Differences in cricket fast bowling kinematics between grass and artificial surface pitches

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ABSTRACT

Cricket fast bowling training and research are often conducted on artificial turf, while matches are played on natural grass. It is unknown if technique differs between the different surfaces, therefore the aim of this study was to explore if fast bowling technique differed between surfaces. Shoe slip distance and kinematic and temporal parameters previously associated with ball release velocity and lumbar bone stress injury were determined for 8 male sub-elite fast bowlers using three-dimensional motion analysis on grass and artificial surfaces. Paired t-test and statistical parametric mapping were used to identify differences in technique between surfaces. Significantly greater slip distance was observed during back and front foot contact on the artificial surface compared to bowling on the grass surface. No kinematic or temporal parameter significantly differed between surfaces, therefore fast bowling technique is likely similar between grass and artificial surfaces, and previous research utilising artificial surfaces in fast bowling research is likely to be valid.

Keywords: shoe-surface interaction, statistical parametric mapping, seam bowling, pace bowling

INTRODUCTION

Cricket fast bowling is a dynamic, asymmetrical movement pattern that requires coordinated, forceful, whole-body movements to achieve high ball release velocity. This technique may be repeated in excess of 300 times in a week and 2500 times per year [1] across limited over matches (maximum of 24 or 60 deliveries per innings for 20 over and 50 over formats), multi-day cricket matches (unlimited deliveries per innings) and training sessions. Fast bowlers often aim to maximise ball release velocity to reduce the time in which batters must respond to the trajectory of the delivery, which may increase the likelihood of obtaining wickets and restricting runs. Thus, to date, most performance research has focused on relationships between technique and ball release velocity. Lumbar bone stress injury is the most prevalent injury in cricket that occurs most commonly in fast bowlers [2], with bowling technique implicated in the aetiology of this injury [3].

Fast bowling is comprised of three continuous phases: the run up commences on a natural grass outfield; the preparation phase, where bowlers bound from the natural grass outfield onto a natural turf pitch; the delivery phase where the bowling action is produced starting when the back foot (ipsilateral to bowling arm) lands and ends with ball release. Natural turf cricket grounds typically comprise an array of hard, clay-soil central pitches (the square), where the focus is on ball bounce, set in the centre of a more freely draining sand/soil outfield where the performance focus is on ball roll. Grass height on the pitch is short, typically 4-8 mm, increasing to approximately 15 mm on the outfield. During the delivery phase, the bowler is interacting with the pitch, which is typically constructed from high clay content soil, and maintained to a high dry bulk density (1.8-2.0 g/cm^{-3}), to create optimum ball rebound [4,5]. Cricket pitches demonstrate a rebound hardness of greater than 250 G, and can exceed 400 G, considerably greater than the natural surface used for football (soccer) or rugby, which has a rebound hardness of 85-125 G [6]. Variations in grass length, grass coverage, soil profiles and water content of the pitch may influence traction and shoe-surface interaction [4].

While professional cricket is played on a natural grass surface, training, junior cricket, recreational cricket and research studies in indoor environments often utilise an artificial turf surface, with shock-pad, laid over an engineered surface. It is unknown if the playing surface affects fast bowling technique factors previously associated with performance and lumbar bone stress injury.

Previous research has highlighted specific kinematic and temporal variables which associate with ball release velocity in male fast bowlers. Worthington et al. [7] demonstrated that 74% of the variation in ball release velocity in elite male fast bowlers by run-up speed, shoulder flexion angle at front foot contact, knee flexion angle at ball release, and the magnitude of thoracolumbar flexion between front foot contact and ball release. These findings have been corroborated in subsequent research, with anterior-posterior mass centre velocity being positively associated with ball release velocity prior to back foot contact, or during the delivery phase [8–12], a negative relationship between knee flexion angle at ball release and ball release velocity [10,12–15] and greater bowling arm shoulder flexion during the front foot contact phase (front foot contact to ball release) also being associated with faster ball release velocity [15]. Further studies have indicated negative relationships between ball release velocity and average anterior-posterior mass centre acceleration during the front foot contact phase [8,11] and back foot contact (until front foot contact) phases [8,9], as well as the duration the delivery phase, back foot contact and front foot contact phases [9].

Prior research has also demonstrated kinematic variables associated with lumbar bone stress injury in male fast bowlers. Alway et al. [3] studied 50 elite fast bowlers, 39 of whom subsequently sustained lumbar bone stress injury in the 2 years following biomechanical analysis. Using a binary logistic regression, this study demonstrated that a model containing rear hip flexion at back foot contact and lumbopelvic flexion at front foot contact correctly classified 88% of participants into the correct lumbar bone stress injury or uninjured group (Lumbar bone stress injury: 97% correctly classified. Uninjured: 55% correctly classified).

Greater hip flexion at back foot contact and lumbopelvic extension at front foot contact was associated with increased likelihood of lumbar bone stress injury. This study also identified significant differences between groups based on 2-year prospective lumbar bone stress injury status. Fast bowlers with lumbar bone stress injury demonstrated greater rear knee flexion, ipsilateral thoracolumbar side flexion and contralateral thoracolumbar rotation angles at back foot contact; greater front hip flexion and anterior pelvic tilt angles at front foot contact; and less contralateral thoracolumbar side flexion angle at ball release. In addition, contralateral lumbopelvic side flexion has often been linked to lumbar bone stress injury [3,16–18] and explains the typically unilateral presentation of the injury [1]. Fast bowlers with non-specific lower back injury were found to have significantly less front hip flexion and greater contralateral trunk side flexion at front foot contact, and significantly greater contralateral pelvic rotation and contralateral thoracolumbar side flexion at ball release [17].

To date, most fast bowling biomechanical research exploring factors related to performance and lumbar bone stress injury has been conducted on artificial turf surfaces. At the professional level, all cricket matches are played on natural compacted clay-soil surfaces, with a grass length of 4-8 mm, with fast bowlers wearing specific 6 mm spiked cricket footwear to assist with enhancing traction with the surface. Players often train indoors, typically on artificial turf surfaces, with fast bowlers typically wearing athletic non-spiked footwear so to not damage the surface. Different shoe-surface interactions may elicit different frictional properties, which may contribute to technique changes in a variety of activities. For example, different movement strategies at the ankle and knee have been observed between playing surfaces during a single leg triple hop [19], cutting [20–23], and a tennis side jump and running forehand stroke [24]. Despite this, no research has explored differences in fast bowling technique between grass and artificial surfaces.

This study is exploratory in nature, therefore no hypotheses is posed. The aim of this study was to compare fast bowling technique parameters, including kinematics, kinetics and temporal parameters previously associated with performance and lumbar bone stress injury, between natural grass and artificial turf surfaces.

