UNIVERSITY OF WEST LONDON
The Career University

UWL REPOSITORY

repository.uwl.ac.uk

Ankle and knee joint differences exist despite restoration of acceleration performance after Achilles tendon repair

McCrea, David, Welch, Neil, Griffin, Colin, Burke, Aoife, Deegan, Orla and Strike, Siobhan ORCID logoORCID: https://orcid.org/0000-0001-8195-6888 (2026) Ankle and knee joint differences exist despite restoration of acceleration performance after Achilles tendon repair. Physical Therapy in Sport, 82. ISSN 1466-853X

https://doi.org/10.1016/j.ptsp.2026.102001

This is the Accepted Version of the final output.

UWL repository link: https://repository.uwl.ac.uk/id/eprint/15774/

Alternative formats: If you require this document in an alternative format, please contact: open.research@uwl.ac.uk

Copyright: Creative Commons: Attribution 4.0

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy: If you believe that this document breaches copyright, please contact us at open.research@uwl.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

Rights Retention Statement:

For the purpose of open access, the author has granted their employer, the University of West London, a non-exclusive, irrevocable, sub-licensable, worldwide license (effective from acceptance of publication) to make any final accepted manuscript publicly available under the terms of a Creative Commons Attribution (CC-BY copyright) license. Please direct any correspondence to open.research@uwl.ac.uk

Ankle and Knee Joint Differences Exist Despite Restoration of Acceleration Performance After Achilles Tendon Repair

David McCrea - University of Roehampton & UPMC Sports Surgery Clinic, Dublin, Ireland* *mccread@upmc.ie*

https://orcid.org/0009-0005-2951-3760

Dr. Neil Welch (PhD) - UPMC Sports Surgery Clinic, Dublin, Ireland

https://orcid.org/0000-0001-6678-6198

Dr. Colin Griffin (PhD) - UPMC Sports Surgery Clinic, Dublin, Ireland

https://orcid.org/0000-0002-3337-0927

Dr Aoife Burke (PhD) - Dublin City University, Dublin, Ireland

https://orcid.org/0000-0003-1234-8840

Dr Orla Deegan (PhD) - Dublin City University & UPMC Sports Surgery Clinic, Ireland

https://orcid.org/0000-0002-3571-9950

Dr. Siobhan Strike (PhD) - University of West London, London, United Kingdom

https://orcid.org/0000-0001-8195-6888

Author's accepted manuscript

Abstract:

This study investigated acceleration performance following Achilles Tendon (AT) repair during an upright, reactive sprint acceleration task relevant to field and court-based sport settings. The aim was to determine whether AT repair influences acceleration performance and joint kinetics and kinematics compared to controls, and whether between-limb differences differ between the groups. 45 participants (23 post AT repair, 22 controls) completed 3 maximum effort reactive sprint accelerations on each leg. Significant main effects of group were observed for several biomechanical variables with the AT repair group demonstrating reduced peak negative ankle power ($p < .001$, $\eta p^2 = .23$), reduced ankle positive work ($p = .009$, $\eta p^2 = .08$), reduced ankle dorsiflexion range of motion ($p = .04$, $\eta p^2 = .04$), increased knee positive power maximum (p =

.04, ηp² = .04), and reduced vertical average ground reaction force (p = .007, ηp² = .08). Significant group × limb interactions were identified for ankle positive work (p = .025, ηp² = .09). No significant effect of group or group x limb interaction was observed for time to complete the task. These effects indicate a reduced capacity to generate and dissipate force through the limbs and specifically at the ankle joint post AT rupture suggesting that biomechanical impairments remain despite a comparable global acceleration performance.

Key words: Achilles, Rupture, Acceleration, Biomechanics, Power, Work

Authors accepted manuscript

Introduction:

The Achilles tendon (AT) plays a central role in dissipating ground reaction forces and transmitting force generated by the triceps surae complex (1). Achilles tendon rupture poses a substantial threat to athletic careers, with 20–30% of elite football and basketball players failing to return to play (2,3). Although injury mechanisms during acceleration are increasingly understood (4), the extent to which the mechanical capacity underpinning acceleration performance is restored following AT rupture remains unclear.

The aim of acceleration in field sports is to cover a set distance in as little time as possible (5), often in response to situational or external cues. Effective acceleration depends on both lower limb kinematic coordination and the capacity to generate and appropriately orient ground reaction forces (GRF) (6, 8). Wild et al. (2022) (6) demonstrated that distinct kinematic strategies, reflected in differences in ground contact time, and stride length, can occur despite comparable acceleration performance in field sport settings. Acceleration is underpinned by the ability to generate large GRFs and effectively orient these forces in the horizontal direction within short ground contact times. Komi et al. (1992) (7) observed that sprinters with faster times and higher velocities after 2.5 m generate larger relative horizontal block impulses than their slower counterparts.

The importance of horizontal force production extends beyond the initial block phase, with the ability to generate high net horizontal GRF and impulse consistently identified as a key mechanical determinant of sprint acceleration performance (8,9,10). In elite sprinters, faster acceleration has been associated with greater net horizontal impulse relative to body mass, particularly during the initial acceleration phase (9). Although vertical GRF appears less directly

associated with acceleration performance than horizontal GRF, the vertical component remains necessary to support body mass and contributes to the magnitude and orientation of the resultant GRF applied during stance. Consequently, assessment of both horizontal and vertical GRF provides insight into not only the magnitude of force generated during acceleration, but also how effectively this force is oriented to produce forward acceleration. Following Achilles tendon (AT) repair, assessment of these GRF components may therefore identify alterations in force production and force orientation that are not apparent from acceleration time alone.

