biomechanics

Article

Capturing in Season Change-of-Direction Movement Pattern Change in Youth Soccer Players with Inertial Measurement Units

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Abstract: This study aimed to examine the utility of inertial measurement unit (IMU) technology to identify angle, step-specific, and side-specific differences between youth soccer players with and without a history of lower limb injury during soccer-specific field tests. Thirty-two youths (mean age 16.4 years) who were elite soccer players (Females n = 13, Males n = 19) wore IMUs during pre- and postseason soccer-specific change-of-direction assessments. A response feature analysis was used to compare the change in peak resultant acceleration of the groups at a level of significance of $p < 0.05$. Statistical analysis revealed significant differences in change of peak resultant acceleration of right leg final foot contact in a 180° pivot turn ($p = 0.012$, ES = 1.0) and a 90° cut ($p = 0.04$, ES = 0.75) between the two groups. These data suggest that players with a history of lower limb injury might experience greater angle and side-specific change within a season in peak resultant acceleration when compared with injury-free athletes. This study demonstrates that IMUs may present a useful method to analyze youth soccer players' change of direction movement after returning to play. These results can inform future studies investigating player monitoring and may prove to be a useful tool for coaches when designing individualized training programs in this population.

Keywords: change of direction movement; inertial measurement unit; youth soccer; injury

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Citation: Alanen, A.-M.; Bruce, O.L.; Benson, L.C.; Chin, M.; van den Berg, C.; Jordan, M.J.; Ferber, R.; Pasanen, K. Capturing in Season Change-of-Direction Movement Pattern Change in Youth Soccer Players with Inertial Measurement Units. *Biomechanics* **2023**, *3*, 155–165. https://doi.org/10.3390/biomechanics3010014

Academic Editor: Shaghayegh Bagheri

Received: 2 February 2023
Revised: 10 March 2023
Accepted: 16 March 2023
Published: 20 March 2023

1. Introduction

Soccer is an evasion sport that requires a multitude of physical performance capacities and soccer-specific skills [1,2]. In evasion sports, the perception–reaction coupling is a determinant of successful attacking and defending, which includes multiple fast change-of-direction (COD) maneuvers. COD ability discriminates between elite and subelite players in soccer [2]. During a soccer game, players perform approximately 700 turns and swerves of up to 360° [1]. Most of the COD movements during a game are under 90° [1], however, sharper COD angles increase joint loading [3,4] and deceleration and reacceleration requirements [5,6]. In relation to increased loading of tissues, COD movements are associated with lower limb injuries in youth and adult soccer [7–10]. For example, anterior cruciate ligament (ACL) injuries typically occur in noncontact pressing and COD situations [7]. In youth players, the highest incidence rates for soccer-related injuries have been reported in the U15 and U18 groups [11]. After an injury, the decision of readiness to return to sport is complex and related to multiple factors. On-field monitoring methods of change of direction movement have been recommended to be incorporated into standard return-to-sport criteria [12]. However, there is no current consensus on which methods would be recommended for long-term follow up of neuromuscular control or function [13].

Faster COD performance has been linked to greater horizontal and vertical braking forces during the final foot contact (FFC) [14,15]. Previous studies have also underlined the importance of penultimate foot contact (PFC – the preparatory step before final foot contact) in COD for both injury prevention and performance [16,17]. A greater proportion of braking force applied during PFC is related to faster CODs. Average horizontal ground reaction forces during PFC are significantly related to peak knee abduction moments during FFC. Quantifying lower body interlimb differences in accelerations during PFC and FFC associated with acute angle CODs may provide important information about injury risk. These differences have not been fully investigated in the scientific literature. Previous studies have shown that greater landing force asymmetry in jump tests is associated with an increased risk of lower extremity injuries in youth male soccer players [18]. In addition, previously injured professional soccer players have significant asymmetries in vertical ground reaction forces in both concentric and eccentric phases of countermovement jumping, despite being cleared to return to sport [19].

