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ORIGINAL ARTICLE

Immediate neuromuscular and autonomic responses to three pre-competition relaxation packages in collegiate basketball players: A preliminary randomized trial

Li-Ying Wei. *Department of Tourism and Leisure Management. Lee-Ming Institute of Technology. New Taipei City, Taiwan.*

Ming-Yi Liu . *Department of Senior Welfare and Service. Southern Taiwan University of Science and Technology. Tainan City, Taiwan.*

Chin-Li Lin. *Department of Athletic Training and Health. National Taiwan Sport University. Taoyuan City, Taiwan.*

ABSTRACT

Brief pre-competition procedures may alter physiological state, but their functional meaning is uncertain. This preliminary, unregistered randomized trial compared three multicomponent packages in 45 male athletes from one Taiwanese collegiate Division A basketball programme (15 per group): guided meditation (MR), topical cedarwood preparation followed by seated rest (AR), and the topical procedure followed by guided meditation (MAR). Heart rate, heart rate variability, and dominant-leg stiffness at four muscles were measured 48 and 24 hours before competition, immediately preintervention approximately 2 hours before competition, and immediately after the 16-minute intervention. Repeated-measures analyses were planned; the primary-outcome designation, change-score, ANCOVA, and marginal-model analyses were post hoc. ANCOVA of T3-to-T4 change adjusted for T3 stiffness, height, and weight showed a group effect, $F(2, 39) = 15.30$, $p < .001$. Adjusted differences were −4.99 N/m for AR versus MR, 95% CI [−8.08, −1.90]; −8.01 N/m for MAR versus MR, 95% CI [−10.95, −5.08]; and −3.02 N/m for MAR versus AR, 95% CI [−5.87, −0.18]. A longitudinal marginal model supported a group-by-time interaction, Wald $\chi^2(6) = 60.88$, $p < .001$. Unadjusted within-group reductions were 1.6%, 3.0%, and 4.2%, respectively. Of nine secondary ANCOVAs, LF/HF, hamstring, and lateral-gastrocnemius effects retained false-discovery-rate significance; autonomic findings remained mixed. No passive or component-matched control was included, and performance was not measured. The packages were associated with different immediate stiffness responses; the active component and performance relevance remain unknown.

Keywords: sport medicine; heart rate variability; myotonometry; pre-performance preparation; team sport; feasibility.

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Corresponding author. *Department of Senior Welfare and Service, Southern Taiwan University of Science and Technology, No. 1, Nan-Tai Street, Yongkang District, Tainan City 71005, Taiwan.*
E-mail: liumiyi@stust.edu.tw
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INTRODUCTION

Pre-performance preparation is not simply a search for maximal relaxation. Team-sport athletes may require an individualized balance of arousal, attention, muscle activation, and mechanical stiffness. Acute game-day routines can influence subsequent physical output, while psyching-up strategies may support force production in some tasks (Mason et al., 2020; Tod et al., 2003). A brief down-regulation procedure immediately before competition should therefore be described as acute state regulation unless readiness or performance is measured directly.

Mindfulness and meditation interventions have been studied in athletes, but effects vary across psychological, physiological, and performance outcomes (Bühlmayer et al., 2017). Aromatic and topical procedures are more difficult to isolate because inhalation, carrier oil, touch, provider attention, expectancy, and quiet rest can contribute to the observed response. Placebo and expectancy effects are relevant in sport and should be measured or controlled when possible (Beedie et al., 2018). Accordingly, a topical aromatherapy condition without carrier-oil, touch-only, placebo-fragrance, and seated-rest controls represents a multicomponent package rather than a test of cedarwood chemistry alone.

Heart-rate variability (HRV) is often used to characterize autonomic regulation, but short recordings are sensitive to respiration, posture, recording duration, signal processing, and device scaling. The LF/HF ratio in particular should not be treated as a direct measure of sympathovagal balance (Billman, 2013). Guided meditation can change breathing, making unpaced and unrecorded respiration a major interpretive constraint.