During sprint acceleration, the ankle joint plays a key role in both force and mechanical energy generation. The ankle has been shown to produce the greatest positive joint work of the lower-limb joints during maximal acceleration, with ankle net work demonstrating a strong relationship with forward acceleration magnitude ($R^2 = 0.64$) (11). Furthermore, greater positive work during acceleration compared with steady-state running appears to be primarily attributable to increased ankle joint work (12). During the first contact of sprint acceleration, the soleus musculotendinous unit (MTU) predominantly acts isometrically during a phase of energy absorption, followed by shortening during energy generation (10, 11). This interaction between the plantarflexor muscles and Achilles tendon facilitates the storage and subsequent release of elastic strain energy, alongside positive muscle fascicle work, thereby contributing to the substantial positive power and work generated at the ankle during acceleration (14). The forces generated by the soleus and gastrocnemius muscles combined are responsible for a large portion of the ground reaction forces (12, 13) in the vertical direction (between 49.0% and 62.3%), and nearly all of the propulsive component of the ground reaction force in the anterior-posterior direction (14). Consequently, ankle joint power and work provide important measures of the ankle's capacity to absorb and generate mechanical energy during acceleration, beyond that captured by joint moments or ground reaction forces alone. Injury to the AT may therefore compromise the ankle joint's ability to absorb and generate energy, reflected in negative and positive ankle joint work and power, potentially resulting in compensatory strategies that redistribute mechanical work demands to more proximal joints within the kinetic chain.

Although the ankle plays a dominant role during early acceleration, the task is inherently multi-joint in nature. The summed positive work of the hip, knee, and ankle decreases as forward acceleration magnitude increases, indicating that acceleration performance reflects the integrated capacity of the entire lower limb to generate mechanical work. In particular, net joint power at the hip and knee has been shown to correlate linearly with forward acceleration

Author's accepted manuscript

magnitude (13), underscoring the contribution of proximal joints to acceleration performance. Following AT rupture, altered lower-limb mechanics have been observed in steady-state running, suggesting redistribution of mechanical demand across the kinetic chain (15). It is possible that similar adaptations may be present during higher-intensity, acceleration-based tasks.

Following AT rupture notable functional impairments are observed, including reduced plantarflexor strength, work capacity, reactive strength index, and increased asymmetry in lower limb kinetics during jumping and running (16, 17,18). These changes are likely associated with alterations in MTU structure and mechanics, affecting power generation and tendon strain capacity. As sprint acceleration requires high force output and efficient use of the stretch–shortening cycle (10), these deficits may negatively influence performance.

This study is the first to investigate acceleration performance following Achilles Tendon (AT) repair during an upright, reactive sprint acceleration task relevant to field- and court-based sport settings. The first aim was to determine whether acceleration performance and lower limb biomechanical variables differed between those who have had an AT repair and healthy controls. We hypothesised that the AT repair group would demonstrate reduced ankle positive power, ankle positive work, vertical and horizontal ground reaction forces, longer task completion time and altered knee power compared to controls. The second aim is to determine if there is a difference in the between-limb symmetry, between groups. We hypothesised that between-limb difference would be greater in the AT repair group than in controls, particularly for ankle mechanical variables.

Methods:

Ethics, consent, health & safety

This research was performed in accordance with the principles stated in the Declaration of Helsinki. Ethical approval was obtained by the University of Roehampton's Ethics Committee (Reference: LSC 23/ 391), which included the health and safety risk assessment. Written informed consent was obtained from the participants prior to data collection.

Author's accepted manuscript

Participants

No formal matching was performed between participant groups. The AT repair group consisted of 23 participants, all of whom had undergone Achilles Tendon surgical repair. The control group consisted of 22 participants. Participant demographic information can be seen in Table 1.

Inclusion & exclusion criteria

Inclusion criteria for the AT repair group required participants to be aged 18 years or older and have undergone a primary open end to end AT repair at least 6 months prior to the time of testing. All participants followed the same post operative weight bearing protocol which allowed for immediate weight bearing as tolerated in a protective walker boot with heel raises in situ to reduce tendon elongation risk. Participants in this group were purposefully recruited to be beyond a time point that has allowed for satisfactory tendon remodelling (6 months), and were required to be actively rehabilitating on field to or have already returned to competitive sport. Participants were required to have commenced steady state, acceleration and change of direction-based running as part of their rehabilitation prior to testing.

Participants were excluded if they had a post operative complication (wound infection, sural nerve injury), if they had AT repair under different technique (Speed bridge, percutaneous repair, tendon transfer), if they had not commenced on field rehabilitation or returned to sport. Participants were excluded if they had no intention of returning to sport.

The control group inclusion criteria required participants to be over the age of 18 years and currently not suffering from or have sustained any lower-limb musculoskeletal injury which required more than two treatment sessions, within the previous 6 months. Participants within the control group were also required to be physically active and routinely participating in sport with regular sprint & acceleration exposure. Participants were excluded if they had undergone any musculoskeletal surgery within the past 2 years. Participants self-reported their primary sport and level of competition. Competitive level was categorised as recreational, national level, or professional. Recreational was defined as sport played not at the top tier/ category of an amateur sport. National level was defined as a sport considered at the top tier/category of an amateur sport. Professional was defined as a sport played as the participants profession.

Author's accepted manuscript

Table 1. Participant characteristics by group

Characteristic	Achilles tendon repair (n = 23)	Control (n = 22)
Age (years)	28.1 ± 4.1	24.6 ± 4.5
Sex, male/female, n	19/4	11/11
Body mass (kg)	83.4 ± 11.1	70.2 ± 10.6
Time since surgery (months)	13.5 ± 7.9	Not applicable
Time since surgery, median (range), months	9.0 (6.0–33.0)	Not applicable
Participant activity level breakdown		
Recreational, n (%)	10 (43.5%)	18 (81.8%)
National, n (%)	10 (43.5%)	4 (18.2%)
Professional, n (%)	3 (13.0%)	0 (0.0%)

Author's accepted

Instrumentation

Three-dimensional (3D) biomechanical data were collected using a 19-camera motion analysis system (10 Bonita-B10 and 9 Vero v2.2 cameras; Vicon Motion Systems Ltd., Oxford, UK) sampling at 200 Hz and synchronised with two embedded force platforms (BP400600; AMTI, Watertown, MA, USA) sampling at 1000 Hz. Three-dimensional marker trajectories were captured using 28 retroreflective markers (14-mm diameter), while ground reaction force (GRF) data were simultaneously recorded from the force platforms. Kinematic and kinetic data were collected and synchronised using Nexus software (version 2.12.1; Vicon Motion Systems Ltd., Oxford, UK). Task completion was recorded using timing gates (SmartSpeed; VALD, Brisbane, Australia).