Inertial measurement units (IMUs) permit player monitoring on the field of play in game and practice situations. IMUs may provide information based on differences in accelerations related to asymmetries and individual differences during PFC and FFC in COD. Previous studies in running have found tibial accelerations to be a valid proxy for ground reaction force (GRF) during running [20–22]. These studies have looked at horizontal, vertical, and anteroposterior accelerations, however, earlier findings by Lafortune and Hennig [23] suggest that to accurately quantify the magnitude of tibial acceleration, it would be important to measure all three planes. Peak resultant acceleration has been used as a metric in running studies as a surrogate measure for impact loading with moderate to good reliability [24]. IMUs have been used to evaluate COD movement in team sports, however, consensus on sensor placement and appropriate metrics is lacking [25]. The variability of these measures on an individual or group level throughout the season or differences between previously injured and noninjured players in youth soccer has not been studied. Nevertheless, this is an important first step for identifying relevant COD parameters that can be measured with IMU technology. IMU sensor placement is also a key consideration for monitoring COD maneuvers. For example, active (e.g., eccentric muscle action) and passive (e.g., connective tissue, bone, and ligament) musculoskeletal attenuation can decrease or increase the magnitude of the impact [26,27]. This highlights the potential relationship between sensor placement and outcome measures aimed at improving performance, identifying risk for lower limb injury, and monitoring return to sport readiness after injury [26,28]. Shin-level measurements might be expected to reflect impact loading most accurately, whereas the relationship with angle-, side, and step-specific differences are unknown.

Therefore, the purpose of this study was to examine the change in peak resultant acceleration measures in a COD test for PFC and FFC in previously injured and noninjured youth female and male soccer players over the course of a soccer season. The primary aim was to evaluate the change of peak resultant acceleration, measured from shin level, within a season in similar test-retest settings to evaluate if there were significant differences between previously injured and noninjured players. Our hypothesis was that previously injured players would experience higher accelerations in cutting movements when compared with noninjured players. Testing this hypothesis of practical significance in that monitoring peak acceleration values throughout the season with IMUs could prove useful for continuous player evaluation, especially after returning to play from a lower extremity injury. Coaches could use this information for determining the need for individualized training and rehabilitation.

2. Materials and Methods

2.1. Participants

A convenience sample of two male and two female Tier 1 (top-level) U15-U17 soccer teams from a member club of the Calgary Minor Soccer Association (CMSA) were recruited for this study. These players have soccer training approximately 3 times per week with 1–2 additional strength and conditioning sessions weekly during indoor and outdoor seasons. A total of 32 players (n = 13 females, n = 19 males) finished both inseason and postseason COD tests and were included in the analysis. Players who did not consent, were currently injured, or did not perform either of the tests were excluded. Player age, playing years, position, and previous lower limb injuries (within 12 months from baseline testing) were collected with a questionnaire. Participant height (cm) was measured using a portable height measurement unit (Seca GmbH, Seca 217, Hamburg, Germany) and body mass (kg) was measured using a portable standard electronic scale (Seca GmbH, Seca 437, Hamburg, Germany). Height and body mass measurements were completed barefoot and wearing a t-shirt and shorts. Participant baseline characteristics are presented in Table 1. The study took place at the club's training facilities in Calgary, Alberta, Canada. The study ethics were approved by the Conjoint Medical Ethics Committee (REB19-0428) and all participants signed a written mature minor consent form prior to participation.

Table 1. Baseline characteristics.

	Female n = 13	**Male n = 19**
Mean age (SD)	16.5 years (0.7)	16.2 years (0.7)
Mean height (SD)	166.0 cm (6.6)	182.7 cm (11.2)
Mean body mass (SD)	59 kg (6)	66 kg (6)
Playing position		
Goalkeeper	0	2
Defender	5	6
Midfielder	4	4
Forward	4	7
Years played (Mean)	8.7	10.6
Leg dominance		
Left	0	4 (injured = 1, noninjured = 3)
Right	13 (injured = 7, noninjured = 6)	15 (injured = 9, noninjured = 6)
Previous injury [1]		
Acute injury	6 (knee = 1, ankle = 3, thigh = 2)	9 (groin = 3, ankle = 4, thigh = 2)
Overuse injury	1 (knee = 1)	1 (knee = 1)
No injuries	6	9

[1] Lower limb, within 12 months.

