The purpose of this study was to identify the kinematic differences between control trials and an ankle twist trial during a 90° side-cut. This is the first time fPCA has been used to evaluate the kinematics of an ankle twist trial to understand the differences with baseline trials, identifying movement adaptations and informing stud design.

METHODS: The case described is part of a larger single-participant design study evaluating the effects of shoe traction on artificial turf. A male participant (height: 1.83 m, body mass: 84 kg, age:31) was recruited for the study. The participant wore Decathlon Kipsta Agility 100 firm ground shoes. The original studs were replaced with six 15 mm long cylindrical studs printed in PLA. An on-shoe marker-set consisting of 14 markers was applied to the shank and the rearfoot segment. Ankle kinematics were expressed using the ISB ankle joint recommendations. The test area was covered with a synthetic grass carpet prepared with sand and rubber crumb by Labosport Ltd. Lower leg kinematics were collected using six Motion

Capture cameras (Motion Analysis Corporation, Rohnert Park, USA) at 240 Hz. The participant started his trials 5m away from a force platform (Kistler Instruments Ltd, Hook, UK) covered with artificial turf. The participant approached the platform and was randomly instructed to perform a side-cut (90°) or turn on the right foot, depending on a set of lights located in sight. On the 11th trial, after 5 turns and 5 side-cuts randomly distributed, the participant twisted his right ankle during the stance phase of the side-cut. He was instructed to rest and after 5 minutes reported no pain, swelling or other indication of injury and wanted to continue. Therefore, testing resumed until a total of 25 trials were recorded. The stance phase of the side-cut trials (24 control, 1 ankle twist) were analysed extracting angles and angular velocities using Visual3D (C-motion, Rockville, USA). The stance phase of the side cut was considered from landing on the platform to take off. Trials were normalised and then processed in open-source fPCA code (http://www.psych.mcgill.ca/misc/fda) in MATLAB (MathWorks, Natick, USA). Each of the kinematic curves were represented using B-spline functions for the fPCA. The first three fPCs were extracted, and Varimax rotated accounting for >80 % of the variation for all variables. For visualisation, each fPC was added/subtracted from the average angle/velocity curves using '+' or a '-' lines to demonstrate variation in patterns due to the effects of adding or subtracting the fPC to the average curve (see figure 2). Each curve was given an fPC score relative to each fPC and used to evaluate how the ankle twist trial deviated from the control trials. Variables studied were: 1) Plantar/Dorsiflexion angle (°), velocity (°/s), 2) Inversion/Eversion angle (°), velocity (°/s), and 3) Internal/External rotation angle (°), velocity (°/s). A z-score (Stephens et al., 2019) for the ankle twist trial was calculated relative to the mean and standard deviation of the control trials using the following equation:

$$z = \frac{x - \mu_{control}}{\sigma_{control}}$$

Where x is the ankle twist trial score for the variable, μcontrol is the mean score of the 24 baseline trials, and σcontrol is the standard deviation in baseline trial scores. Z-scores with values of >1.96 or <-1.96 were highlighted as potentially deviating from normal side-cut behaviour as suggested in previous athlete monitoring schemes. The +/-1.96 threshold was selected as it is considered statistically significant at the 0.05 probability level.

RESULTS: Ankle angles and velocities show how the ankle twist trial differs from the other 24 side-cuts recorded (Figure 1). The ankle twist trial showed an atypical increase in inversion after 10% of the stance phase and internal rotation after 30%. Peak inversion and internal rotation were reached around 70-80% of stance. For both inversion and internal rotation angles and velocities, a two-step increase can be observed. From 65% of the stance phase onwards, it can be observed that the participant went into dorsiflexion compared to control trials that showed a decrease in plantarflexion until the end of stance. Increased inversion and internal rotation velocities can also be observed, and there was a considerable increase in dorsiflexion velocity in the second half of the stance phase. Both the increases in dorsiflexion angle and velocity are faster than in control trials.