Testing protocol

Participants wore their own athletic footwear. Reflective markers were secured using double-sided tape at bony landmarks on the lower limbs, pelvis, and trunk per the adapted Plug-in-Gait marker set (20).

The testing protocol was consistent with that previously described by McCrea et al. (19), which demonstrated excellent reliability for ankle and knee joint kinetic and kinematic variables during sprint acceleration. Participants completed a standardised 10-minute progressive warm-up consisting of stationary cycling, five bodyweight squats, three countermovement jumps, three drop jumps, and three 4-m acceleration efforts on each limb. Acceleration efforts were progressively increased to approximately 50%, 75%, and 90% of perceived maximal effort. During familiarisation, control participants were not instructed which limb to initiate the acceleration with. The limb selected spontaneously was subsequently classified as the *preferred* limb and used to define the index limb for between-group comparisons. Participants in the AT repair group familiarised themselves with the task using the non-repaired limb first, followed by the repaired limb.

Following familiarisation, participants completed a reactive 4-m acceleration task, with the testing setup and acceleration sequence illustrated in **Figure 1**. Participants adopted an upright, parallel-stance starting position with their arms by their sides and their heels immediately anterior to the embedded force plates (Figure 1A and 1C). The first set of timing gates (SmartSpeed; VALD, Brisbane, Australia) was aligned with the participant's toe box, while a second set was positioned 4 m from the anterior edge of the force plates. Timing gates were standardised to a height of 1.5 m, and a reactive sprint protocol was administered through VALDHub.

At the initiation of each trial, the timing gates illuminated yellow, followed by a randomised delay of 1–6 s to minimise anticipation of the start stimulus. The lights subsequently changed to green, providing the visual stimulus to initiate the acceleration. In response, participants were instructed to step backwards onto the embedded force plate with the test limb (Figure 1B) and accelerate as rapidly as possible through the second set of timing gates, completing the 4-m acceleration (Figure 1D). The 4m acceleration time was measured from the lighting of the green stimulus until the completion of the 4m, thus it included the response and task completion time. The randomised visual stimulus was used to elicit a reactive rather than self-initiated acceleration, thereby more closely representing the unpredictable initiation of acceleration encountered during field-sport scenarios.

Control participants completed trials with their preferred limb first, followed by their non-preferred limb. In the AT repair group, the contralateral limb was tested first, followed by the repaired limb. Participants walked back to the starting position between trials, and three valid

Author's accepted manuscript

trials were collected for each limb and the mean calculated. Trials were excluded and repeated if the test foot made only partial contact with the force plate or crossed both the left and right force plates during the initial step.

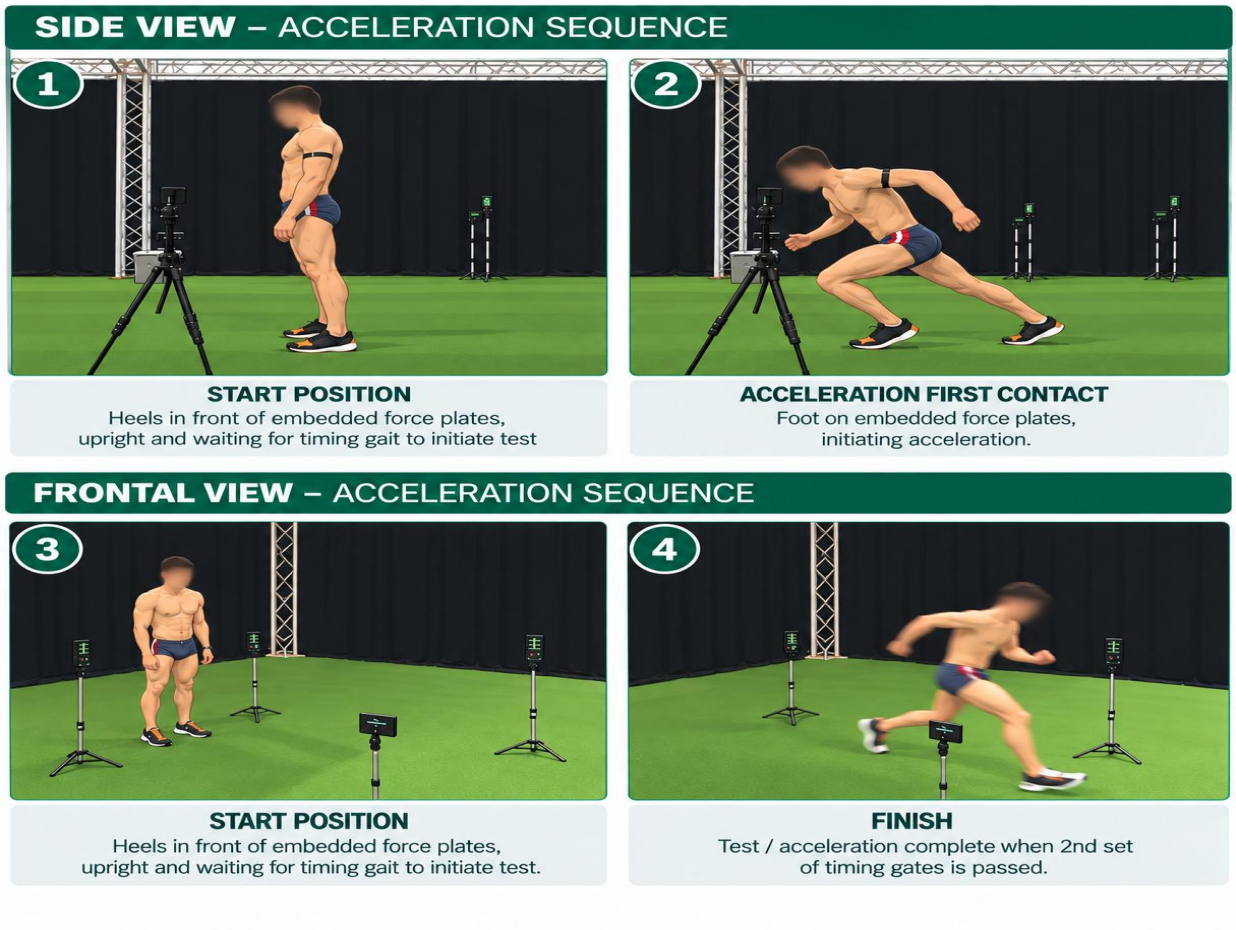


Figure 1. Reactive acceleration testing protocol. (1) Side-view starting position, with the participant standing upright and heels positioned immediately anterior to the embedded force plates; (2) initial acceleration contact, with the test limb stepping backwards onto the force plate in response to the visual stimulus; (3) frontal-view starting position demonstrating the timing-gate and force-plate configuration; and (4) completion of the 4-m acceleration following passage through the second set of timing gates (4m distance fore-shortened for illustration).