Localized muscle stiffness is likewise not uniformly beneficial or detrimental. Greater resting calf stiffness has been associated with some explosive-performance measures, whereas massage research does not show consistent direct improvements in sprint, jump, strength, or endurance performance (Ando et al., 2021; Davis et al., 2020). Myotonometry can quantify a local mechanical parameter with useful reliability under specified protocols, but reliability and minimal detectable change depend on the muscle, posture, assessor, and device protocol (Lee et al., 2021; Trybulski et al., 2024). An unweighted mean across muscles should therefore be interpreted as a descriptive summary rather than a validated latent construct of readiness.

This preliminary randomized three-arm trial compared the immediate autonomic and dominant-leg stiffness responses associated with three pragmatic pre-competition packages: guided meditative relaxation, a topical cedarwood preparation followed by seated rest, and the topical procedure followed by guided meditation. The study was designed for feasibility and signal detection in an applied tournament setting. Because it did not include a neutral or component-matched control, it estimates differences among packages and cannot identify the specific effects of meditation, cedarwood, touch, carrier oil, expectancy, or their interaction.

MATERIAL AND METHODS

Design, setting, registration, and analytical timeline

This was a preliminary three-arm, parallel-group randomized trial conducted in a quiet player lounge during the pre-competition period of a collegiate basketball tournament. Recruitment began on 6 June 2024, and data collection was completed within the following three weeks. The trial was not prospectively registered, no public protocol was available, and no formal sample-size calculation was performed. These design limitations were known when the revised report was prepared.

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Before data analysis, the investigators planned to examine HRV and lower-limb stiffness across four time points using repeated-measures analysis of variance. The plan did not document a single primary outcome, a covariate set, or a multiplicity strategy. During preparation of the original journal submission, the unweighted mean of four muscle-specific stiffness values was designated the primary outcome, and T3-to-T4 change scores, 95% confidence intervals, standardized effects, analysis of covariance (ANCOVA), and marginal-model sensitivity analyses were added. These designations and analyses are therefore reported as post hoc. The present revision centres interpretation on the randomized between-group estimates while retaining within-group tests as descriptive secondary analyses.

Participants

Forty-five male athletes aged 18–25 years were recruited from one institution and one collegiate basketball programme. All 45 athletes approached and screened were eligible, consented, were randomized, completed all measurements, and were analysed. No athlete declined participation or failed screening. 'Division A' refers here to the locally designated first-tier Taiwanese collegiate competition category; the sample should not be assumed to represent other national competition systems.

Eligibility criteria included at least 20 hours of basketball training per week, at least two consecutive years of training experience, and previous exposure to aromatherapy and meditation guidance. The amount and type of prior exposure were not quantified. Exclusion criteria were skin or infectious disease, active medical treatment for psychiatric, emotional, or sleep disorders, hospitalization or surgery within the preceding three months, addiction, and regular use of neuromuscular-relaxation supplements. Playing position, ethnicity, weekly match exposure, caffeine, food, hydration, sleep, prior training load, warm-up activity, time of day, perceived relaxation, state anxiety, expectancy, fragrance preference, and intervention credibility were not recorded in the analysis dataset.

The study complied with the Declaration of Helsinki and received approval from the Institutional Review Board of National Taiwan Sport University (approval No. NTSUIRB-113-011; 16 April 2024). All participants provided written informed consent.

Randomization, allocation, and blinding

Li-Ying Wei recruited participants, conducted the simple non-stratified lottery, assigned participants in a 1:1:1 ratio, and delivered the interventions. No blocking, stratification, or formal allocation concealment was used. Chin-Li Lin, who did not deliver the intervention, performed the HRV and myotonometry measurements. Ming-Yi Liu conducted the statistical analyses. Participant and provider blinding was infeasible because the packages differed in scent, touch, rest, and meditation. Outcome-assessor blinding and statistical blinding were not documented or implemented. These procedures create risks of selection, performance, and detection bias, even though intervention delivery and outcome measurement were performed by different investigators.

