INTERNATIONAL JOURNAL OF ATHLETIC THERAPY & TRAINING
The Professional Journal of Certified Athletic Trainers and Athletic Therapists

The Influence of 9-marathons completed in 9 days on injury incidence and selected musculoskeletal tests

Journal:	*International Journal of Athletic Therapy & Training*
Manuscript ID	IJATT.2018-0002.R4
Manuscript Type:	Research Report
Specialty Areas:	Musculoskeletal < System < Evaluation & Examination < Examination, Treatment, and Rehabilitation, Neuromuscular control/proprioception < Functional progressions < Rehabilitation < Examination, Treatment, and Rehabilitation, Postural stability < Functional progressions < Rehabilitation < Examination, Treatment, and Rehabilitation, Proprioception < Sensorimotor / Neuromuscular / Neuromechanical Biomechanics < Examination, Treatment, and Rehabilitation, Range of motion < Sensorimotor / Neuromuscular / Neuromechanical Biomechanics < Examination, Treatment, and Rehabilitation
Keywords:	Multi-day running, athletic therapy, Musculoskeletal Physiology

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Key Points:

- Flexibility, proprioception and balance performance progressively decrease during a multi-day running event.
- Athletic trainers should design recovery and injury prevention strategies to be used with-in competition based on with-in event data collection.
- Future studies should adopt this novel with-in competition data collection method to appreciate the dynamic nature of musculoskeletal physiology.

Key words: Multi-day running; athletic therapy; musculoskeletal testing.

Abstract

Multi-day running events are increasingly popular however, research in these events is lacking and fails to consider the dynamic nature of musculoskeletal physiology. Twenty-three athletes completing a ten-day marathon event participated in the study. Proprioception, dynamic balance, knee valgus and flexibility were assessed the day before the event and after one, five and nine consecutive marathons. There were significant reductions in these measurements across the event and reductions were more apparent in the non-dominant side. Each runner suffered on average 4.2 injuries. Runners performed significantly worse in musculoskeletal measurements, particularly on the non-dominant side, as the competition progresses. Therefore, athletic trainers should design appropriate between-day recovery strategies during events based on with-in event data collection.

Introduction

Ultra-distance running events continue to increase in popularity[1]. The distance of these events is greater than 26.2 miles with total running times typically over six hours, occurring over multiple days[2]. It is perhaps not surprising that there are higher injury rates in these events relative to shorter running distances[3], running of this nature may cause repeated stresses on tissues in a fatigued state[4]. Indeed, injuries occurred in between 60% and 100% of all competitors in previous research on ultra-distance events[5-7]. Furthermore, in a 7-day running event 84.8% of 396 runners required medical attention, which was equivalent to 3.8 injuries per runner or 7.2 injuries per 1000 hours[3]. However, there is a lack of research investigating musculoskeletal physiology changes that may inform athletic practice during multi-day running events.

It is important for practitioners to know how the musculoskeletal system changes to design effective with-in event treatments[8]. A dynamic approach to injury prevention has been developed in a model of etiology in sport injury[9]. Importantly, this incorporates repeated exposure to events that may lead to musculoskeletal adaptations[9]. This cyclical approach is one that is often missed in literature with clinical measurements being taken only once, before the race occurs; for example, static measures of alignment[10]. However, it is important to consider how the body may adapt across a performance taking the dynamic nature of injury occurrence into consideration.

There is very little research on the changes in musculoskeletal physiology during a multi-day running event[5]. One important measurement is neuromuscular control which has been linked to efficient running technique[11]. Poor proprioceptive ability (the ability to perceive position, movement and force of the limbs during running[12]) may be linked to changes in running performance as the central nervous system may not receive effective afferent information (feedback mechanisms) and hence prepare the correct muscle activity for impending perturbations (feed-forward mechanisms)[12]. Dynamic balance relies on good neuromuscular control and poor ability is possibly linked to running injuries due to excessive knee valgus positions from poor hip adductor strength during running[13-15]. An increased or decreased range of motion has previously been cited as a potential risk of injury[16-17] due to a potential increase in compressive and tensile stress on lower-limb joints[18]. Therefore, it is important these measures are monitored across a multi-day event to identify when musculoskeletal physiology changes and if athletic therapy is required.