Authors

Data Processing

Motion data were and low-pass filtered using a fourth-order Butterworth filter (cutoff frequency, 15 Hz) in Vicon Nexus software (14). Kinetic and kinematic analyses were performed for the first

stance phase of each acceleration test, which was defined by when the vertical GRF >20 N, with end of stance phase being determined by vertical GRF dropping to <20N.

Standard inverse dynamics was used to calculate joint moments (reported as internal moments) at the ankle, knee and hip in all three planes using the Vicon Nexus software. All moments were normalized to body mass. Maximum and average values were extracted for the vertical and horizontal GRFs, knee and ankle joint moments, positive and negative powers. Joint power was calculated as the product of joint moment and angular velocity, where positive values indicate energy generation and negative values indicate energy absorption. Positive ankle joint work was calculated as net joint power integrated over time in regions with positive internal power and negative ankle work in regions with negative internal power. Ankle dorsiflexion range of motion was defined by the change in ankle angle from initial ground contact to maximum dorsiflexion.

For spatiotemporal variables, task time was defined as the time the light turned green until the participant passed through the second timing gate over 4 metres. Stride length was calculated using the anterior displacement of the toe marker from stepping on the force plate to the next ground contact of the same foot. Specifically, the distance between the average positions of the toe marker during the stance phases of the first (i.e. the step back step) and the second step was calculated, the stance phase was defined as when the toe marker moved less than 1 mm (i.e. when the foot was stationary on the ground).

Biomechanical data were exported from the Vicon Nexus system and processed using a bespoke MATLAB script (MathWorks, Natick, MA, USA) to extract the relevant kinetic, kinematic, and performance variables for each trial. Processed variables were subsequently exported to Microsoft Excel for data organisation, calculation of means and quality checking. The final dataset was then imported into IBM SPSS Statistics for statistical analysis.

The dataset for this present study is available from the corresponding author, [DMC], upon reasonable request.

Author's accepted ma

Statistical Analysis

Descriptive statistics were used to summarise the characteristics of the participants and measurements. Normality of distribution of data was assessed with the Shapiro-Wilk test and Q-Q plots. To examine between groups and between limb differences, linear mixed effects

ANOVA was performed. For each dependent variable, group (AT repair and control) limb (repaired, non-repaired for the AT repair and preferred, non-preferred for the control group) and their interaction (group x limb) were included as fixed effects. To account for repeated measures within individuals, participants were included as a random intercept. The parameter estimates were adjusted for age. Sensitivity analyses were performed to assess whether sex or time from surgery influenced the observed between-limb differences within the Achilles tendon repair group. Given the imbalance in sex distribution between groups, analysis was performed adjusting for sex, with p-values additionally corrected for multiple comparisons using the Benjamini–Hochberg false discovery rate (FDR) procedure. To examine the influence of time from surgery, analyses were restricted to participants following Achilles tendon repair, with postoperative time (mean-centred) included as a continuous predictor of the repaired-to-contralateral limb difference. These analyses were used to determine whether the magnitude of between-limb differences varied according to sex or postoperative time.

In the AT repair group, limbs were defined as repaired and non-repaired, whereas in the control group limbs were defined as preferred and non-preferred. As these limb definitions do not represent a common construct across groups, limb main effects were not interpreted in isolation. Instead, the group × limb interaction was used as the primary test of whether the magnitude of between-limb differences was different between groups. Where a significant group x limb interaction was observed, post-hoc comparisons were conducted to examine the between-limb differences within each group and between-group differences within each limb. Effect sizes were reported as partial eta squared (ηp^2). Interpretation followed conventional benchmarks (small ≈ .01, medium ≈ .06, large ≈ .14), as proposed by Cohen (21). In order to examine injury-related limb asymmetry, limb was treated as a within-participant factor and interpreted relative to group membership.

Results

A summary of fixed effects for group, and the group × limb interaction effects across dependent biomechanical and spatiotemporal variables is presented in Table 2.

Given the differing limb definitions between groups, limb main effects were not interpreted independently; therefore, results are presented in terms of group effects and group × limb interactions, with the latter reflecting repair-specific limb asymmetry.

Author's accepted manuscript

AT Repair vs Control group comparison

Across limbs, significant fixed effects of group were observed for several ankle and knee variables. Participants in the AT repair group demonstrated reduced peak negative ankle power ($p < .001$, $\eta p^2 = .23$), reduced ankle positive work ($p = .009$, $\eta p^2 = .08$), reduced ankle range of motion ($p = .04$, $\eta p^2 = .04$) and reduced vertical average ground reaction force ($p = .007$, $\eta p^2 = .08$) compared to controls. In contrast, peak knee positive power maximum ($p = .04$, $\eta p^2 = .04$) was increased in the AT repair group compared to controls. These effects ranged from small to large in magnitude, with the largest effect observed for peak negative ankle power. No significant group effects were found for task completion time, stride length, contact time, peak positive ankle power, or horizontal average ground reaction force ($p > .05$). Full results are reported in Table 2.

Group x Limb interactions

Significant group × limb interactions were identified for ankle positive work ($p = .025$, $\eta p^2 = .09$), indicating that the magnitude of between-limb differences differed for AT repair participants and controls. No other group x limb interactions reached statistical significance threshold. Full results are reported in Table 2.