METHODS

Participants:

Due to resource constraints (time available to collect data in an outdoor environment), eight sub-elite (University Centre of Cricketing Excellence, comparable to Professional English County 2nd XI) fast bowlers (mean ± SD; age: 19.4 ± 1.3 years; height: 1.83 ± 0.09 m; body mass: 77.4 ± 9.1 kg) provided written informed consent to participate in the study after ethical approval was obtained from the Loughborough University Ethics Advisory Committee (Reference number G00-P1).

Data Collection:

Following a self-selected warm-up, fast bowlers performed a minimum of six maximal effort deliveries targeting a “good length” (4 – 7 m from the batter’s stumps [25]), which was recorded using an 18-camera Vicon Motion Analysis System (OMG Plc, Oxford, United Kingdom) operating at 300 Hz. Data were collected initially outdoors on a grass pitch, and then repeated the next day on an indoor 11 mm pile height, monofilament polyethylene fibre carpet artificial surface (JMS Cricket CoolPlus 11-2-40, Polytan Sports Surfaces, Barrow-on-Soar, UK), laid over a 15 mm thickness bound granular rubber shockpad, over concrete floor at the bowling end (SIS Pitches, Maryport, UK), with space for a full run-up. For each session, forty-seven retroreflective 14 mm markers were attached to each fast bowler, positioned over bony landmarks in accordance with the marker set used by Worthington et al. by the same researcher in both sessions for all participants. In addition, a 2 cm^2 piece of reflective tape was added to the ball to determine the instant of release and velocity. Static and dynamic (lumbopelvic side flexion range of motion) calibration trials were performed for each participant, allowing body segment length and neutral spine position to be calculated [18]. Ninety-five anthropometric measurements were taken enabling participant-specific segmental inertia parameters to be determined for each bowler [26].

Data Processing

The six trials per participant and condition were manually labelled and processed using Vicon Nexus software (OMG Plc). Marker trajectories were filtered using a recursive fourth-order low-pass Butterworth filter with a cutoff frequency of 30 Hz as determined by residual analysis [27]. Joint centres, global coordinate systems, local reference frames, global segment orientations and joint angles were calculated according to the methodology of Worthington et al. [7]. Accordingly, the anatomical position of the knees, hips, pelvis, shoulder and neutral positions of the lumbar and thoracic spine corresponded to 180°, with flexion and contralateral side flexion, twist and rotation (in respect to bowling hand) corresponding to < 180°, and extension and ipsilateral side flexion, twist and rotation corresponding to > 180°. Back and front foot contact were defined as the frame where any foot marker trajectory deviated due to interaction with the ground. Ball release was determined from the frame in which the distance between the ball marker and the midpoint of a pair of markers over the wrist exceeded 20 mm relative to the previous frame [7]. Joint angles were determined for parameters associated with lumbar bone stress injury and ball release velocity (Table 1) and time normalised to 101 points for each of back foot and front foot contact phases (0 – 100% of each phase) via linear length normalization [28]. The back foot contact phase is defined as back foot contact to front foot contact, while the front foot contact phase is defined as front foot contact to ball release. The six selected trial per player-condition combination were ensemble averaged to produce a single time-normalised curve for each phase of the movement.

Table 1: Kinematic variables associated with ball release velocity and lumbar bone stress injury in cricket fast bowlers analysed in the current study

Outcome	Kinematic variable
Ball release velocity	Bowling shoulder flexion
	Front knee flexion
	Thoracolumbar flexion
Lumbar bone stress injury	Rear hip flexion
	Lumbopelvic flexion
	Rear knee flexion
	Thoracolumbar side flexion
	Thoracolumbar rotation
	Front hip flexion
	Pelvic tilt
	Lumbopelvic side flexion
	Pelvic twist

Time across the delivery, back foot and front foot contact phases were recorded. Ball release velocity was calculated over a period of 10 frames (0.033 s) from the instant of ball release using the equations of constant acceleration. Run-up velocity (in the global anterior-posterior direction) was calculated as the mean anterior-posterior mass center velocity over a period of 18 frames (0.060 s) immediately before the instant of back foot contact [7]. Anterior-posterior whole body and pelvic mass centre accelerations were calculated through their change in velocity during back foot and front foot contact phases, divided by the phase time [9]. Slip distance was calculated as the average distance (in the global anterior-posterior direction) of the 4 markers placed on the shoe (superior hallux interphalangeal joint, medial hallux metatarsophalangeal joint, lateral 5th toe metatarsophalangeal joint and heel) from foot contact to the instant in which velocity of the marker was 0, or its lowest value before velocity increased [29].

Statistical Analysis

The six trials analysed were averaged for each parameter to provide representative data for each bowler. Normality of ball release velocity, run-up velocity, time of the delivery phase, back foot and front foot contact phases, acceleration of the whole body and pelvic mass centre acceleration and slip distance were assessed using Shapiro-Wilk tests (SPSS v29, IBM, Armonk, NY). Paired t-tests were used to compare normally distributed variables between surfaces, and if the assumption of normality was violated, the nonparametric Mann Whitney *U* test was performed instead. Cohen's d, with 95% confidence intervals, was also calculated to determine the effect size of the difference (Small: $d \geq 0.20$; Medium: $d \geq 0.50$; Large: $d \geq 0.80$) [30]. All time-normalised one-dimensional joint angle waveforms were compared between the different surfaces via statistical parametric mapping (SPM) paired samples t-test (spm1d.org, T. Pataky) within Matlab (Version R2022b, The MathWorks Inc., Natick, MA). For each continuous one-dimensional test, the critical test statistic and supra-threshold cluster were reported where the test statistic field exceeded the critical threshold. An alpha level of 0.05 was set *a priori* for all tests with no control for multiple comparisons due to the exploratory nature of the study. Finally, additional exploratory analysis of the normalised time-series joint angle plots of mean difference of joint angles were explored for occasions where the 95% confidence interval of the mean difference did not include zero, indicating possible differences in technique between surfaces.

RESULTS

No statistically significant differences were found between groups for ball release velocity, run-up velocity, time variables or mass centre accelerations ($p = 0.28 – 0.81$, $d = 0.09 – 0.41$, 95% CI of effect size = -0.61 – 1.12, Table 2). There was statistically significantly greater slip distance with large effect sizes at both back foot contact ($p < 0.01$, $d = 2.12$, 95% CI of effect size = 0.81 – 3.39, Table 2) and front foot contact ($p = 0.01$, $d = 1.16$, 95% CI of effect size = 0.23 – 2.06, Table 2) on the artificial surface compared with the grass surface.