The lower-extremity is the most common location for running injuries in multi-day events[19]. Therefore, the current study considered knee joint position sense (JPS), lower-limb dynamic balance, knee neuromuscular control during single-leg landing and hip and ankle flexibility adaptations during a multi-day event. The aim of this study was to evaluate the effect of running one, five and nine consecutive marathons on musculoskeletal physiology using in-competition data collection methods.

Methods

Participants

A total of 23 athletes (age 44.7±7.59years, mass 75.1±12.99kg, self-reported weekly mileage 43.3±12.67miles) participated in this prospective cohort study. The event involved completing 10 marathons in 10 consecutive days on the same course, however data was collected after day zero (D0), marathon one (M1), five (M5) and nine (M9). Table 1 describes participant characteristics. All participants provided voluntary, written informed consent and the rights of the participants were protected. The study was ethically approved by the University Review Board (ref: DC/SB 15/19).

Instrumentation

Knee JPS was collected using a camera (Casio Exilim, EX-FC100, Casio Electronics Co., Ltd. London, UK) on a fixed, level tripod. Dynamic balance was collected using a "Y symbol" taped to the floor (see figure 1) and tape measure. Knee neuromuscular control data was collected using a camera (Casio Exilim, EX-FC100, Casio Electronics Co Ltd, London, UK) mounted on a fixed, level tripod. Flexibility was collected using a 30cm goniometer (Baseline® Evaluation Instruments, White Plains, NY) and tape measure.

Tasks

Reliability statistics for tasks are reported in Table 2.

Knee JPS

Markers were placed on a point on a line following the greater trochanter to the lateral femoral epicondyle, the lateral femoral epicondyle and the lateral malleolus on the dominant leg. The athlete was seated on the end of a treatment table and blindfolded. The leg was passively moved by the experimenter through 30°–60° of extension from a starting knee angle of 90° or 60°–90° of flexion from a starting angle of 0° at an approximate angular velocity of 10°/s (see figure 2). The target angle was held by the athlete for 5s before the researcher returned the limb to the starting position. The athlete then replicated the target position. Knee positions were captured using photographs and digitising software (Kinovea, v0.8.15, Joan Chamant & Contrib, 2006-2011). The delta score between target and reposition angles was taken as the absolute error score in degrees and averaged across five trials. The protocol has been validated against an isokinetic dynamometer[20].

The Modified Star Excursion Balance Test (SEBT)

Dynamic stability was measured using the modified SEBT. Briefly, this task involves single leg squats, with the non-weight bearing leg reaching maximally towards anterior, posterior-medial and posterior-lateral directions along a designated line and then returning to the start position of single leg stance. Further detail of this protocol can be found in Munro and Herrington[22]. Each runner completed four trials in each direction on both legs and results were normalised to leg length.

Knee Neuromuscular Control

Knee neuromuscular control was measured using maximum knee valgus angle during single-leg-landing. Markers were placed on the mid-point of the femoral condyles, the mid-point of the ankle malleoli and the anterior superior iliac spine on both legs. The athlete stepped forward from a 30-cm height, dropping as vertically as possible landing in a single-leg stance and holding for 3s, completing three trials on each leg. A trial was void if the non-stepping leg touched either the step or the floor during the task. Knee valgus angles were measured as the greatest angle between the line from the ASIS to the patella and the patella to the ankle marker during the landing performance using digitising software (Kinovea, v0.8.15, Joan Chamant & Contrib, 2006-2011) and the average taken. This task is correlated to forward running technique[25].