Sensitivity analysis for sex

Given the imbalance in sex distribution between groups, a sensitivity analysis was performed incorporating sex as an additional between-subject adjustment variable. The principal group × limb interaction for ankle positive work remained significant following adjustment for sex ($F = 6.05$, $p = .018$). The group effect ($F = 6.72$, $p = .013$) and limb effect ($F = 11.48$, $p = .002$) also remained significant. An exploratory sex × limb sensitivity analysis was performed to determine whether sex influenced repaired-to-contralateral limb differences. No sex × limb interaction remained significant following false discovery rate correction across the assessed outcomes (all $q \geq .273$). Importantly, the repaired-limb deficit in ankle positive work was similar in males (-0.251 J·kg^{-1}) and females (-0.205 J·kg^{-1}), with no evidence of a sex × limb interaction (interaction difference = 0.046 J·kg^{-1}, 95% CI −0.338 to 0.429; $P = .807$; $q = .970$). Although unadjusted sex × limb interactions were observed for ankle ROM ($P = .016$) and ankle stiffness

Author's accepted manuscript

(P = .045), neither remained significant following FDR correction (q = .273 and .385, respectively). Full results are reported in Table 3.

Sensitivity analysis for postoperative time

Within the Achilles tendon repair group, postoperative time was examined as a potential modifier of repaired-to-contralateral limb differences (Table 4). The repaired-limb deficit in ankle positive work remained evident at the mean postoperative time of 13.5 months (adjusted limb difference: −0.242 J·kg^{-1}, 95% CI −0.387 to −0.097; p = .002), with no evidence of a limb × postoperative-time interaction (slope = −0.008 J·kg^{-1} per month, p = .382; FDR q = .649). Similarly, postoperative time did not significantly modify limb differences in peak positive or negative ankle power or average vertical GRF. A significant limb × postoperative-time interaction was identified for peak vertical GRF (slope = 0.238 N·kg^{-1} per month, 95% CI 0.087 to 0.389; p = .004; q = .031). An unadjusted association was also observed for peak positive knee power (p = .031), although this did not remain significant following FDR correction (q = .174). Full results are reported in Table 4.

Author's accepted manuscript

Table 2 – Summary of Results

Variable	Control Group		AT repair group		Statistical Analysis			
	Preferred Limb *Mean (SD) (95% CI)*	Non-preferred Limb *Mean (SD) (95% CI)*	Injured Limb *Mean (SD) (95% CI)*	Non-injured Limb *Mean (SD) (95% CI)*	Group *p*	Group np^2	Group x Limbs *p*	Group x Limbs np^2
Peak ankle positive power *(W/kg)*	18.72 (4.28) *(16.72, 20.72)*	19.13 (3.92) *(17.29, 20.96)*	15.85 (3.55) *(14.27, 17.42)*	18.29 (5.79) *(15.73, 20.86)*	0.63	.04	.095	.055
Peak ankle negative power *(W/kg)*	-14.69 (3.52) *(-16.33, -13.04)*	-14.80 (2.70) *(-16.06, -13.53)*	-11.82 (3.37) *(-13.31, -10.32)*	-12.27 (3.36) *(-13.76, -10.78)*	<.001*	.23	.77	.006
Ankle positive work (Joules)	1.20 (0.26) *(1.08, 1.33)*	1.15 (0.32) *(1.00, 1.30)*	0.87 (0.28) *(0.75, 1.00)*	1.12 (0.33) *(0.97, 1.27)*	.009*	.08	.025*	.09
Ankle ROM (Degrees)	34.02 (3.71) *(32.28, 35.75)*	34.13 (8.53) *(30.14, 38.12)*	32.43 (6.24) *(29.66, 35.19)*	30.98 (6.46) *(28.12, 33.85)*	.04*	.04	.95	.001
Peak knee positive power *(W/kg)*	5.30 (2.65) *(4.06, 6.54)*	4.91 (2.53) *(3.72, 6.09)*	5.74 (4.35) *(3.81, 7.67)*	5.85 (3.39) *(4.35, 7.35)*	.04*	.04	.96	0.001
Avg GRF Vertical *(N/kg)*	12.65 (0.96) *(12.20, 13.10)*	12.76 (0.97) *(12.30, 13.21)*	11.86 (1.06) *(11.39, 12.32)*	12.24 (0.98) *(11.80, 12.67)*	.007*	.08	.32	.02
Avg GRF Horizontal *(N/kg)*	7.15 (0.82) *(6.76, 7.53)*	7.02 (0.81) *(6.64, 7.40)*	6.57 (0.84) *(6.20, 6.94)*	6.97 (0.96) *(6.54, 7.39)*	.15	.02	.27	.03
Task completion time (Seconds)	1.58 (0.07) *(1.55, 1.61)*	1.59 (0.06) *(1.56, 1.62)*	1.59 (0.08) *(1.56, 1.63)*	1.58 (0.08) *(1.54, 1.62)*	.38	.009	.89	.003
Stride length (Metres)	1.61 (0.24) *(1.50, 1.72)*	1.61 (0.40) *(1.42, 1.80)*	1.52 (0.18) *(1.43, 1.60)*	1.52 (0.18) *(1.44, 1.60)*	.13	.02	.89	.00
Contact time (Seconds)	0.26 (0.03) *(0.24, 0.27)*	0.25 (0.03) *(0.24, 0.27)*	0.26 (0.03) *(0.25, 0.27)*	0.26 (0.02) *(0.25, 0.27)*	.23	.01	.99	.00

P = <0.05 statistical significance * ; np^2: partial eta squared effect size

Aut

Table 3 – Sex-adjusted sensitivity analysis

Mixed ANOVA results adjusting for sex as a covariate

Variable	Group effect			Limb effect			Group x Limb interaction		
	F	*p*	FDR q	F	*p*	FDR q	F	*p*	FDR q
Peak ankle positive power (W/kg)	2.382	.127	.270	2.518	.117	.497	3.695	.061	.346
Peak ankle negative power (W/kg)	8.612	**.005***	.079	0.415	.524	.745	0.506	.480	.965
Ankle positive work (Joules)	6.718	**.013***	.079	11.479	**.002***	**.034***	6.050	**.018***	.298
Ankle ROM (Degrees)	2.763	.104	.253	0.000	.984	.994	0.179	.673	.965
Peak knee positive power (W/kg)	2.105	.156	.295	0.104	.752	.913	0.013	.910	.965
Average vertical GRF (N/kg)	2.960	.091	.253	1.604	.214	.606	4.720	**.035***	.298
Average horizontal GRF (N/kg)	1.212	.282	.436	4.998	**.030***	.170	2.455	.124	.527
Task completion time (Seconds)	0.984	.326	.462	1.654	.207	.606	0.353	.556	.965
Stride length (Metres)	3.290	.074	.252	0.404	.530	.745	0.075	.786	.965
Contact time (Seconds)	0.176	.680	.826	0.013	.911	.994	0.087	.772	.965