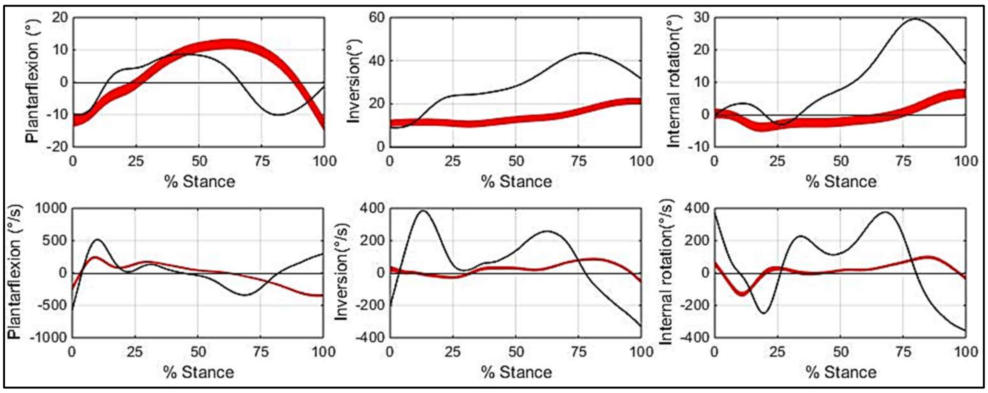

Figure 1: Top: Ankle angles 95 CI plots (red), Bottom: Ankle angular velocities 95 CI plots (red). All plots show the curve of the ankle twist trial (black).

Z-scores of the ankle twist trial indicates which fPCs depict the statistically significant kinematic changes between the ankle twist and the control and indicated variation in movement curves for all variables (Table 1). The highest z-score was observed for fPC1 of the Inversion/Eversion velocity.

Table 1. Kinematics Z-scores of the ankle twist trial when compared to the baseline trials. Scores highlighted with * exceeded the 1.96 threshold.

	Z-scores	Plantar/Dorsiflexion	Inversion/Eversion	Internal/External rotation
Ankle angles	fPC1	-2.43*	8.92*	8.43*
	fPC2	1.08	-5.42*	7.18*
	fPC3	-0.52	1.41	0.49
Ankle angular velocities	Z-scores	Plantar/Dorsiflexion	Inversion/Eversion	Internal/External rotation
	fPC1	8.59*	13.06*	2.31*
	fPC2	-0.88	-0.68	-8.68*
	fPC3	-4.02*	-0.05	3.42*

Figure 2 shows the fPCs of the analysis. In fPC1 of plantarflexion, the '-' curve describes the switch to dorsiflexion in the ankle twist trial. For inversion, fPC2 shows the increase at the beginning of stance and fPC1 shows the increase in the second half of stance. fPC2 and fPC1 of internal rotation describe similar two increases around the first and the second half of stance. For the ankle angular velocities, fPC1 of plantarflexion depicts mainly the sudden increase in velocity towards the end of the side-cut. fPC1 of inversion describes the two-step increase in inversion velocity, this is also the case of fPC2 of internal rotation velocity.