Lower-Limb Flexibility

Two experienced athletic trainers took flexibility measurements on both legs with consistent roles in each protocol. The pelvis was stabilised to avoid compensatory movements in hip measurements. The flexibility of the iliotibial band was collected using the Ober's protocol[26]. Hip adductor flexibility measurements were taken in a supine position, the goniometer arms placed in-line with the contralateral anterior-superior iliac spine and the anterior mid-line of the ipsilateral femur. The runner actively performed maximal hip abduction and the value on the goniometer was recorded. Ankle dorsiflexion flexibility was measured using the knee to wall protocol detailed in Powden, Hoch and Hoch[28]. The runner completed the test in a tandem stance, with the tibia progressing over the talus and the heel remaining fully on the ground until the knee touches the wall. Internal and external rotation of the hip was measured following the Bullock-Saxton and Bullock protocol[29]. The runner was in prone and the knee passively flexed by the first examiner to 90°. The stationary arm of the goniometer was positioned parallel to the testing surface and the moving arm was placed along the tibia. The additional examiner then palpated the opposite posterior-superior iliac spine and the original examiner passively externally or internally rotated the limb. The measurement was taken at the point before the pelvis began rotating.

Procedures

Data was collected in a sports clinic between May 2015 and June 2016. The number of injuries per athlete was recorded by two athletic trainers three times daily (further details of injury data is reported elsewhere[30]). An injury was defined as a specific musculoskeletal abnormality that the runner perceived to affect performance[5].

Statistical Analysis

Normality was checked using the Shapiro-Wilk test, if confirmed, the means and standard deviations of parametric measures were calculated. One-way repeated measures ANOVAs were used to explore the main effect of time and then post-hoc Bonferroni comparisons were utilised when required to complete multiple (six) comparisons. Non-normal data was presented as medians and interquartile ranges and analysed using Friedman's ANOVA and Wilcoxon Signed Rank tests. The significance level was accepted at $p \leq 0.05$.

Results

In total 73%, 50%, 69% and 70% of the sample completed all knee JPS, SEBT, knee valgus and flexibility testing respectively (see Table 3). Post-hoc analysis revealed no significant differences between completers and drop-outs for baseline measures of each tests. Non-parametric data (medians) and parametric data (means) is presented in Table 4.

Knee JPS

There were no effects of time on knee JPS into extension but was into flexion. JPS ability improved from D0 to M1 by 2.4° and reduced from M0 to M5 by 1.3°. On one or more occasions in the event 85% of runners demonstrated JPS difference scores above the SDD into flexion.

Dynamic Balance

Results of the modified SEBT did not alter during the competition on the dominant leg for anterior and posterior-lateral reach directions. However, posterior-medial reach distances reduced from D0 to M5 by 15% of leg length and from D0 to M9 by 19% of leg length (both above the SDD) and 80% of participants produced results above the SDD.

Anterior reach distance, posterior-medial reach distance and posterior-lateral reach distance all reduced on the non-dominant side. The anterior reach distances reduced by 9% of leg length from D0 to M9 (above the SDD). The posterior-medial reach distance reduced by 5% of leg length from D0 to M1 (below the SDD) and by 13% of leg length from D0 to M9 (above the SDD). The posterior-lateral reach distances reduced by 12% of leg length from D0 to M9 (above the SDD). 70% of runners produced differences greater than the SDD for anterior reach, 90% for posterior-medial reach data and 80% for posterior-lateral reach data.

Knee Neuromuscular Control

Knee neuromuscular control did not significantly change during the event for either the dominant or non-dominant side, indeed 77% of runners did not demonstrate difference values over the reported SDD.

Lower-Limb Flexibility

Adductor flexibility and ankle dorsiflexion flexibility on the dominant side of the body reduced. Adductor flexibility reduced from D0 to M5 by 5.6° and M9 by 10.8°. This flexibility also reduced from M1 to M9 by 11°. 91% of runners' data exceeded the reported SDD. Ankle dorsiflexion flexibility was reduced from D0 to M1 (by 1.41cm), M5 (by 2.65cm) and M9 (by 3.40cm). There was also a significant reduction in this flexibility between M1 and M9 (by

2.00cm). 87% of runners had differences above the SDD during the event. The remaining flexibility measurements on the dominant side did not change.