2.2. Testing Protocol

Players performed a soccer-specific COD test [29], twice at the club's indoor training facility. Players wore t-shirts, shorts, and soccer cleats, and tests were performed in the afternoon before the regular training session. Players followed their team's normal training schedule (soccer practice 3 times/week, strength and conditioning 1 time/week) before and after the testing sessions. Intense sessions were not scheduled prior to testing sessions. Outdoor soccer season runs from May until October and Test 1 was performed in July 2019 (inseason) and Test 2 in October 2019 (postseason). Two bidirectional maximal effort COD trials were performed at three consecutive cut angles (180° pivot turn, 135° cut, and 90° cut) (Figures 1 and 2). Before the test, players performed a supervised and structured general warmup protocol (5 min running drills including hopping and change of direction movements), led by a research assistant. Players then performed the test first at jogging speed to perform a test-specific warmup and for protocol familiarization. Players did not receive specific instructions about technical execution, in order to run and cut as naturally as possible. After the trial run, players were verbally instructed to complete the test as fast as possible. Each trial was initiated by the player performing a one-touch pass back to the research assistant (Figure 2) and was terminated by receiving a pass (Figure 2) to attempt to simulate the urgency experienced in gameplay.

Figure 1. Change of direction test: player making a left turning 180° pivot turn (PFC—left leg, FFC—right leg).

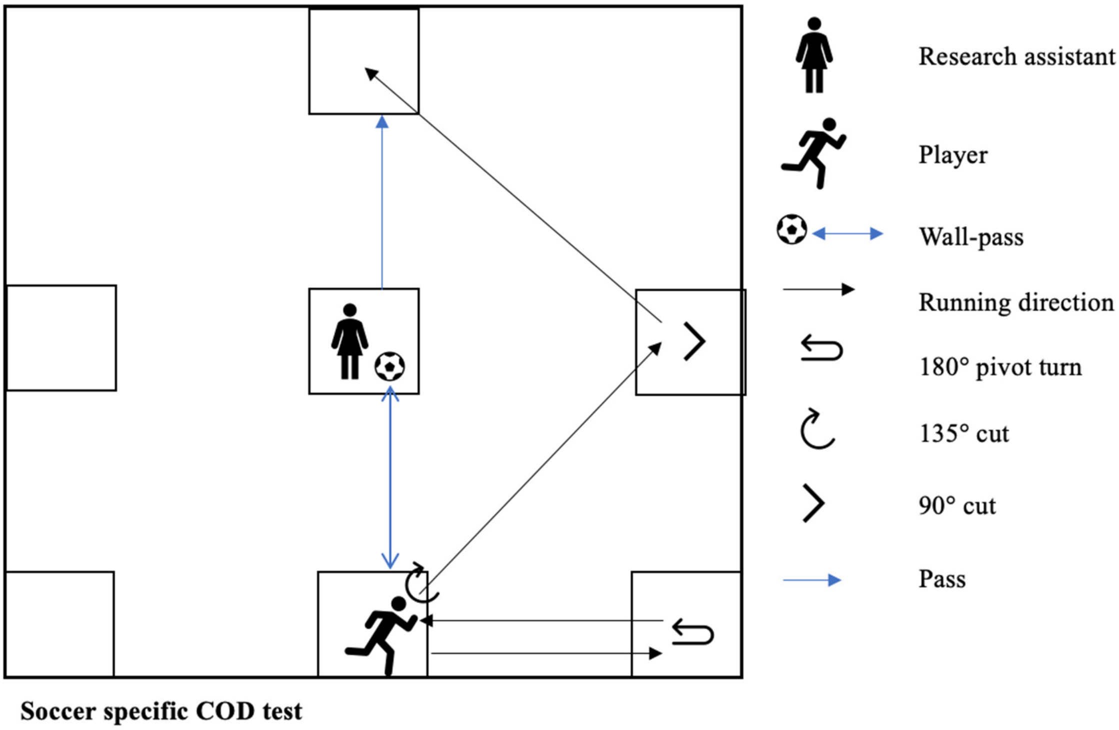

Figure 2. Map of the test, displaying cuts on the right side.