Outcome measurements

Anthropometry

Height, weight, and body-fat percentage were assessed using a bioelectrical impedance analyser (InBody 230; Biospace, South Korea). The dominant leg was identified using a simulated forward-kicking task and backward balance-perturbation test.

Autonomic outcomes

Heart rate and HRV were recorded once at each time point with an SC-101 portable HRV spectral analyser (Want Want Biotech, Taiwan). The device acquired a lead-I electrocardiographic signal at 500 Hz while the participant sat naturally relaxed on a sofa with the fingers of both hands contacting the electrode plates. Each recording lasted approximately 4–5 minutes, until the proprietary analysis was completed. Device software generated heart rate, the standard deviation of normal-to-normal intervals (SDNN), low-frequency power (LF), high-frequency power (HF), and the LF/HF ratio. LF and HF were reported on the device scale rather than in conventional absolute or normalized units. Respiration was neither paced nor recorded. The pre-recording stabilization period, analysed window, artefact-detection and correction rules, and independent validity of the proprietary processing were not available in the study records.

Muscle stiffness

A single assessor (Chin-Li Lin) used a Myoton-3 myometer (Muomeetria AS, Tallinn, Estonia) to assess the dominant-leg quadriceps, tibialis anterior, hamstrings, and lateral gastrocnemius. The probe was held perpendicular (90 degrees) to the selected site. Three consecutive readings were obtained at each site and averaged. Exact anatomical landmarks, participant posture, muscle-state verification, stabilization interval, measurement order, assessor training details, and within-session reliability were not recorded with sufficient specificity for complete replication.

The manuscript reports an unweighted arithmetic mean of the four muscle-specific averages. This measure was designated after data collection, has not been validated as a latent construct, and assumes equal contribution of muscles with different functions and distributions. It is therefore termed the four-muscle mean stiffness in this revision. Muscle-specific outcomes and all autonomic outcomes are exploratory.

Procedures and intervention packages

Measurements were collected 48 hours before competition (T1), 24 hours before competition (T2), approximately 2 hours before competition immediately before intervention (T3), and immediately after intervention (T4). The player lounge was quiet and comfortable, maintained at approximately 25 °C, naturally lit, equipped with soft sofas, and kept free of pre-existing odours, fragrances, television, and audio interference. Ventilation was not quantified.

Meditative-relaxation package (MR)

Participants received a standardized 16-minute guided session delivered by a certified hypnosis and psychological consultant. The session included preparatory verbal guidance, breath observation, guided meditation, and imagery. Participants sat comfortably with eyes closed and palms facing upward on the thighs.

Topical-aromatherapy/rest package (AR)

A certified international aromatherapy instructor (Li-Ying Wei) mixed 0.9 mL (18 drops) of Himalayan cedarwood essential oil (Cedrus deodara) with 30 mL sweet almond carrier oil, labelled as an approximately 3% blend. Participants lay prone on a clean treatment table while the provider slowly spread the blend from the first cervical to the twelfth thoracic vertebra over an area approximately 10 cm wide, ensuring coverage. Participants then sat on a sofa with eyes closed for 16 minutes. The exact volume applied per participant, contact duration, rationale for the anatomical region, body-surface-area adjustment, batch chemistry, and volatile exposure were not measured.

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Combined package (MAR)
Participants received the same topical procedure as AR followed by the same 16-minute guided meditation as MR. Consequently, AR and MAR included fragrance, carrier oil, tactile contact, provider attention, and quiet rest, while MAR also included guided meditation. No passive seated-rest, placebo-fragrance, carrier-oil-only, or touch-only group was included.

Adverse-event monitoring
Li-Ying Wei actively asked participants about skin irritation, dizziness, discomfort, respiratory symptoms, and other adverse reactions during the procedures and again after T4. The same investigator followed participants after the competition. No standardized checklist or prespecified severity grading was used.