Table 2: Mean ± SD, mean difference ± SD, *p* value and effect size (95% CI) for slip distance, ball release velocity, run up velocity, phase time and whole body and pelvic mass centre accelerations between grass and artificial surfaces

Parameter	Grass	Artificial	Mean Difference	*p*	Effect Size
BFC Slip Distance (cm)	**7.1 ± 3.5**	**8.8 ± 3.6**	**-1.7 ± 0.8**	**0.001**	**2.12 (0.81 – 3.39)**
FFC Slip Distance (cm)	**6.6 ± 2.5**	**8.7 ± 2.0**	**– 2.1 ± 1.8**	**0.013**	**1.16 (0.23 – 2.06)**
Ball release velocity (m/s^{-1})	30.2 ± 2.2	30.4 ± 2.2	-0.1 ± 0.5	0.438	0.29 (-0.43 – 0.99)
Run-Up Velocity (m/s^{-1})	5.4 ± 0.4	5.4 ± 0.3	-0.1 ± 0.2	0.282	0.41 (-0.33 – 1.12)
BFC – BR (s)	0.328 ± 0.032	0.327 ± 0.038	0.001 ± 0.008	0.813	0.09 (-0.61 – 0.78)
BFC – FFC (s)	0.218 ± 0.033	0.215 ± 0.034	0.003 ± 0.007	0.336	0.36 (-0.36 – 1.07)
FFC – BR (s)	0.110 ± 0.008	0.111 ± 0.009	-0.002 ± 0.005	0.331	0.37 (-0.36 – 1.08)
Whole body mass centre acceleration BFC – FFC (m/s^{-2})	-3.7 ± 0.6	-3.8 ± 0.7	0.1 ± 0.4	0.622	0.18 (-0.52 – 0.88)
Whole body mass centre acceleration FFC – BR (m/s^{-2})	-11.0 ± 2.5	-11.4 ± 1.8	0.5 ± 1.5	0.448	0.28 (-0.43 – 0.98)
Pelvic mass centre acceleration BFC – FFC (m/s^{-2})	1.2 ± 1.0	1.0 ± 1.3	0.2 ± 0.8	0.567	0.21 (-0.50 – 0.91)
Pelvic mass centre acceleration FFC – BR (m/s^{-2})	-25.5 ± 4.3	-26.4 ± 4.2	0.9 ± 2.7	0.410	0.31 (-0.31, 1.01)

BOLD indicates significant difference between groups. Effect sizes: small (*d* ≥ 0.2), medium (*d* ≥ 0.5) and large (*d* ≥ 0.8) BFC: Back foot contact. FFC: Front foot contact. BR: Ball Release.

No significant statistical differences in bowling technique were observed during back or front foot phases (p > 0.05).

Additional exploratory analysis of the normalised time-series mean difference joint angle plots demonstrated non-statistically significant differences during the back foot contact phase of: less knee flexion (phase time: 99 – 100%, peak mean difference = 4°, Figure 1); greater ipsilateral pelvic twist (phase time: 73 – 100%, peak mean difference = 7°, Figure 1); and greater contralateral lumbopelvic side flexion (phase time: 43 – 48%, peak mean difference 2°, Figure 1) when bowling on the artificial surface compared with grass. Compared with bowling on grass, bowling on the artificial surface demonstrated non-statistically significant differences during the front foot contact phase of: greater rear knee flexion (phase time: 0 – 21%, peak mean difference = 3°, Figure 2); less rear hip flexion (phase time: 50 – 87%, peak mean difference = 2°, Figure 2); greater ipsilateral pelvic twist (phase time: 0 – 49%, peak mean difference = 7°, Figure 3); greater contralateral lumbopelvic side flexion (phase time: 92 – 100%, peak mean difference = 4°, Figure 3); and less ipsilateral thoracolumbar rotation (phase time: 85 – 100 – %, peak mean difference = 2°; Figure 3). No other kinematic differences were observed between surfaces. During the back foot contact phase this included: rear knee flexion, rear hip flexion, front hip flexion, pelvic tilt, lumbopelvic flexion, thoracolumbar flexion, thoracolumbar side flexion, thoracolumbar rotation and bowling shoulder flexion (Appendix 1a). During the front foot contact phase this included: Front knee flexion, front hip flexion, pelvic tilt, lumbopelvic flexion, thoracolumbar flexion, thoracolumbar side flexion and bowling shoulder flexion (Appendix 1b).