Tests that were performed incorrectly (i.e., not stepping into one of the designated cone areas when performing a COD movement) were discarded and repeated. Data were collected by research assistants who had soccer backgrounds and were trained to evaluate the tests by the experienced principal investigator. Values from the successful trials for both directions (i.e., left and right) were used in the analysis. Players needed to complete one successful trial and the trial order (left or right side first) was randomized. The penultimate foot ground contact (PFC) was defined as the last step before the step that initiates the

COD (inside leg during the turn). Final foot ground contact (FFC) was defined as the step initiating the COD (outside leg during the turn) [6,14,30].

2.3. Accelerometer Data

Wireless triaxial IMU devices (Shimmer 3 IMU (±16 g), Shimmer Sensing, Dublin, Ireland) were used to collect the data with a sampling frequency of 200 Hz (IMU mass = 23.6 g). Each player had an IMU positioned on both of their shins with elastic straps, on top of the lower third of the tibia. The IMUs were placed by research assistants who were trained for the task by the lead investigator. The devices were calibrated prior to each test by turning each sensing axis 180°, based on manufacturer recommendations (shimmersensing.com/product/shimmer-9dof-calibration/).

2.4. Injury Data

Players reported information about previous injuries in the prebaseline questionnaire. Injuries were reported based on the anatomical location, severity, type, and time of injury. In case of missing or inadequate information, the players were contacted by phone by a research assistant, to ensure data accuracy. Only the injuries that had happened within 12 months before the baseline testing were included. If the players had more than one lower limb injury in this period, the most recent one was used in this analysis (Table 1). Four players reported left leg dominance (kicking) leg and only one injury was reported for the left leg. Due to the fact that most players were right-leg dominant, and to simplify the interpretation of the analysis, it was decided to compare left and right legs and disregard the leg dominance.

2.5. Data Processing

All trials were video recorded with a 4K camera (Sony, FDR-AX53, 120fps) that was set on a tripod, 5 m behind the setting. The videos were downloaded into the Dartfish video-analysis tool (Dartfish Live S) and tagged for start and stop of PFC and FFC for all angles (180°, 135°, and 90°). The tagging was done by two independent reviewers, who had previous experience with video analysis. To identify touch down and toe off, zooming was used. The tagged video was synchronized with IMU data using a custom script in MATLAB (Version R2011b, MathWorks Inc., Natick, MA, USA).

The start and end of both PFC and FFC were tagged for each limb and each COD angle. The start of the step was defined as the video frame when the foot touched the ground and ended at the video frame when the foot left the ground. Accelerometer data were filtered with a 60 Hz cut-off frequency using a fourth-order Butterworth low-pass filter in MATLAB (Version R2011b, MathWorks Inc., Natick, MA, USA). The cut-off frequency was chosen based on Fast Fourier analysis, which showed that 99% of signal power was retained below 60 Hz. Peak resultant acceleration for PFC and FFC were extracted and used for analysis.

2.6. Statistical Analysis

The normal distribution of peak resultant acceleration values was determined with a Shapiro–Wilk's test, which confirmed the normality of the PRA values. Response feature analysis [31,32] was used to compare the change of peak resultant acceleration in the two tests between the previously injured and noninjured groups. For the response feature analysis, the change in peak resultant acceleration for each participant in each cut and step was calculated and Welch's *t*-test was used to compare the mean change of peak resultant acceleration between the injured and noninjured groups. The significance level was set at $p < 0.05$. Standardized effect sizes (Cohen's d) were calculated and interpreted as trivial ($d \leq 0.20$), small ($0.20 \leq d \leq 0.60$), moderate ($0.61 \leq d \leq 0.1.20$), large ($1.21 \leq d \leq 2.0$), very large ($2.01 \leq d \leq 4.0$), or near perfect ($d \geq 4.0$). Tables 2 and 3 include the adjusted p-values (Bonferroni correction) for multiple comparisons. The peak resultant acceleration data is shown in Table 3. R-software (R-foundation) was used for statistical analysis. All R-packages that were used for data analysis are presented in Appendix A.