Statistical analysis
Continuous variables are presented as means and standard deviations ($M \pm SD$). Baseline group differences were examined with one-way analysis of variance. The central revised inference is the post hoc ANCOVA of T3-to-T4 change in four-muscle mean stiffness, adjusted for the T3 value, height, and weight. Adjusted group contrasts are reported with 95% confidence intervals. All 45 randomized participants were analysed in their assigned groups, with no missing outcome data.

Longitudinal sensitivity analyses used Gaussian generalized estimating equations with group, time, their interaction, height, and body mass. An exchangeable working correlation accounted for repeated observations within participants, and participant-clustered sandwich standard errors were used. The models report Wald group-by-time tests, estimated marginal means at the sample mean height and body mass, model-based T3-to-T4 changes, and between-group change contrasts. Separate paired T3-to-T4 tests are descriptive and do not establish comparative efficacy. Post hoc pooled Pearson correlations explored associations of height and weight with T3 stiffness and stiffness change.

The post hoc primary family comprised the ANCOVA omnibus test for four-muscle mean stiffness and three pairwise contrasts; the contrasts used Holm correction. Nine secondary ANCOVA omnibus tests (five autonomic and four muscle-specific outcomes) used the Benjamini-Hochberg false-discovery-rate procedure and pairwise contrasts within each outcome used Holm correction. The nine secondary group-by-time tests used a separate Benjamini-Hochberg family. Twenty-seven secondary paired tests used Benjamini-Hochberg correction and remained descriptive. Confidence intervals for Cohen's d for paired observations were estimated with 10,000 participant-level bootstrap samples using the percentile method. Two-sided $p < .05$ or $q < .05$ was used as applicable.

RESULTS

Feasibility, participant flow, and baseline characteristics
All 45 enrolled athletes were randomized (15 per group), received the allocated package, completed all four measurements, and were included in analysis (Figure 1). No protocol discontinuation occurred. The procedures and repeated measurements were completed within the tournament schedule approximately two hours before competition.

Baseline characteristics are presented in Table 1. The MR group was taller and heavier than the other groups, whereas body mass index and body-fat percentage did not differ. This imbalance is consistent with the vulnerability of simple randomization in a small heterogeneous team-sport sample and may also reflect unmeasured playing-position or body-composition differences.