*p = <0.05 statistical significance * ; FDR q = Benjamini–Hochberg adjusted p-value for multiple comparisons*

Author's accepte

Table 4. Sex sensitivity analysis within the Achilles tendon repair group

Outcome	Male limb difference (mean ± SD) (n = 19)	Female limb difference (mean ± SD) (n = 4)	Sex × limb difference (95% CI)	Interaction *p* value	FDR-adjusted *q* value
Ankle positive work ($J \cdot kg^{-1}$)	−0.251 ± 0.420	−0.205 ± 0.312	0.046 (−0.338 to 0.429)	0.807	0.970
Peak positive ankle power ($W \cdot kg^{-1}$)	−3.50 ± 6.12	−0.22 ± 4.81	3.28 (−4.68 to 11.24)	0.401	0.889
Peak negative ankle power ($W \cdot kg^{-1}$)	−4.11 ± 7.03	−1.36 ± 5.27	2.75 (−6.21 to 11.71)	0.531	0.889
Peak positive knee power ($W \cdot kg^{-1}$)	1.92 ± 3.48	0.74 ± 2.96	−1.18 (−5.77 to 3.41)	0.604	0.889
Vertical GRF (BW)	−0.18 ± 0.27	−0.12 ± 0.21	0.06 (−0.25 to 0.36)	0.722	0.970

Limb difference represents repaired minus contralateral limb (mean ± SD). Positive sex × limb difference values indicate a greater limb difference in females relative to males. *P* values represent unadjusted interaction tests and *q* values represent Benjamini–Hochberg false discovery rate-adjusted values. The Achilles tendon repair group comprised 19 males and 4 females.

Table 5. Postoperative time sensitivity analysis within the Achilles tendon repair group

Outcome	Adjusted limb difference at 13.5 months (95% CI)	Limb × postoperative month slope (95% CI)	Interaction *p* value	FDR-adjusted *q* value
Ankle positive work ($J \cdot kg^{-1}$)	−0.242 (−0.387 to −0.097)	−0.008 (−0.027 to 0.011)	0.382	0.649
Peak positive ankle power ($W \cdot kg^{-1}$)	−2.932 (−5.976 to 0.112)	−0.113 (−0.506 to 0.279)	0.554	0.804
Peak negative ankle power ($W \cdot kg^{-1}$)	0.644 (−0.920 to 2.208)	−0.049 (−0.251 to 0.152)	0.615	0.804
Peak positive knee power ($W \cdot kg^{-1}$)	−0.131 (−1.711 to 1.448)	−0.227 (−0.430 to −0.023)	0.031	0.174
Average vertical GRF ($N \cdot kg^{-1}$)	−0.443 (−0.949 to 0.062)	0.012 (−0.053 to 0.078)	0.697	0.847
Peak vertical GRF ($N \cdot kg^{-1}$)	−0.180 (−1.353 to 0.994)	**0.238 (0.087 to 0.389)**	**0.004**	**0.031**

Note: Limb difference represents repaired minus contralateral limb. The adjusted limb difference represents the estimated repaired-versus-contralateral difference at the mean postoperative time of 13.5 months. The limb × postoperative month slope represents the estimated change in this limb difference for each additional month following surgery. Positive slopes indicate that the repaired-minus-contralateral difference becomes more positive with increasing postoperative time. *P* values represent unadjusted interaction tests and *q* values represent Benjamini–Hochberg false discovery rate-adjusted values. Analyses included 23 participants, except ankle positive work ($n = 22$).

Discussion

The present study investigates lower-limb biomechanics during reactive sprint acceleration in participants following ATR and healthy controls. The first aim was to determine if acceleration performance and lower-limb biomechanical variables differed between groups. The findings provide partial support for the hypothesised between-group differences in lower limb biomechanics following

AT repair. Consistent with our hypothesis, participants in the AT repair group demonstrated reduced ankle negative power and ankle positive work compared to controls, indicating reduced ankle mechanical energy absorption and generation during the initial acceleration step. Average vertical GRF was also lower in the AT repair group, suggesting a whole-body reduction of limb load. Greater peak positive knee power than controls indicates altered distribution of mechanical demands across the lower-limb kinetic chain. The task completion time and stride length did not differ between groups, nor did the peak positive power, indicating that not all hypothesised performance or kinetic differences were present.

The second aim was to determine whether between-limb differences differed between groups. The second hypothesis was partially supported with a significant group x limb interaction observed for ankle positive work, with greater between-limb difference in the AT repair group compared to controls. Secondary analysis into this revealed both time post op and sex did not reduce the significance of this finding. These findings indicate that biomechanical differences particularly at the ankle joint persisted following AT repair despite comparable task time and strategy.

The significant group-by-limb interaction observed for positive ankle work indicates that the between-limb difference was dependent on group. Specifically, the repaired limb demonstrated lower positive ankle work than the contralateral limb, with this asymmetry being greater than the preferred-to-non-preferred limb difference observed in the control group. This finding suggests that the reduction in positive ankle work represents a repair-specific inter-limb deficit rather than the magnitude of limb-to-limb variation typically observed in uninjured individuals. Importantly, this deficit was evident despite comparable task completion times between groups, suggesting that restoration of acceleration performance does not necessarily reflect restoration of symmetrical ankle joint mechanical function. The reduced contribution of the repaired ankle may therefore require redistribution of mechanical work within the affected limb or across the lower extremities to maintain overall task performance.