Table 2. Response feature analysis (mean changes) for peak resultant acceleration in all CODs.

	Injured, N = 17 [1]	Noninjured, N = 15 [1]	Cohen's *d*	95% CI [2]	*p*-Value [3]	Adjusted *p*-Value [4]
180° Pivot Turns	Mean Change between the Tests (m/s²)					
FFC right leg	33 (36)	−6 (43)	1.0	0.23, 1.7	0.012*	0.14
PFC right leg	1 (65)	3 (80)	−0.02	−0.72, 0.67	>0.9	>0.9
FFC left leg	3 (36)	10 (70)	−0.13	−0.82, 0.57	0.7	>0.9
PFC left leg	14 (53)	−9 (49)	0.44	−0.26, 1.1	0.2	>0.9
135° cuts						
FFC right leg	16 (41)	10 (71)	0.10	−0.60, 0.79	0.8	>0.9
PFC right leg	7 (64)	−2 (96)	0.11	−0.58, 0.81	0.8	>0.9
FFC left leg	1 (54)	8 (30)	−0.17	−0.86, 0.53	0.6	>0.9
PFC left leg	−1 (51)	−8 (56)	0.14	−0.56, 0.83	0.7	>0.9
90° cuts						
FFC right leg	20 (60)	−17 (35)	0.75	0.02, 1.5	0.039 *	0.5
PFC right leg	20 (56)	0 (86)	0.28	−0.42, 1.0	0.4	>0.9
FFC left leg	18 (80)	19 (43)	−0.01	−0.70, 0.69	>0.9	>0.9
PFC left leg	5 (65)	0 (50)	0.08	−0.61, 0.78	0.8	>0.9

* Statistically significant; [1] Mean (SD); [2] CI = Confidence Interval for Cohen's *d*; [3] Welch's Two Sample *t*-test; [4] Bonferroni correction for multiple testing.

Table 3. Comparison of injured and noninjured leg peak resultant acceleration (m/s²) differences in the previously injured group.

COD	Test 1						Test 2					
	PRA (m/s²)						PRA (m/s²)					
	Injured Leg, N = 17 [1]	Noninjured Leg, N = 17 [1]	Cohen's *d* [2]	95% CI [2,3]	*p*-Value [4]	Adjusted *p*-Value [5]	Injured Leg, N = 17 [1]	Noninjured Leg, N = 17 [1]	Cohen's *d* [2]	95% CI [2,3]	*p*-Value [4]	Adjusted *p*-Value [5]
FFC180	178 (48)	158 (52)	0.39	−0.29, 1.1	0.3	>0.9	145 (47)	154 (49)	−0.18	−0.85, 0.50	0.6	>0.9
PFC180	156 (53)	180 (61)	−0.43	−1.1, 0.25	0.2	>0.9	159 (43)	162 (37)	−0.10	−0.77, 0.58	0.8	>0.9
FFC135	164 (51)	159 (58)	0.09	−0.58, 0.77	0.8	>0.9	151 (38)	156 (43)	−0.14	−0.81, 0.54	0.7	>0.9
PFC135	136 (49)	163 (58)	-0.52	−1.2, 0.17	0.14	0.9	140 (45)	152 (44)	−0.29	−1.0, 0.39	0.4	>0.9
FFC90	178 (63)	186 (63)	-0.13	−0.81, 0.54	0.7	>0.9	156 (37)	170 (46)	−0.33	−1.0, 0.35	0.3	>0.9
PFC90	173 (64)	183 (61)	-0.16	−0.83, 0.52	0.7	>0.9	157 (46)	175 (37)	−0.43	−1.1, 0.25	0.2	>0.9

[1] Mean (SD); [2] Cohen's *d*; [3] CI = Confidence Interval; [4] Welch's Two Sample *t*-test; [5] Bonferroni correction for multiple testing.