All flexibility measures on the non-dominant side significantly reduced. ITB flexibility reduced from D0 to M9 (by 0.98cm) and from M1 to M9 (by 0.50cm). Flexibility of the adductor muscles again reduced from D0 to M9 (difference 9.1°) and M5 (difference 8.2°). This flexibility also significantly decreased when comparing M1 to M5 (difference 7.4°) and M9 (difference 8.3°). 87% of runners' data was above the reported SDD. A similar pattern was evident in ankle dorsiflexion flexibility, there were differences between D0 and M5 (difference 2.72cm) and M9 (difference 4.6cm). Ankle dorsiflexion flexibility was also worse after M9 compared to M1 (difference 3.6cm) and marathon five (difference 1.8cm). For this measurement 83% of runners displayed differences above the SDD. Internal hip rotation on the non-dominant side significantly increased between D0 and M9 (difference 6.0°). External hip rotation also significantly reduced over time from D0 to M5 by 7.6° and M9 by 10.5°. 78% of runners displayed differences greater than the SDD for hip rotation measures.

There were 4.2 injuries per runner; 89% of injuries involved the lower extremity; 24.1% in the foot, 18.5% the hip/buttock, 16.7% the ankle and 16.7% in the lower leg.

Discussion

The aim of this study was to measure the effects of a multi-day running event on knee proprioception, dynamic balance, knee neuromuscular control and flexibility. The results suggest these measures, particularly on the non-dominant side, decrease in performance from D0 to M5 and again to M9 during the event.

Knee Proprioception

There was an initial improvement in knee JPS into flexion from D0 to M1, but this difference was below SDD values[21]. However, knee JPS into flexion reduced from D0 to M5 and this difference was above SDD values[21]. This suggests knee JPS may not reduce after running one marathon but could be impaired after five marathons. To our knowledge this is the first paper to consider JPS ability during a multi-stage running competition. However, previous research has reported a reduction in JPS ability following treadmill running to fatigue[31-32]. Three theories have been proposed to explain the mechanisms behind this finding; impaired excitation of motor units[33], increase in knee laxity[34] and increase in pain[33]. All explanations suggest the afferent signalling used by the CNS to process JPS information is disrupted with fatigue, therefore making this process unstable and increasing errors[35]. Knee flexion occurs in running from initial touch down to mid-swing phases[36]. If the runner is unable to correctly perceive the position of their knee this could lead to errors in efferent signalling used for movement preparation. The results of the current study suggest knee JPS ability into flexion reduces after completion of five marathons. Therefore, athletic trainers may incorporate proprioceptive exercises after five days of running.

Dynamic Balance

Dynamic balance significantly reduced in all reach directions on the non-dominant limb and the posterior-lateral direction on the dominant limb from D0 to M9 and all average differences were above SDD values[22]. Again, to the author's knowledge, this is the first study to measure dynamic balance ability during a multi-day running event. However, the findings from the current study support previous literature that reported a decrease in balance performance following shorter running activities; for example, Steib[37] reported a decrease in SEBT performance following treadmill running to exhaustion. Other authors used different methods of balance measurement to present a reduction in ability with fatigue[38-39]. A reduction in dynamic balance has been suggested to potentially increase the risk of running injuries due to a loss in neuromuscular control in lower extremity joints[31, 40]. The results of dynamic balance in the non-dominant leg got progressively worse across the event with the biggest performance decrease from D0 to M9. This has important implications for the timing of prevention and treatment strategies during an ultra-endurance event, athletic trainers should introduce dynamic balance exercises with-in ultra-running events.