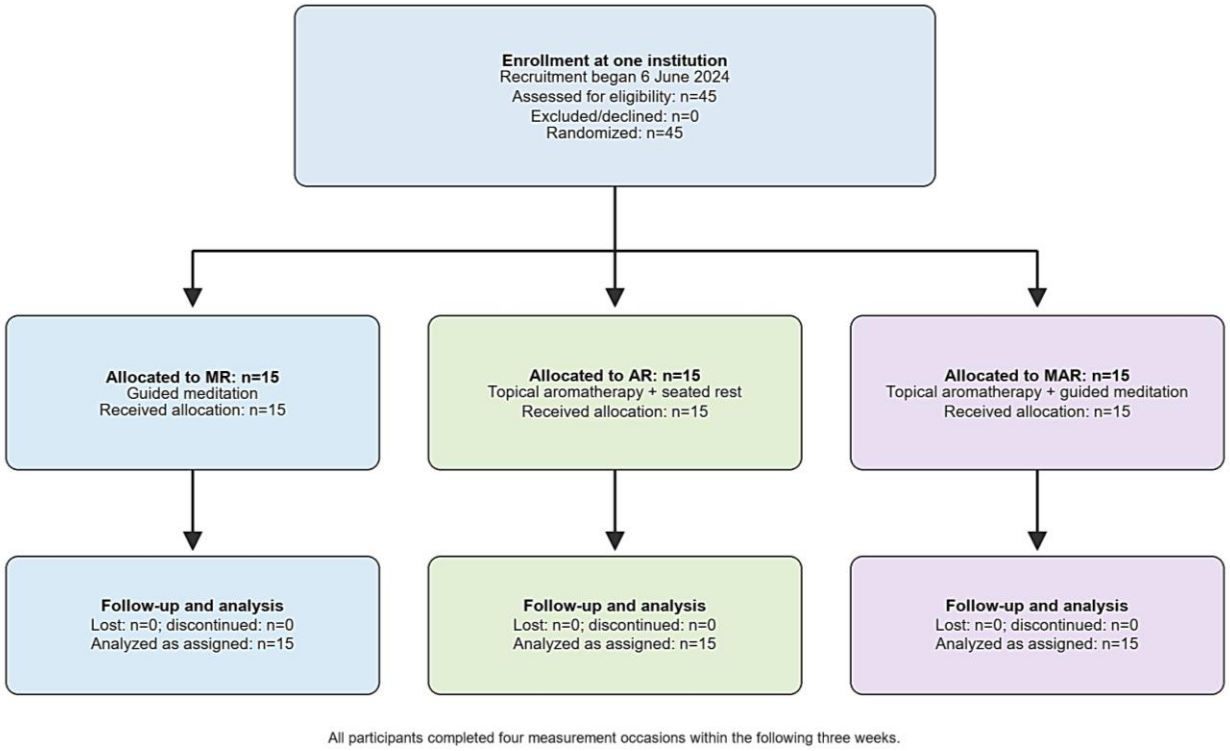

Figure 1. CONSORT participant flow. Recruitment began on 6 June 2024 at one institution. All 45 approached and eligible male collegiate Division A basketball athletes consented, were randomized equally, received the assigned package, completed follow-up, and were analysed.

Table 1. Baseline characteristics of participants.

Characteristic	MR (n = 15)	AR (n = 15)	MAR (n = 15)	*p*
Height, cm	186.40 ± 10.96	174.87 ± 6.35	180.20 ± 10.75	.008
Weight, kg	84.93 ± 16.47	73.33 ± 12.66	74.40 ± 11.84	.049
Body mass index, kg/m^2	24.41 ± 4.13	23.85 ± 2.74	22.80 ± 1.88	.349
Body fat, %	14.25 ± 6.66	17.79 ± 3.72	15.59 ± 2.48	.120

Note. Values are means ± standard deviations (*M* ± *SD*). The *p* values are from one-way ANOVA using the final study dataset. MR = meditative relaxation; AR = aromatherapy relaxation; MAR = combined meditative aromatherapy relaxation.

Table 2. Immediate T3-to-T4 changes in autonomic outcomes.

Outcome	Group	T3, M ± SD	T4, M ± SD	Change (95% CI)	Raw p	FDR q	Cohen's dz (95% CI)
Heart rate, beats/min	MR	71.21 ± 1.69	70.54 ± 1.85	−0.67 [−1.18, −0.17]	.012	.018	−0.74 [−1.35, −0.30]
Heart rate, beats/min	AR	70.93 ± 5.31	69.53 ± 4.41	−1.40 [−2.26, −0.54]	.004	.006	−0.90 [−1.38, −0.64]
Heart rate, beats/min	MAR	71.87 ± 4.09	69.27 ± 3.51	−2.60 [−4.12, −1.08]	.003	.004	−0.95 [−2.10, −0.41]
SDNN, ms	MR	36.67 ± 2.70	36.23 ± 2.81	−0.44 [−0.89, 0.01]	.057	.076	−0.54 [−1.64, −0.05]
SDNN, ms	AR	38.87 ± 3.27	37.80 ± 3.45	−1.07 [−2.63, 0.49]	.164	.211	−0.38 [−0.93, 0.12]
SDNN, ms	MAR	42.80 ± 2.48	40.93 ± 3.01	−1.87 [−2.65, −1.09]	< .001	< .001	−1.33 [−3.26, −0.69]
High-frequency power (device units)	MR	4.52 ± 0.23	4.32 ± 0.21	−0.20 [−0.29, −0.11]	< .001	< .001	−1.28 [−2.84, −0.70]
High-frequency power (device units)	AR	4.75 ± 0.32	4.64 ± 0.39	−0.11 [−0.30, 0.09]	.254	.298	−0.31 [−0.84, 0.20]
High-frequency power (device units)	MAR	5.53 ± 0.61	5.27 ± 0.62	−0.26 [−0.31, −0.21]	< .001	< .001	−3.14 [−4.94, −2.39]
Low-frequency power (device units)	MR	5.50 ± 0.52	5.38 ± 0.37	−0.12 [−0.30, 0.06]	.175	.215	−0.37 [−1.14, 0.12]
Low-frequency power (device units)	AR	5.15 ± 0.48	5.05 ± 0.46	−0.10 [−0.30, 0.10]	.290	.327	−0.28 [−0.91, 0.23]
Low-frequency power (device units)	MAR	5.27 ± 0.43	5.12 ± 0.38	−0.15 [−0.26, −0.05]	.008	.012	−0.80 [−2.08, −0.27]
LF/HF ratio	MR	0.25 ± 0.18	0.27 ± 0.09	0.02 [−0.03, 0.07]	.435	.470	0.21 [−0.67, 0.58]
LF/HF ratio	AR	0.27 ± 0.09	0.26 ± 0.06	−0.01 [−0.04, 0.02]	.598	.620	−0.14 [−0.70, 0.41]
LF/HF ratio	MAR	0.24 ± 0.08	0.29 ± 0.07	0.05 [0.03, 0.07]	< .001	< .001	1.70 [0.91, 5.39]