3. Results

The mean change in peak resultant acceleration between the two tests for previously injured and noninjured groups showed a statistically significant difference ($p < 0.05$) in FFC 180° and FF C90° when turning left (right foot as final contact foot) with moderate effect sizes of 1.0 and 0.75 (Table 2, Figure 3).

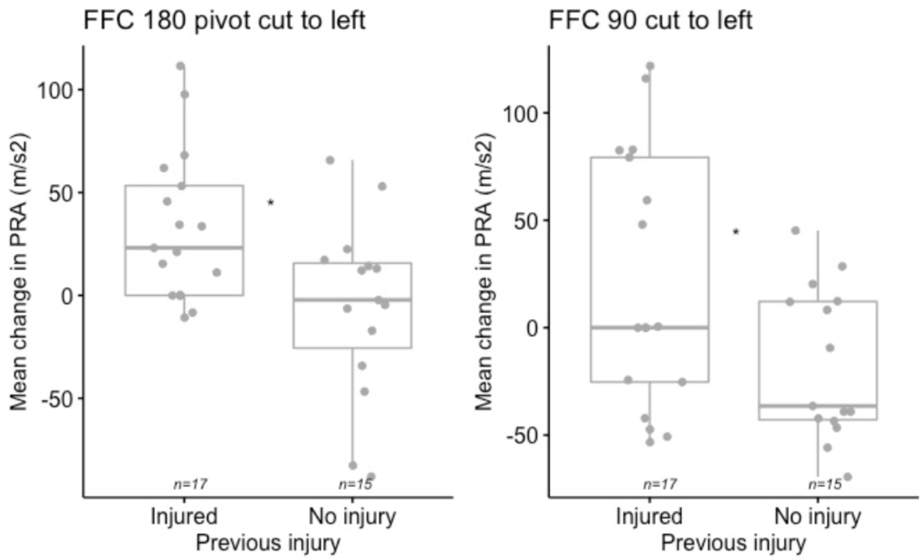

Figure 3. Boxplots of differences in peak resultant acceleration (PRA) change between previously injured and noninjured groups for the final foot contact (FFC) in 180° and 90° degree left change of direction (COD) maneuvers.

Positive mean change (m/s^2) indicates that the peak resultant accelerations in the second test were lower. For the other angles or steps, there were no statistically significant differences ($p > 0.05$), and the effect sizes were from small to trivial (≤ 0.5).

When considering comparisons between injured and noninjured legs, within the previously injured group, no statistical differences between the injured limb and noninjured limb were found ($p > 0.05$). (Table 3).

In addition, notable inseason variation in peak resultant acceleration (m/s^2) was visible for both the injured and the noninjured groups between the two tests, with standard deviations between 50–100 m/s^2 (Table 3, Figure 4).