Knee Neuromuscular Control

There were no significant changes to knee neuromuscular control on either leg. This is an unexpected finding however, Munro[24] stated the SDD as 7.54°-7.90° for the task and the greatest differences in this study were below the SDD. Therefore, 2D manual digitisation may not be sensitive enough to identify changes in knee valgus angle.

Lower Limb Flexibility

Increased flexibility may be desirable for optimal running performance[41]. The flexibility of the adductor muscles and ankle dorsi-flexors significantly reduced on both the dominant and non-dominant sides during the event. All adductor differences were above the reported SDDs apart from dominant leg, D0 to M5. Poor hip adductor flexibility has been linked to reduced stability at the hip and knee joint during gait and increased risk of ITB syndrome[42]. The flexibility of the adductor ankle dorsi-flexors also significantly reduced on both legs and differences were above the SDD except between D0 and M1 on the dominant leg. A reduction in ankle dorsi-flexion may change running mechanics at the ankle, specifically in preparation for foot strike; if the ankle is less flexed, this can modify foot strike patterns and lower-limb absorption mechanics and hence increase ground reaction forces[43]. Reduced ankle dorsi-flexion has been linked to injuries to the knee[44] and foot[45] due to an increase in force transmitted along the kinetic chain.

The non-dominant limb also had reduced flexibility in the remaining measurements. Hip internal rotation increased, and external rotation decreased in flexibility across the competition and all differences were above the SDD. A modification in hip internal movement has been associated with modified knee kinematics that may possibly be linked to injury[46]. Poor hip control can lead to reduced neuromuscular control lower in the kinetic chain and potentially an increased risk of injury[46]. Furthermore, a reduction in ITB flexibility may potentially cause patello-femoral pain[47] and ITB syndrome[48]. These results suggest athletic trainers should consider flexibility recovery strategies after each day of a multi-day running event, particularly on the non-dominant side.

Limitations

Fatigue was not measured objectively, however, previous research has demonstrated fatigue will be present during ultra-marathon events[49]. Reliability estimates were taken from prior studies. However, knee JPS measures were taken by the same assessor from the reliability study. Also, there is over a decade's worth of reliability literature on both flexibility and SEBT measurements. The dropout levels should also be acknowledged; however, appropriate statistical analysis was used based on the assumption of normality.

Clinical Implications

The results of this study suggest musculoskeletal physiology performance worsens after five days of marathon running and by nine days this may be significant. Athletic trainers should design individual interventions based on in-event testing that runners can perform both before and during events that target flexibility, knee neuromuscular control and dynamic balance.

Future Research

The Meeuwisse model[11] of injury prevention states risk of injury is cyclical, hence is event and time dependent, therefore, it is recommended that the in-event data collection design should be utilised in further work with larger sample sizes.

Conclusion

Multi-day running events can cause over four injuries per runner and musculoskeletal physiology measures worsen progressively across competitions. Athletes should be aware of the potential changes that will occur and prepare appropriately. Importantly, these modifications became more apparent during the competition; these findings would not have been identified if traditional research designs that do not take measurements within competition had been used. Hence athletic trainers should consider in-event measurement with a view to prescribe recovery strategies that incorporate this knowledge (i.e. balance and flexibility recovery methods) in competition.

Acknowledgements

The authors would like to thank Brathay Trust for their assistance in recruiting runners to participate in this research study and to all the runners themselves for their commitment to the study.