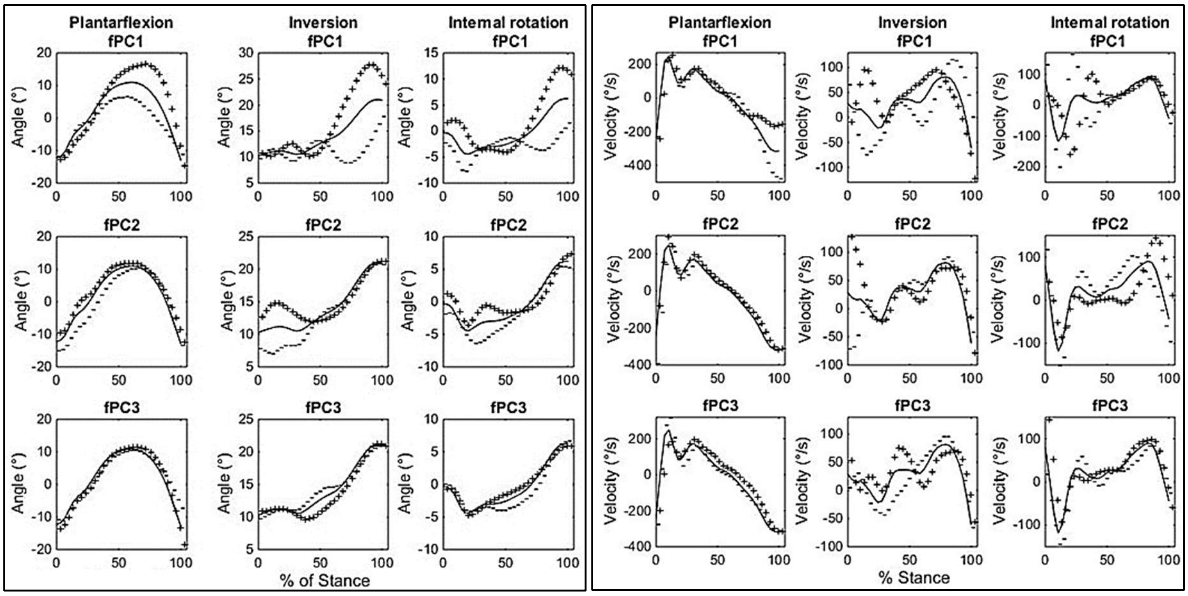

Figure 2: Scores for each fPC on the ankle angles (left) and velocities (right). The '+' line is an fPC added and the '−' is an fPC subtracted to the average curve (in black)

DISCUSSION: This study identified the kinematic differences between control trials and an ankle twist trial during a 90° side-cut using fPCA and Z-scores This study also shows the strengths of an analytical approach using fPCA to assess changes in ankle kinematics as previously done in athlete monitoring programs to evaluate changes pre- and post-surgery (Stephens et al., 2019). Ankle angles showed a marked increase in inversion and internal rotation together with a shift in flexion where the participant moves into dorsiflexion. This agrees with the findings of Kristianslund (2011) and Fong (2009), where the reported ankle sprain trials showed markedly lower plantarflexion compared to normal tests. On the other hand, the analysis on ankle injuries by Andersen (2004), pointed at a combination of increased inversion, internal rotation and plantarflexion. Even though some injury occurrences have been associated with less plantarflexion compared to baseline trials (Mok et al., 2011), in agreement with Kristianslund (2011), this case suggests that the sudden increase in dorsiflexion angle and velocity may have acted as an unloading mechanism, reducing discomfort and preventing the participant from suffering ligament injury. The sudden increase in inversion and internal rotation velocities is in agreement with the observations from Fong (2009), they differ in the observed increase in dorsiflexion velocity, which further suggests that dorsiflexion could have been an unloading mechanism. The largest z-score (13.06) was observed for fPC1 of inversion velocity, indicating that inversion velocity has the most distinctive pattern. The inversion velocity showed a peak above 300 °/s, which Chu (2010) suggested as a threshold to prevent lateral sprains. Findings agree that inversion velocity is reduced in normal side-cut trials; therefore, an unusual increase can differentiate between normal and sprain/injury risk trials. Z-scores highlighted which fPCs within the variables describe the statistically significant differences between the ankle twist trial and the control trials. A major advantage of using fPCA in this exploratory context over other conventional discrete point approaches is the ability for fPCs to identify changes in variables at different parts of the movement. fPCs of the ankle angles described the switch from plantarflexion to dorsiflexion and the two-step increase in inversion and external rotation. fPCA reinforces the sudden change in dorsiflexion during the ankle twist likely acted as an unloading mechanism, reducing the inversion and internal rotation velocity momentarily, as depicted by fPC1 of inversion velocity and fPC2 of internal rotation velocity. As differences in kinematics were observed in all three axes of motion, it is recommended that future research uses coordination analysis methods such as vector coding or bivariate functional Principal Component Analysis (bfPCA), to ascertain if indeed dorsiflexion can help to prevent injuries in sudden changes of direction.

CONCLUSION: Even though the participant did not suffer an injury, this case study complements previous reports of ankle injuries occurring in the laboratory. Similarities between this study and previous cases point at common injury patterns and differences suggest possible mechanisms that prevented an injury in this case. As the ankle twist trial showed variability in all ankle angles and velocities, z-scores helped to identify specifically how the ankle twist trial deviated from the control trials, mainly in inversion velocity and plantar/dorsiflexion, using statistical confidence intervals. It would appear from this study, as with others, that ankle inversion velocity is the main mechanism of unsafe ankle biomechanical behaviour, whereas dorsiflexion is likely to appear as an unloading mechanism. FDA serves as a useful analytical method for understanding sports injuries using a novel, exploratory and unconventional datasets, aiding athletes and coaches to identify high-risk scenarios in the daily training environment. fPCA can help to identify potential mechanisms behind injury during sudden changes of direction in real sports environments, aiding coaches and sports scientists to determine if changes in movement technique can increase the risk of injuries. Future analyses are warranted to evaluate coordination biomechanics to understand the nature of complex ankle injury scenarios.

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