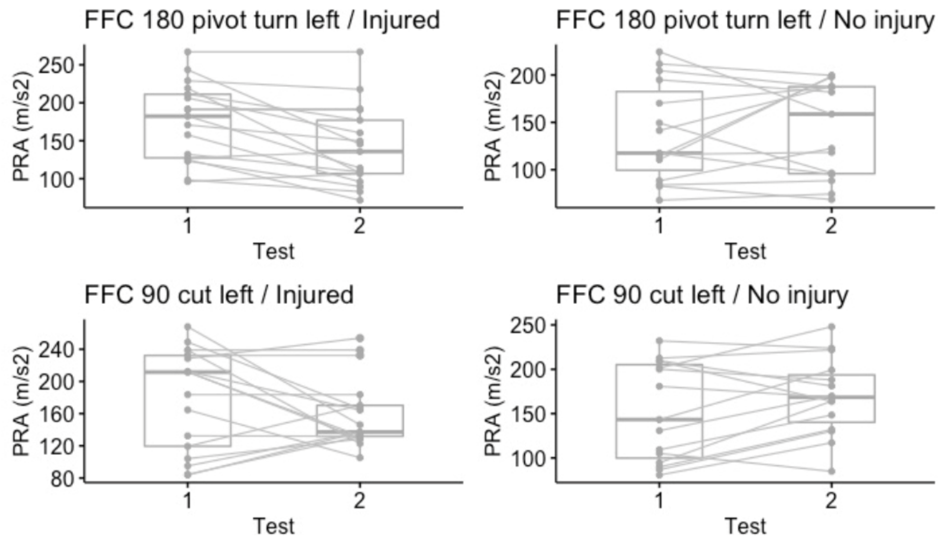

Figure 4. Boxplots showing the individual change of the peak resultant acceleration (PRA) (m/s^2) for the final foot contact (FFC) in 180° pivot turns and 90° cuts between Test 1 and Test 2.

4. Discussion

Altered biomechanics are known to be associated with higher injury risks. To the authors' knowledge, this is the first study to assess changes of the side-, angle- and step-specific peak resultant accelerations during change of direction movements The primary aim of this study was to evaluate within-season change in tibial peak-resultant accelerations during COD tests in previously injured and noninjured players. Substantial inseason variation in peak resultant acceleration between the two timepoints was observed using IMU sensors during PFC and FFC in the COD movements. The injured group seemed to have a greater change in peak resultant accelerations between the tests when performing a 180° pivot cut to the left. In the left turning 90° cut there was also a statistically significant difference between the groups, however, during this COD, the injury-free group had higher peak resultant accelerations in the second test and the previously injured group slightly lower. Additionally, high within-subject variation was observed between test one and test two.

IMU assessments without the orientation of the device have been used to monitor peak resultant accelerations outside laboratory conditions in previous studies [33]. Giandolini et al. [34] concluded that speed and terrain increased the variability of peak resultant acceleration values considerably, and in a study by Simons et al. [35] intraday variability of peak resultant acceleration was good but interday (one week apart) was moderate to good in hopping, drop landings, and rebound jumps. The results of our study show variability in the individual peak resultant acceleration between the two tests. Similar results have been reported also in previous studies examining jumping and landing movements [36,37]. Jump-landing tasks are commonly used to evaluate return-to-play readiness. In the study by Hanzlikova et al. [38], the authors concluded that rotated jump landing tasks were more closely related to cutting kinematics and more proper to use when identifying risky movement patterns. As cutting is a more complex movement than jumping and landing, the high within-subject variation reflected in our data is not surprising.

Previous studies [36,39] have shown that asymmetries are task and variable specific and tend to change when measured several times during the season. The results of our study suggest that there might be differences between previously injured and noninjured players in tibial peak resultant acceleration while executing cutting movements, especially for 180° pivot turn and 90° cut during final foot contact when turning left. All but one of the players had a previous injury to their right limb, which could explain why only left turning cuts (right foot as outside leg during the cut) were different. COD ability is commonly tested in soccer with agility tests that evaluate the time to complete a specific task, including varying numbers (from 2 to over 10) and varying angles of CODs [40]. One hundred and eighty degree and 90° cutting angles are commonly used in COD testing protocols [40] and running drills, which could easily be complemented with IMUs. In order to evaluate if peak resultant acceleration could be used to determine the individual baseline, future studies should follow the variability more frequently, for example throughout the season. In addition, injury patterns and risks vary depending on the adolescent growth spurt [41,42], underlining the importance of continuous movement pattern follow up and research for this age group.