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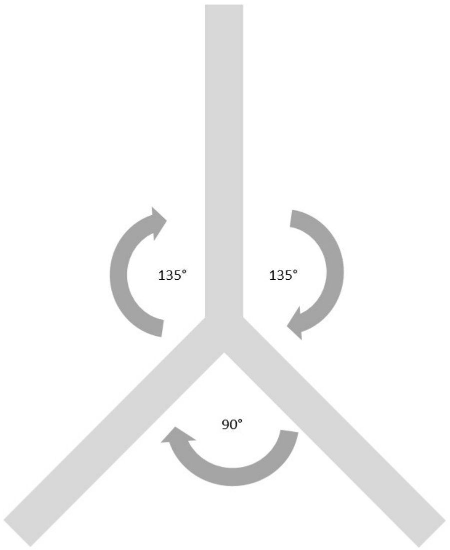

Figure 1. Modified Star Excursion Balance Test (SEBT) set-up

215x279mm (150 x 150 DPI)

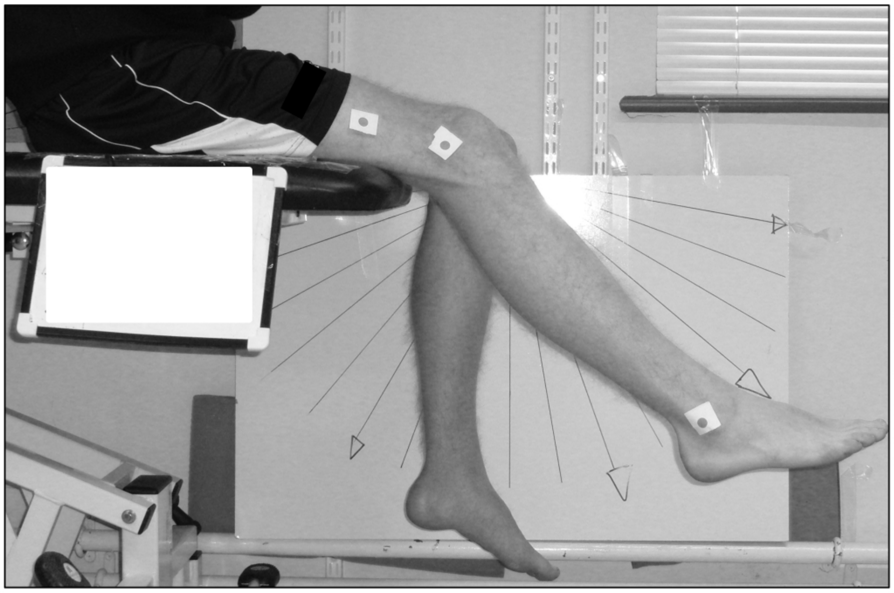

Figure 2. Example of Knee Joint Position Sense (JPS) data collection set-up

665x563mm (144 x 144 DPI)

Table 1. Participant Characteristics (mean±SD unless stated).

Flexibility Testing (n=23)	
Age (years)	44.7±7.59
Mass (kg)	75.1±12.99
Gender (males/females)	16/7 (number)
Knee JPS and Neuromuscular Control (n=13)	
Age (years)	46.8±5.03
Mass (kg)	72.3±13.02
Gender (males/females)	9/4
Dynamic Balance (n=10)	
Age (years)	42.0±9.61
Mass (kg)	78.8±12.66
Gender (males/females)	7/3 (number)

Table 2. Reliability statistics

Protocol	Test-retest reliability (ICC)	Smallest Detectable Difference (SDD)
Knee Joint Position Sense[21]	Knee Flexion 0.92 Knee Extension 0.86	Knee Flexion 1.10° Knee Extension 1.67°
Star Excursion Balance Test[22-23]	0.84-0.92	Anterior reach 6.87% leg length Posterior-medial reach 8.15% leg length Posterior-lateral reach 7.11% leg length
Knee Neuromuscular Control[24]	Men 0.80 Women 0.82	Men 7.54° Women 7.90°
Ober's Protocol[26]	0.82-0.92	Not available
Hip Adductor Flexibility[27]	0.92-0.99	5.1° - 7.6°
Ankle Dorsiflexion Flexibility[28]	0.99	1.57cm
Internal Hip Rotation[29]	0.98	4.29°
External Hip Rotation[29]	0.99	6.11°

Table 3. Drop out data (absolute number of runners at each time phase).