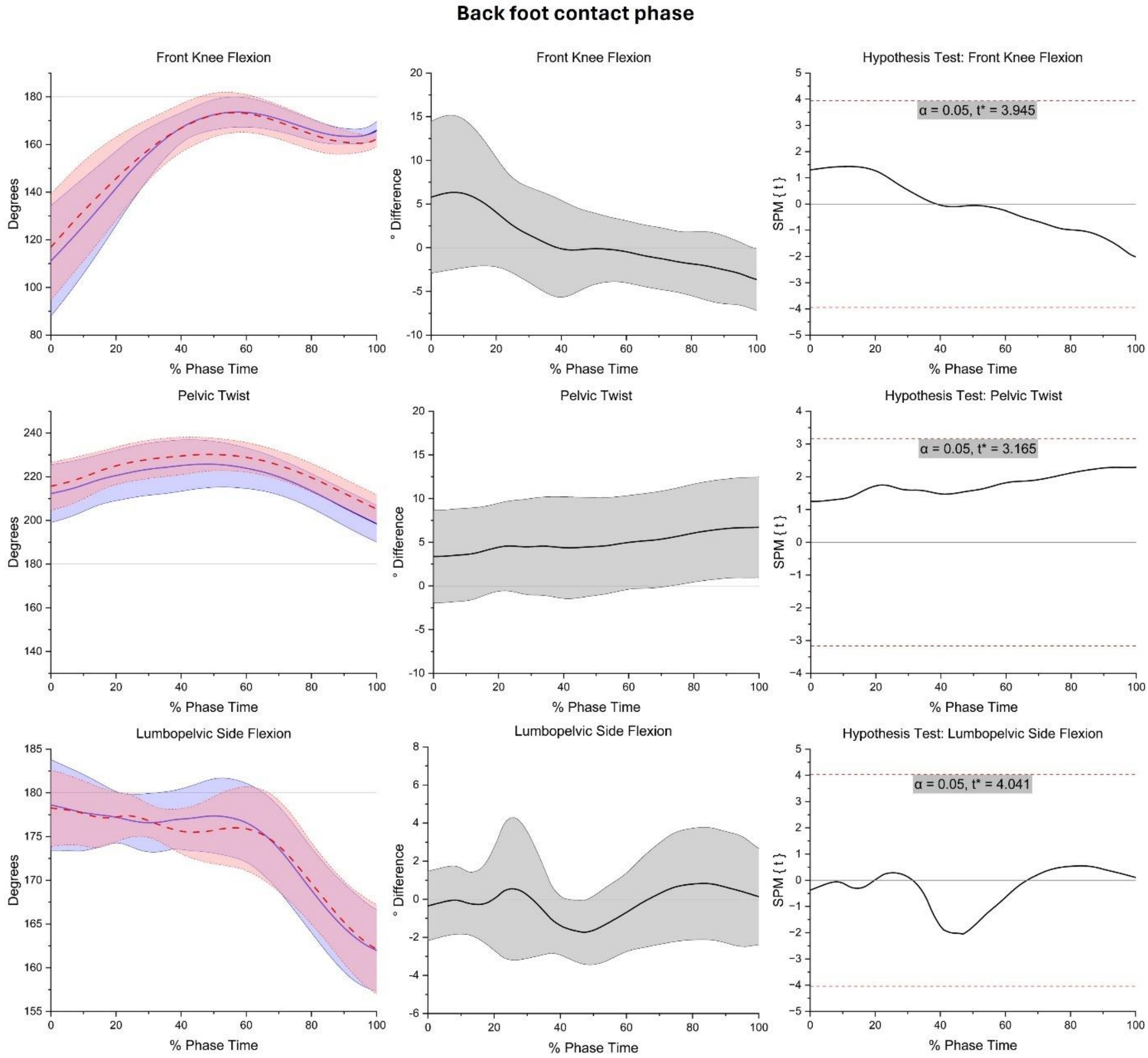

Figure 1: Mean (95% CI) normalised time-series data (Grass: Blue solid lines; Artificial: Red dashed lines), mean difference (95% CI) and statistical parametric mapping analysis of front knee flexion, pelvic twist and lumbopelvic side flexion during the back foot contact phase between artificial and grass surfaces. Positive mean difference value indicates less knee flexion, greater ipsilateral pelvic twist and less contralateral lumbopelvic side flexion on the artificial surface. The right-hand aspect of each row indicates statistical significance if the black *t*-statistic crosses the red dashed critical threshold.

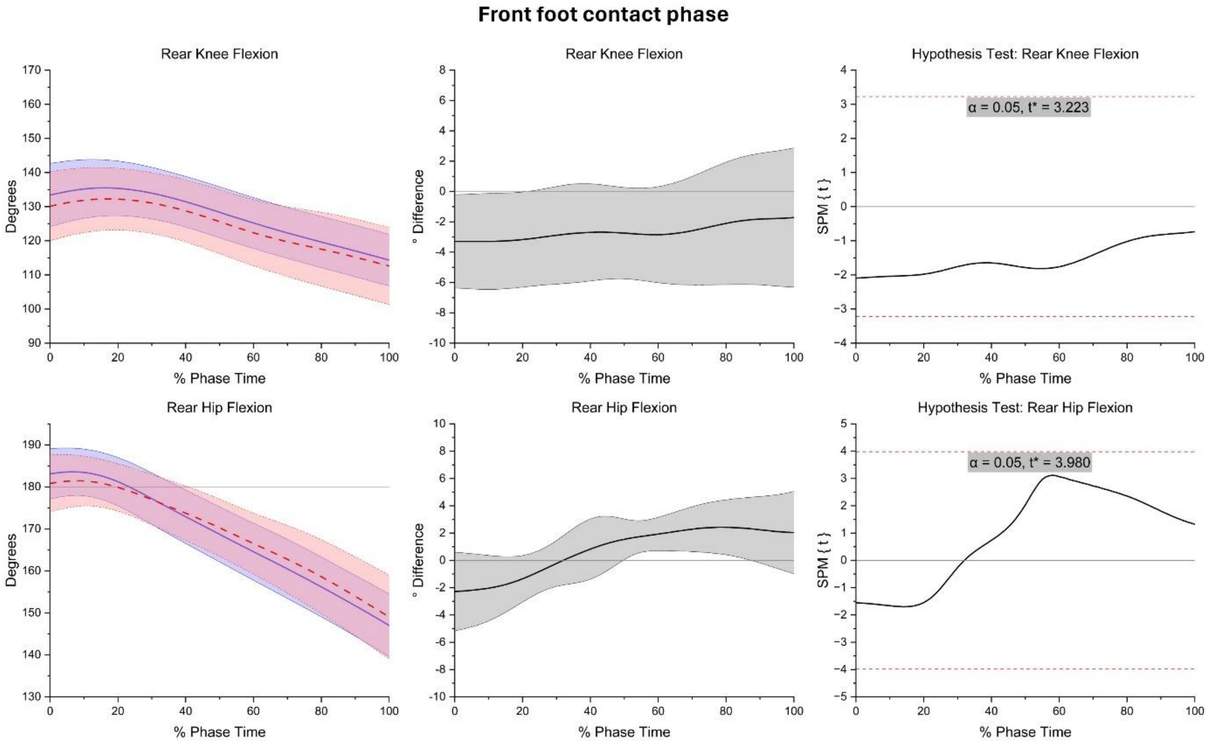

Figure 2: Mean (95% CI) normalised time-series data (Grass: Blue solid lines; Artificial: Red dashed lines), mean difference (95% CI) and statistical parametric mapping analysis of rear knee flexion and rear hip flexion during the front foot contact phase between artificial and grass surfaces. Positive mean difference value indicates less knee and hip flexion on the artificial surface. The right-hand aspect of each row indicates statistical significance if the black *t*-statistic crosses the red dashed critical threshold.