The reduced ankle work observed during acceleration may reflect several potential mechanisms; however, these mechanisms were not directly assessed in the present study and should therefore be considered speculative. Previous research has demonstrated persistent reductions in triceps surae muscle mass following AT repair, which have been associated with reduced ankle work and force-generating capacity during heel-rise endurance testing and isokinetic dynamometry (17, 22, 23). It is possible that similar deficits in muscle capacity may influence ankle contribution during higher-velocity stretch–shortening cycle activities such as

Author's accepted manuscript

acceleration, although this requires further investigation. Structural alterations to the AT following repair, including increased tendon length (24), increased cross-sectional area (25), and reduced tendon stiffness measured using shear-wave elastography (26), have also been reported. Such alterations could theoretically influence the mechanical behaviour of the muscle–tendon unit and its capacity to transmit force during acceleration. However, as muscle morphology and tendon structure or mechanical properties were not assessed in the present study, their contribution to the observed reduction in ankle work cannot be determined. Future studies combining acceleration biomechanics with measures of muscle morphology and tendon structure and mechanical properties are required to investigate these potential mechanisms.

The absence of differences in spatiotemporal variables between groups and limbs, despite reductions in force in the AT repair group, suggests that performance may be maintained through compensatory movement strategies within the kinetic chain rather than restoration of normal joint function or through changes in spatiotemporal parameters. Specifically, increased knee positive power observed in the present study may indicate a redistribution of mechanical demand to proximal joints within the kinetic chain. However, because hip kinetics and subsequent acceleration steps were not analysed, redistribution of mechanical demand cannot be established. This finding is consistent with previous research demonstrating increased hip and knee joint loading during running following Achilles tendon repair (15), as well as compensatory strategies observed after anterior cruciate ligament reconstruction during jumping and change of direction tasks (27, 28). These results emphasise that time-based performance measures may lack sensitivity to detect persistent biomechanical deficits at the repaired joint and performance may be maintained via re-distribution of force generation within the kinetic chain.

Participants were assessed at a mean of 13.5 months following ATR, but differences in ankle and knee kinetics remained. This suggests that using time since surgery to determine restoration of lower-limb mechanical function and readiness to return to sport may not be sufficient. From a return-to-sport perspective, our findings support the use of functional and biomechanical assessment when evaluating recovery following repair. Within the limitation of cross-sectional nature of this study, the results indicate that deficits persist beyond the time at which athletes are typically returning to sport.

Author's accepted manuscript

Acceleration performance is strongly associated with the ability to generate force (5). Consequently, impairments in force production following injury may necessitate compensatory strategies to maintain performance. These may include alterations in spatiotemporal parameters such as ground contact time or stride length. However, no between-group or between-limb differences in ground contact time or stride length were observed in the present study. An alternative compensatory mechanism may involve a shift in force generation demands to the contralateral limb or across subsequent steps may have occurred, although these were not directly assessed in this study.

Limitations:

This study has several limitations. One limitation is that only the initial step of acceleration was assessed, limiting the analysis to a single phase of a multi-step task. Furthermore, no data was collected regarding the post-surgical architectural status of the muscle–tendon unit, which may influence interpretation of the findings. In this study hip joint data were not included despite acceleration being a whole-chain task; however, this decision was informed by previous work (19) which reported poor reliability of hip joint measures when using this testing protocol. The unequal sex distribution between groups represents a study limitation and may have influenced between-group comparisons, although sensitivity analyses adjusting for sex were performed to assess the robustness of the findings. The absence of formal matching between the AT repair and control groups represents a study limitation and may have introduced residual between-group differences that could influence the observed biomechanical outcomes.

Future work:

Future work should focus on assessing the underpinning mechanisms that contribute to reduced ankle work during acceleration post-AT rupture. This work can help determine whether the deficits identified in the present study post-injury derive from one or a combination of kinesiophobia, MTU architectural changes, reduced calf strength, reduced explosive and reactive strength, or changes in motor control or movement co-ordination post repair. To determine the effect of time since surgery on restoration of biomechanics, a longitudinal study which follows players over an extended timeline, and which tracks reinjury and injury to other

Author's accepted manuscript

sites is required, in order to determine if biomechanical differences predict injury, performance and readiness to return to sport. .

Clinical Perspective:

This study demonstrates that participants following AT repair may present ankle and knee joint kinetic differences despite a comparable 4 m task completion time. Data suggest that reduced ankle work and power during a maximal forward acceleration persist, therefore clinical rehabilitation post AT rupture should aim to investigate how to restore the production and dissipate force efficiently.

Conclusion:

Participants in the AT repair group demonstrated significant differences in lower-limb biomechanics compared with controls, with significant between-group differences observed primarily in ankle- and knee-related kinetic variables. These effects indicate an altered capacity to generate and dissipate force primarily at the ankle joint post-AT rupture. Significant group-by-limb interactions for ankle positive work with no group interactions observed for task completion time suggest that biomechanical impairments remain even with comparable global acceleration performance. Collectively, these findings highlight the importance of incorporating joint-level mechanical assessments alongside traditional performance metrics when evaluating functional recovery post-AT rupture.

r's accepted manuscript

Acknowledgments

The authors acknowledge the commitment and dedication to testing each of the 45 participants who took part in this investigation. We also thank the biomechanics laboratory and their staff at UMPC Sports Surgery Clinic for their assistance in data collection and processing. The study was approved by the University of Roehampton Ethics Committee (LSC 23/ 391).

Conflicts of Interest

The authors declare no conflicts of interest.

Author's accepted manuscript

References:

1. O'Brien M. The anatomy of the Achilles tendon. Foot Ankle Clin. 2005;10(2):225-238. doi:10.1016/j.fcl.2005.01.011.
2. Trofa DP, Miller JC, Jang ES, Woode DR, Greisberg JK, Vosseller JT. Professional athletes' return to play and performance after operative repair of an Achilles tendon rupture. Am J Sports Med. 2017;45(12):2864-2871. doi:10.1177/0363546517713001.
3. Forlenza EM, Lavoie-Gagne OZ, Lu Y, Diaz CC, Chahla J, Forsythe B. Return to play and player performance after Achilles tendon rupture in UEFA professional soccer players: a matched-cohort analysis of players from 1999 to 2018. Orthop J Sports Med. 2021;9(9):23259671211024199. doi:10.1177/23259671211024199.
4. Della Villa F, Buckthorpe M, Tosarelli F, Zago M, Zaffagnini S, Grassi A. Video analysis of Achilles tendon rupture in male professional football (soccer) players: injury mechanisms, patterns and biomechanics. BMJ Open Sport Exerc Med. 2022;8(3):e001419. doi:10.1136/bmjsem-2022-001419.
5. Bezodis NE, Willwacher S, Salo AIT. The biomechanics of the track and field sprint start: a narrative review. Sports Med. 2019;49(9):1345-1364. doi:10.1007/s40279-019-01138-1.