Risk Factor	**Day zero**	**Marathon 1**	**Marathon 5**	**Marathon 9**	**Completion**
Flexibility	23	23	18	16	70%
Knee JPS	13	12	11	8	73%
Knee Neuromuscular Control	13	12	10	9	69%
SEBT	10	10	6	5	50%

Table 4. Mean±SD measurements for parametric data and Median [IQR] measurements for nonparametric data at day zero (D0), marathon one (M1), five (M5) and nine (M9) for parametric data. SEBT = Star Excursion Balance Tests. *p≤0.05, **p≤0.01, ***p≤0.001.

Variable	**D0**	**M1**	**M5**	**M9**	**Main Effect p-value**	**Significant Post-hoc analysis**
Knee Joint Position Sense Extension (°)	3.6±1.9	3.7±1.8	3.3±2.3	2.8±1.2	0.65	N/A
Knee Joint Position Sense Flexion (°)	4.7 [3.3]	2.9 [2.2]	3.3 [2.9]	3.3 [3.4]	0.03	D0 v M1** M1 v M5*
Dominant Leg SEBT Anterior (% of leg length)	85±8.3	85±5.0	80±11.5	75±6.6	0.15	N/A
Dominant Leg SEBT Posterior Medial (% of leg length)	101 [18.0]	90 [11.2]	86 [13.6]	82 [17.6]	0.01	D0 v M5* D0 v M9*
Dominant Leg SEBT Posterior Lateral (% of leg length)	86±10.7	84±14.5	80±14.2	79±11.4	0.42	N/A
Non-Dominant Leg SEBT Anterior (% of leg length)	86 [12.4]	83 [11.6]	80 [8.7]	77 [6.4]	0.05	D0 v M9*
Non-Dominant Leg SEBT Posterior Medial (% of leg length)	96±8.6	91±10.4	84±10.9	83±7.4	0.004	D0 v M* D0 v M9*
Non-Dominant Leg SEBT Posterior Lateral (% of leg length)	86 [15.4]	85 [12.7]	82 [19.1]	74 [118.6]	0.02	D0 v M9*
Dominant Leg Knee Valgus (°)	5.8±2.0	5.5±3.1	6.5±5.4	6.9±5.1	0.57	N/A
Non-Dominant Leg Knee Valgus (°)	7.6±4.9	8.6±3.5	5.9±4.7	7.8±3.7	0.85	N/A
Dominant Leg Iliotibial Band Flexibility (cm)	14.9±1.7	14.8±1.8	15.3±1.8	15.6±2.0	0.21	N/A
Non-Dominant Leg Iliotibial Band Flexibility (cm)	14.6±1.9	15.1±1.7	15.6±1.8	16.8±2.0	0.001	D0 v M9** M1 v M9*

Dominant Leg Ankle Dorsiflexion Flexibility (cm)	11.0±3.1	9.6±3.3	8.4±3.3	7.6±2.9	0.001	D0 v M1** D0 v M5 *** D0 v M9 *** M1 v M9*
Non-Dominant Leg Ankle Dorsiflexion Flexibility (cm)	10.5±3.0	9.6±3.7	7.8±2.8	5.9±2.5	0.001	D0 v M5*** D0 v M9*** M1 v M9** M5 v M9**
Dominant Leg Internal Hip Rotation (°)	31.8±9.5	35.3±9.7	34.7±9.4	34.1±5.4	0.32	N/A
Dominant Leg External Hip Rotation (°)	29.8±11.4	30.5±13.5	30.4±9.6	29.1±8.5	0.24	N/A
Non-Dominant Leg Internal Hip Rotation (°)	31.1±9.9	32.9±10.6	34.3±7.4	37.1±6.5	0.01	D0 v M9**
Non-Dominant Leg External Hip Rotation (°)	34.7±11.6	31.8±12.3	27.2±8.0	24.2±6.9	0.001	D0 v M5* D0 v M9*