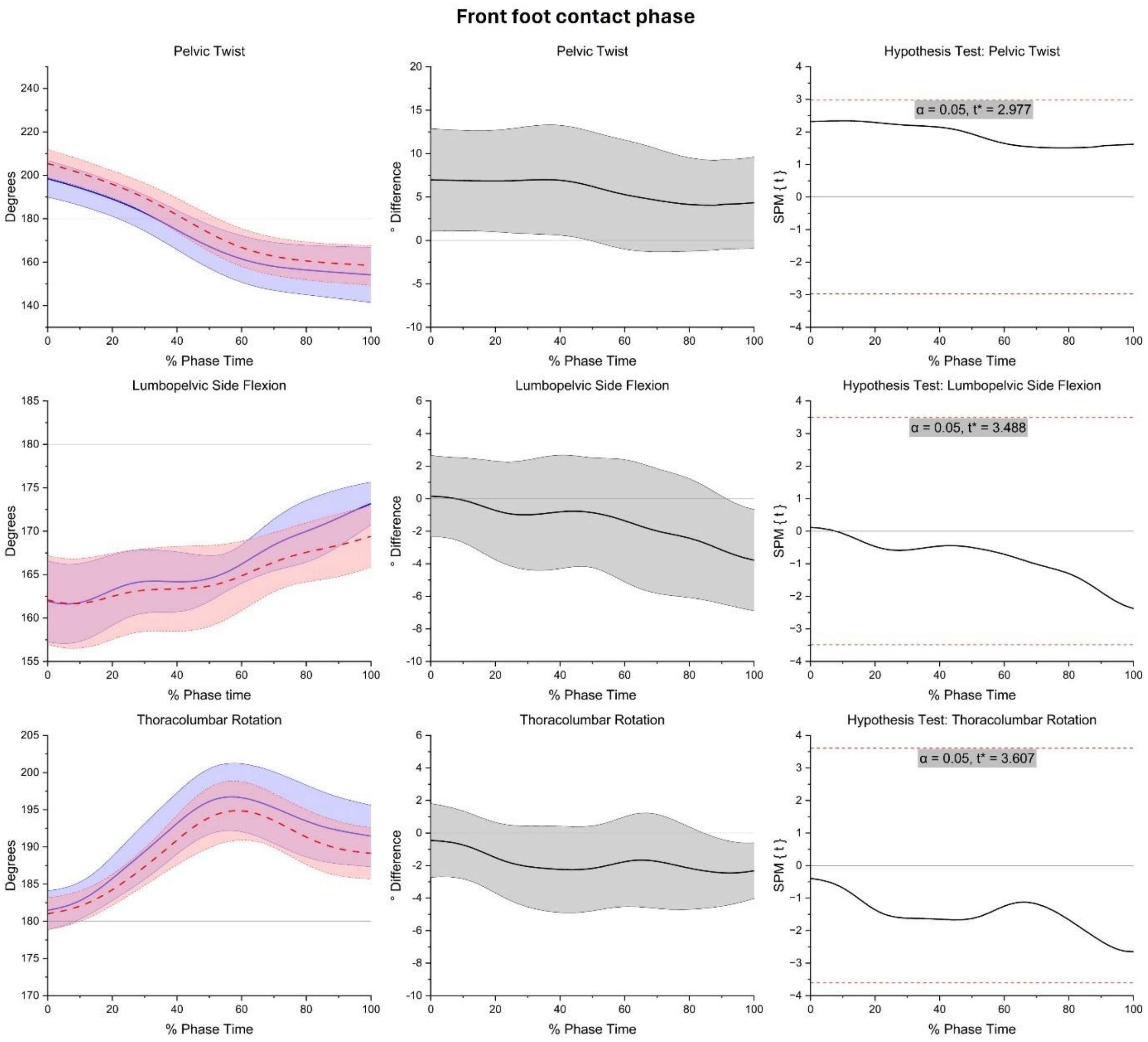

Figure 3: Mean (95% CI) normalised time-series data (Grass: Blue solid lines; Artificial: Red dashed lines), mean difference (95% CI) and statistical parametric mapping analysis of pelvic twist, lumbopelvic side flexion and thoracolumbar rotation during the front foot contact phase between artificial and grass surfaces. Positive mean difference value indicates greater ipsilateral pelvic twist, less contralateral lumbopelvic side flexion and greater ipsilateral thoracolumbar rotation on the artificial surfaces. The right-hand aspect of each row indicates statistical significance if the black *t*-statistic crosses the red dashed critical threshold.

DISCUSSION AND IMPLICATION

The aim of this study was to investigate if there are differences in key fast bowling performance and lumbar bone stress injury related technique parameters between bowling on natural grass and artificial turf surfaces. The main finding of the study is that there are no statistically significant differences between surface conditions in kinematic or temporal parameters previously associated with performance and lumbar bone stress injury.

The only statistically significant difference observed in the current study was the magnitude of slip at both back and front foot contact, where greater slip was observed on the artificial surface (Table 2). This is a likely consequence of the differing traction between surfaces, where the friction between the non-spiked athletic footwear and the artificial surface is lower than that of the spiked fast bowling specific footwear and grass. Previous research has demonstrated that changes in traction can influence frontal and transverse plane lower limb movement strategies. For example, during a cutting movement, there is greater ankle inversion throughout the movement on high traction surfaces compared to medium or low traction surfaces [22], and on artificial turf compared with grass turf [23], and when wearing high traction footwear [31]. In addition, during cutting tasks there is greater peak knee internal rotation on grass turf compared with artificial turf [23], as well as increased ankle plantarflexion and ankle internal rotation during the landing phase in high traction footwear compared with low traction footwear [31]. Further, greater foot inversion angle at touchdown and decreased medio-lateral foot translation was observed in a turning task in high traction footwear compared with low traction footwear [32]. Ecological dynamics describes the interaction between task, environmental and organismic constraints [33]. Previous research has indicated that cricket fast bowlers are able adjust technique in order to find a movement solution to maintain performance characteristics where the constraints may change from trial to trial [34,35]. In the current study, a small non-significant difference (where the 95% confidence interval of the mean difference did not include zero) in pelvic twist was observed, with the pelvis orientated more ipsilaterally in the late back foot (73 – 100%) and early front foot (0 – 49%) phases when bowling on the artificial surface. It is plausible that this change in movement strategy, potentially coupled with changes in lower limb movement, organise the body as such to permit thoracolumbar flexion and shoulder extension in the front foot contact phase to be unaffected by the change in surface, therefore maintaining ball release velocity.

It is also plausible that while less slip was observed at foot contacts on the natural grass surface, that the foot itself may slide within the shoe to a similar magnitude to the slip observed on the artificial surface, which may result in similar kinematics between surfaces. Future research is required to understand the foot-shoe-surface interface in cricket fast bowling.

Previous research has identified rear hip flexion at back foot contact and lumbopelvic flexion at front foot contact to be the best predictors of subsequent lumbar bone stress injury [3]. In the current study, there was a non-significant difference towards greater rear hip flexion between 50 – 87% of the front foot contact phase while bowling on the grass surface (Figure 2). This is unlikely to influence lumbar bone stress injury risk as this occurs significantly after back foot contact and does not have to support the entire mass of the fast bowler. Other technical factors previously identified as possible contributors to lumbar bone stress injury or low back pain either demonstrated no differences in technique between surfaces, including lumbopelvic flexion, front hip flexion, pelvic tilt and thoracolumbar side flexion or demonstrated small non-significant differences between surfaces which occurred at different time periods to those previous associated with lumbar bone stress injury. Examples of this include, thoracolumbar rotation (Figure 3), lumbopelvic side flexion (Figure 1 and 3), rear knee flexion (Figure 2) and pelvic twist (Figure 1, Figure 3). As a result, it is plausible to suggest that lumbar bone stress injury risk as a result of fast bowling kinematics may not differ between bowling on artificial turf and natural grass surfaces, and these deliveries should be included as part of any workload monitoring. The current study did not measure ground reaction forces, but it is possible that the differing shoe-surface interaction between surfaces may affect vertical and horizontal ground reaction forces, which are known to be high at front foot contact [12]. While ground reaction forces are not associated with lumbar bone stress injury [3], they may influence risk of other injuries, particularly to the lower limb [36].