Injured players had consistently higher mean peak resultant acceleration values in both tests which is also in line with the previous literature. In addition, when looking at the injured limb vs. noninjured limb in the injured group, the peak resultant accelerations for FFC during sharper CODs (180° and 135°) were higher in the first test. Altered biomechanics, such as more flexed positions in the knee and hip, in the injured limb, can increase the ground impact resulting in higher peak resultant acceleration values [43]. This was supported by our findings on higher peak resultant acceleration values in the injured group and higher peak resultant acceleration values in the injured limb within the injured group. Based on our findings, peak resultant accelerations measured with IMUs could provide a feasible method to screen within-season changes in injured players during rehabilitation and provide useful information to evaluate return to sport readiness. However, this would require reliable measures for "normal" baseline values of peak resultant acceleration. Until the reliability of this test is more thoroughly assessed longitudinally, the usefulness of this method for routine athlete monitoring in soccer players remains unclear. In addition, more injury-specific research is warranted. The injured group in our study had several different types of lower limb injuries with varying times of injury.

There were several limitations to our study. First, biological maturation was not assessed, which may have a profound influence on the agility performance of adolescent soccer players. Further, it is possible that biological maturation may have changed between the two testing sessions. There was an increase in physical test performance due to maturation around peak height velocity in adolescent athletes—especially when looking at consistent acceleration, deceleration, and COD ability. Additionally, the approach speed was not known and since COD ability is both angle and approach velocity dependent [44], this information could be crucial when comparing in-season differences. The players were instructed to run as fast as possible, though the running speed was not objectively controlled between the two testing sessions. This would not explain the differences between injured and noninjured groups but would most likely explain the substantial individual variability. Variation between and within subjects in approach velocity would affect also peak resultant accelerations. A larger sample size, and especially a more homogeneous group of injured players, would be recommended for future studies. The testing protocol used in this study is also lacking perception and decision-making factors; the comparison of differences in injured and noninjured players' peak resultant acceleration values should be monitored in game-like situations. Finally, there are several variables that can cause a change in results measured two months apart. Therefore, a reliability analysis of this testing method should be conducted with a shorter time between testing dates, to be able to reliably recommend a similar approach in the future.

5. Conclusions

IMU-measured tibial peak resultant accelerations revealed large between- and within-individual variability between soccer-specific COD tests during the season. This can be affected by several factors that were not controlled in this study, such as training and growth status. However, there seem to be differences between previously injured and noninjured groups, which are angle- and side-specific. Against our hypothesis, players in the injured group exhibited decreased peak resultant acceleration values between the tests in FFC for the previously injured leg in the 180° pivot turn condition. For the 90° cut, the noninjured group exhibited increased values in the second test. COD tests complemented with IMUs could provide a time-efficient tool for practitioners to screen large player groups throughout the season and guide recommendations for individualized training.

Author Contributions: Conceptualization, A.-M.A., L.C.B., M.J.J., R.F. and K.P.; methodology, A.-M.A., L.C.B., M.J.J., R.F. and K.P.; software, L.C.B. and O.L.B.; validation, A.-M.A., L.C.B. and O.L.B.; formal analysis, A.-M.A., L.C.B. and O.L.B.; investigation, A.-M.A., L.C.B., M.C. and C.v.d.B.; resources, R.F. and K.P.; data curation, C.v.d.B. and M.C.; writing—original draft preparation, A.-M.A.; writing—review and editing, A.-M.A. and K.P.; visualization, A.-M.A.; supervision, K.P.; project administration, K.P.; funding acquisition, K.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received internal funding from the Faculty of Kinesiology, University of Calgary—Dean's Doctoral Scholarship, and external funding from Sport Institute Foundation of Finland—Research Grant 20220021. Partial funding was provided by the NSERC Wearable Technology Research and Collaboration (WeTRAC) CREATE training program.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Conjoint Medical Ethics Committee (REB19-0428).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The participants of this study did not provide consent for their data to be shared publicly.

Acknowledgments: The authors would like to thank Stephen Chaudhary, Meghan Critchley, Manraj Kang, Larissa Taddei, Stacey Sick, Haley Young, and Valeriya Volkova for their assistance with data collection.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

R Package	Version
ggplot2	3.3.3
dplyr	1.0.5
readxl	1.3.1
tidyverse	1.3.1
gtsummary	1.4.1

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