6. Wild JJ, Bezodis IN, North JS, Bezodis NE. Characterising initial sprint acceleration strategies using a whole-body kinematics approach. J Sports Sci. 2022;40(2):203-214. doi:10.1080/02640414.2021.1985759.
7. Komi PV, Fukashiro S, Järvinen M. Biomechanical loading of Achilles tendon during normal locomotion. Clin Sports Med. 1992;11(3):521-531.
8. Morin JB, Edouard P, Samozino P. Technical ability of force application as a determinant factor of sprint performance. Med Sci Sports Exerc. 2011;43(9):1680-1688. doi:10.1249/MSS.0b013e318216ea37.
9. Morin JB, Slawinski J, Dorel S, Saez de Villarreal E, Couturier A, Samozino P, et al. Acceleration capability in elite sprinters and ground impulse: push more, brake less? J Biomech. 2015;48(12):3149-3154. doi:10.1016/j.jbiomech.2015.07.009.
10. Rabita G, Dorel S, Slawinski J, Sàez-de-Villarreal E, Couturier A, Samozino P, et al. Sprint mechanics in world-class athletes: a new insight into the limits of human locomotion. Scand J Med Sci Sports. 2015;25(5):583-594. doi:10.1111/sms.12389.
11. Schache AG, Lai AKM, Brown NAT, Crossley KM, Pandy MG. Lower-limb joint mechanics during maximum acceleration sprinting. J Exp Biol. 2019;222(22):jeb209460. doi:10.1242/jeb.209460.
12. Qiao M, Jindrich DL. Leg joint function during walking acceleration and deceleration. J Biomech. 2016;49(1):66-72. doi:10.1016/j.jbiomech.2015.11.022.
13. Mero A, Kuitunen S, Harland M, Kyröläinen H, Komi PV. Effects of muscle-tendon length on joint moment and power during sprint starts. J Sports Sci. 2006;24(2):165-173. doi:10.1080/02640410500131753.
14. Lai A, Schache AG, Brown NAT, Pandy MG. Human ankle plantar flexor muscle-tendon mechanics and energetics during maximum acceleration sprinting. J R Soc Interface. 2016;13(121):20160391. doi:10.1098/rsif.2016.0391.
15. Crotty ED, Furlong LAM, Harrison AJ. Ankle and plantar flexor muscle-tendon unit function in sprinters: a narrative review. Sports Med. 2024;54(3):585-606. doi:10.1007/s40279-023-01967-1.
16. Hamner SR, Delp SL. Muscle contributions to fore-aft and vertical body mass center accelerations over a range of running speeds. J Biomech. 2013;46(4):780-787. doi:10.1016/j.jbiomech.2012.11.024.
17. Jandacka D, Silvernail JF, Uchytil J, Zahradnik D, Farana R, Hamill J. Do athletes alter their running mechanics after an Achilles tendon rupture? J Foot Ankle Res. 2017;10:53. doi:10.1186/s13047-017-0235-0.

Author's accepted manuscript

18. Walker J, Nicholson G, Jongerius N, Parelkar P, Harris N, Bissas A. Commonly reported isokinetic parameters do not reveal long-term strength deficits of the triceps surae complex following operative treatment of Achilles tendon rupture. J Biomech. 2020;101:109630. doi:10.1016/j.jbiomech.2020.109630.
19. Heikkinen J, Lantto I, Piilonen J, Flinkkilä T, Ohtonen P, Siira P, et al. Tendon length, calf muscle atrophy, and strength deficit after acute Achilles tendon rupture: long-term follow-up of patients in a previous study. J Bone Joint Surg Am. 2017;99(18):1509-1515. doi:10.2106/JBJS.16.01491.
20. Mullaney MJ, McHugh MP, Tyler TF, Nicholas SJ, Lee SJ. Weakness in end-range plantar flexion after Achilles tendon repair. Am J Sports Med. 2006;34(7):1120-1125. doi:10.1177/0363546505284186.
21. McCrea D, Welch N, Griffin C, Moran K, Kung S, Strike S. Inter trial & inter session reliability of a novel reactive step back acceleration test in athletes post Achilles tendon repair. Phys Ther Sport. 2026;78:101884. doi:10.1016/j.ptsp.2025.12.006.
22. Cross J, Kung SM, Welch N. Assessing the reliability of biomechanical variables during a horizontal deceleration task in healthy adults. J Sports Sci. 2024;42(3):263-269. doi:10.1080/02640414.2024.2327874.
23. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum Associates; 1988.
24. Silbernagel KG, Nilsson-Helander K, Thomeé R, Eriksson BI, Karlsson J. A new measurement of heel-rise endurance with the ability to detect functional deficits in patients with Achilles tendon rupture. Knee Surg Sports Traumatol Arthrosc. 2010;18(2):258-264. doi:10.1007/s00167-009-0889-7.
25. Leppilahti J, Lähde S, Forsman K, Kangas J, Kauranen K, Orava S. Relationship between calf muscle size and strength after Achilles rupture repair. Foot Ankle Int. 2000;21(4):330-335. doi:10.1177/107110070002100410.
26. Rosso C, Buckland DM, Polzer C, Sadoghi P, Schuh R, Weisskopf L, et al. Long-term biomechanical outcomes after Achilles tendon ruptures. Knee Surg Sports Traumatol Arthrosc. 2015;23(3):890-898. doi:10.1007/s00167-013-2726-2.
27. Hiramatsu K, Tsujii A, Nakamura N, Mitsuoka T. Ultrasonographic evaluation of the early healing process after Achilles tendon repair. Orthop J S

Author's accepted manuscript

Author's accepted manuscript