No significant differences between bowling on the different surfaces were found for any temporal or kinematic parameter previously associated with performance or lumbar bone stress injury. This suggests that it is possible that the fast-bowling movement is similar between grass and artificial surfaces, therefore the artificial surface is a reliable and suitable surface for developing fast bowling technique and is unlikely to be detrimental to developing ball release velocity or, influence risk of lumbar bone stress injury. In addition, studies exploring temporal and kinematic variables and their association to performance and lumbar bone stress injury are unlikely to be invalidated by using an artificial surface. Although surfaces in the current study were characterised as natural grass and artificial, these are two examples of these surface types and may not be representative of all natural grass or artificial cricket surfaces (although typical of those used in professional cricket in England and Wales). The range of natural turf surfaces, influenced by soil types, grass types, soil moisture content and surface management [4], and the range of artificial surfaces, influenced by carpet materials, pile length, shock pads and sub-layers, mean that the results of this study should be limited to the surfaces tested and may not apply to other surfaces or environment.

Limitations of the current study include the small sample size, which likely underpowered the current study. The sample size was substantially impacted by the number of available bowlers available in the timeframe the outdoor environment was available, and the maximum number of fast bowlers who could complete both sessions. Results should therefore be interpreted with caution. Variability in placement of retroreflective markers between bowling sessions may have contributed to kinematic differences between each condition [37], although attempts were to mitigate these with the use of the same skilled researcher attaching markers and repeated static and dynamic calibration trials in each condition. There is intra-individual variability within any human movement [38], however previous kinematic studies in cricket fast bowling have demonstrated low intra-individual variability between deliveries [7], particularly in proximal segments [35], suggesting that the average of six trials used in the current study will provide a good representation of individual technique. No alpha corrections were employed to control for multiple comparisons due to the exploratory nature of the study. Therefore, results should be interpreted with caution. Future research should explore if bowling kinematics and kinetics differ across cricket pitches of different characteristics, differ in-game compared to under laboratory conditions, and if IMU derived segmental accelerations differ between different surfaces.

Conclusion

Fast bowling on an artificial grass carpet surface is representative of the technique used on natural grass, despite likely differences in shoe-surface interactions. Therefore, it is plausible to suggest that bowling technique on artificial turf surfaces compliments grass sessions without any detrimental effect to performance or lumbar bone stress injury risk, and further suggests previous research exploring relationships between fast bowling technique and performance and lumbar bone stress injury is valid. Further research is required to corroborate the findings of the current study, and to understand any differences regarding the foot-shoe-ground interface in cricket fast bowlers.

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Disclosure

The authors report that there are no competing interests to declare

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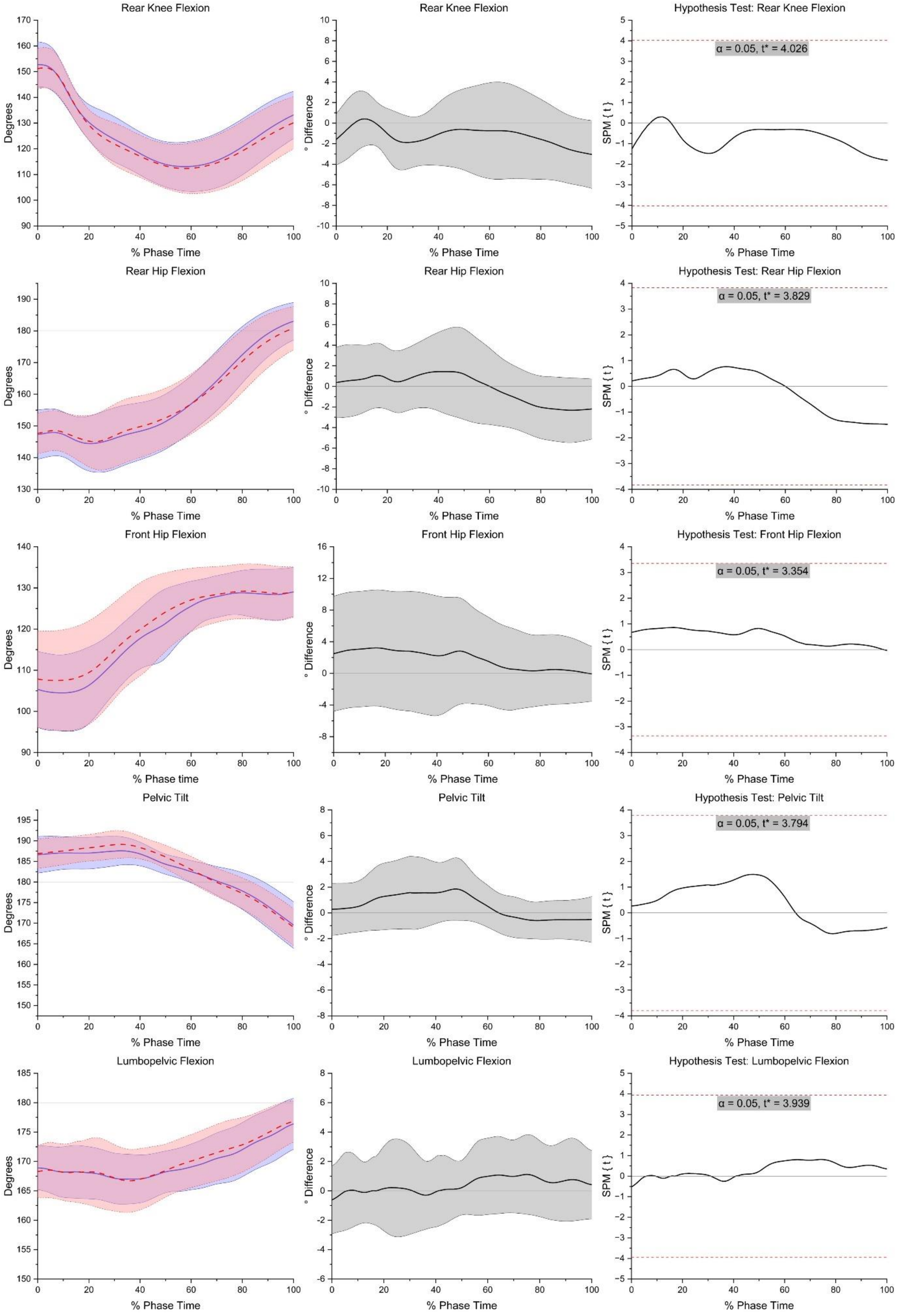
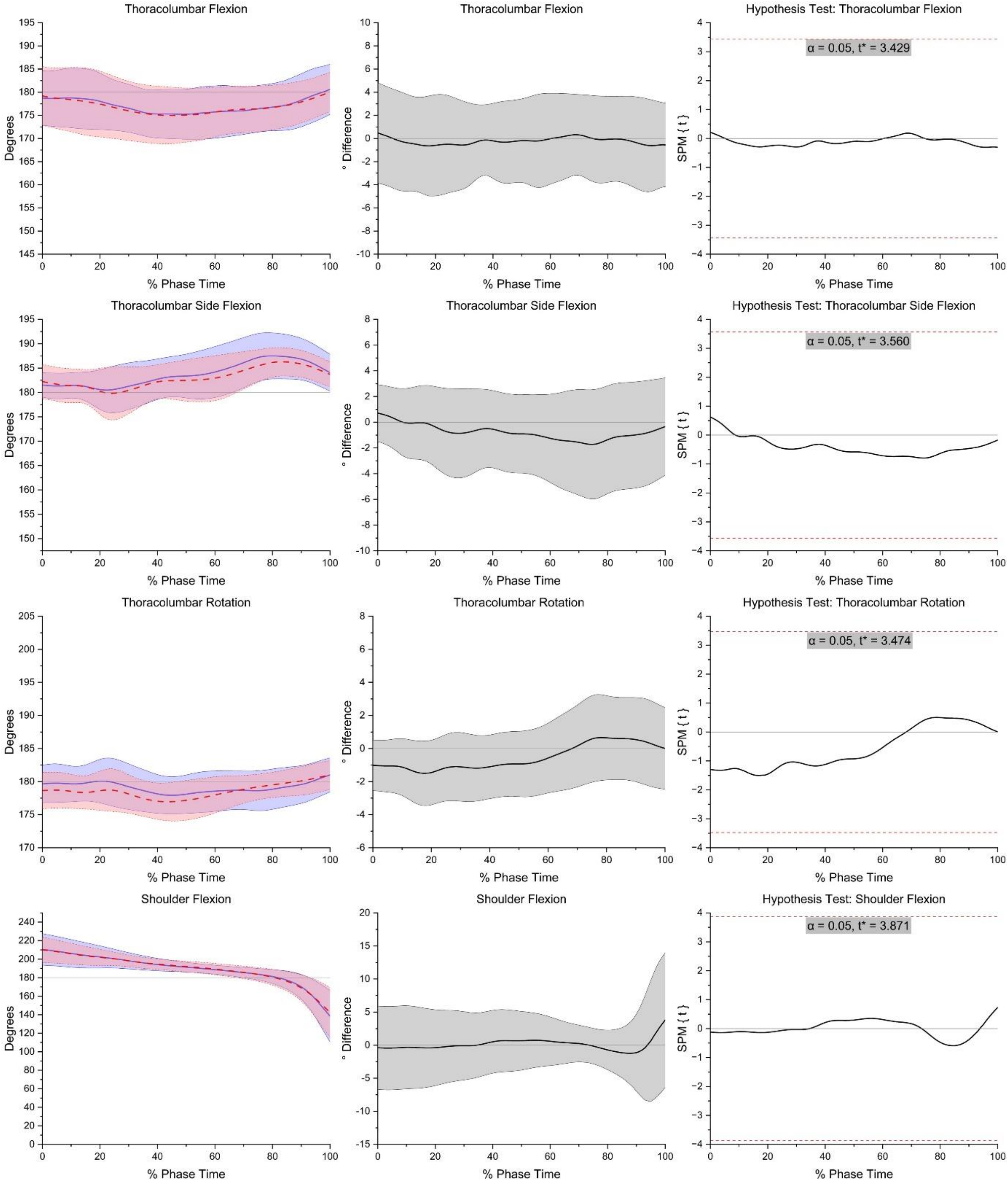
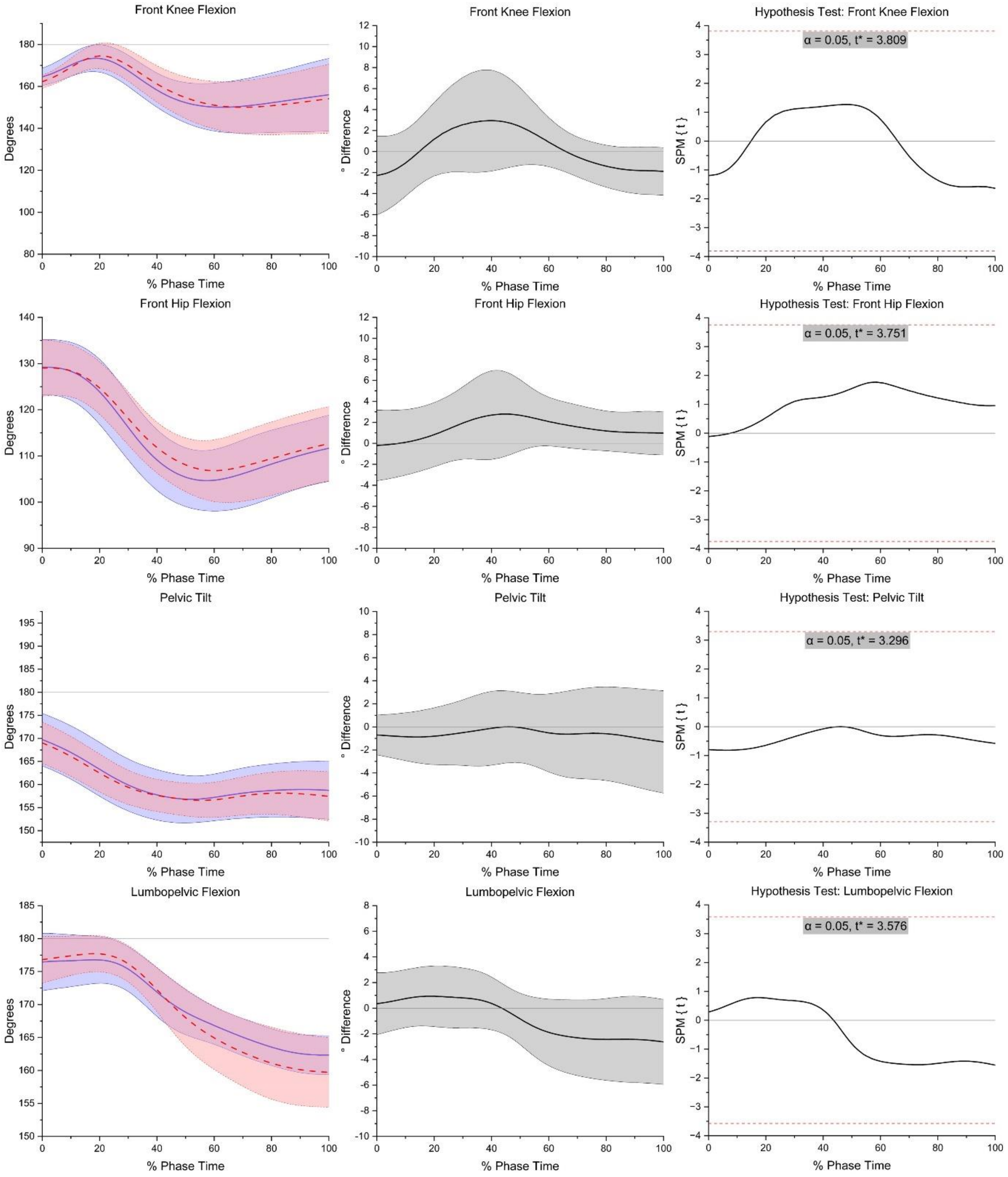
Appendix 1a: Back foot contact phase

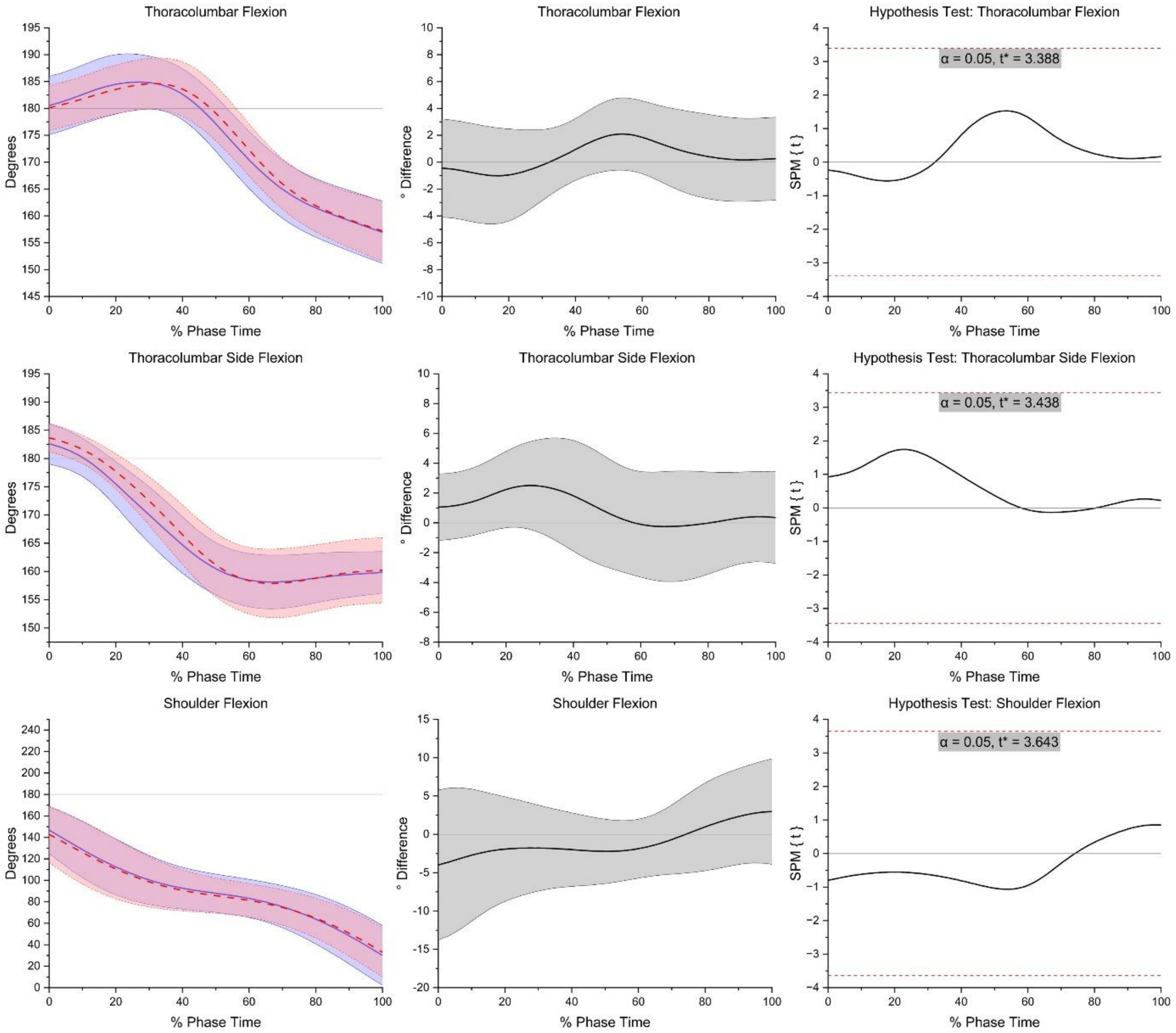




Appendix 1a: Mean (95% CI) normalised time-series data (Grass: Blue solid lines; Artificial: Red dashed lines), mean difference (95% CI) and statistical parametric mapping analysis of rear knee flexion, rear hip flexion, front hip flexion, pelvic tilt, lumbopelvic flexion, thoracolumbar flexion, thoracolumbar side flexion, thoracolumbar rotation and bowling shoulder flexion during the back foot contact phase between artificial and grass surfaces. Positive mean difference value indicates less knee, hip, lumbopelvic and thoracolumbar flexion (with the exception of the shoulder, where a positive value indicates greater flexion), greater posterior pelvic tilt, and greater ipsilateral thoracolumbar side flexion and rotation.

Appendix 1b: Front foot contact phase





Appendix 1b: Mean (95% CI) normalised time-series data (Grass: Blue solid lines; Artificial: Red dashed lines), mean difference (95% CI) and statistical parametric mapping analysis of front knee flexion, front hip flexion, pelvic tilt, lumbopelvic flexion, thoracolumbar flexion, thoracolumbar side flexion, and bowling shoulder flexion during the front foot contact phase between artificial and grass surfaces. Positive mean difference value indicates less knee, hip, lumbopelvic and thoracolumbar flexion (with the exception of the shoulder, where a positive value indicates greater flexion), less anterior pelvic tilt, and less contralateral side flexion.