Note. Within-group tests are descriptive. MR = meditative relaxation; AR = aromatherapy relaxation; MAR = combined meditative aromatherapy relaxation; SDNN = standard deviation of normal-to-normal intervals; LF = low-frequency power; HF = high-frequency power; CI = confidence interval; FDR = false discovery rate. Change = T4 − T3. *q* values use Benjamini-Hochberg correction across 27 secondary within-group tests. Cohen's d_z denotes the standardized effect for paired observations. Standardized-effect intervals are 10,000-sample participant-level bootstrap percentile intervals.

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In exploratory pooled correlations, neither height (r = −.16, p = .282) nor weight (r = −.10, p = .503) was associated with T3 four-muscle mean stiffness. Weight showed a weak positive association with T3-to-T4 change (r = .30, p = .042; negative values indicate reduction), suggesting smaller reductions among heavier participants. These unadjusted correlations are exploratory.

Between-group stiffness comparison

The post hoc adjusted group effect for T3-to-T4 change in four-muscle mean stiffness was significant, $F(2, 39) = 15.30$, $p < .001$. Adjusted contrasts were −4.99 N/m for AR versus MR, 95% CI [−8.08, −1.90], Holm-adjusted p = .005; −8.01 N/m for MAR versus MR, 95% CI [−10.95, −5.08], Holm-adjusted $p < .001$; and −3.02 N/m for MAR versus AR, 95% CI [−5.87, −0.18], Holm-adjusted p = .038. The longitudinal marginal model also showed a group-by-time interaction, Wald $\chi^2(6) = 60.88$, $p < .001$, with exchangeable working correlation ρ = .992. Model-based T3-to-T4 contrasts were −4.54 N/m for AR versus MR, 95% CI [−6.97, −2.11]; −8.60 N/m for MAR versus MR, 95% CI [−11.72, −5.48]; and −4.06 N/m for MAR versus AR, 95% CI [−7.33, −0.80]. Estimated marginal means and robust intervals are reported in Supplementary Table S3.

Table 3. Immediate T3-to-T4 changes in dominant-leg stiffness.

Outcome (N/m)	Group	T3 M ± SD	T4 M ± SD	Change (95% CI)	Raw p	FDR q	Cohen's dz (95% CI)
Four-muscle mean stiffness	MR	293.61 ± 39.31	288.99 ± 40.74	−4.62 [−6.27, −2.97]	< .001	—	−1.55 [−2.63, −1.07]
Four-muscle mean stiffness	AR	310.38 ± 31.12	301.22 ± 30.06	−9.16 [−11.10, −7.22]	< .001	—	−2.61 [−5.43, −1.79]
Four-muscle mean stiffness	MAR	312.14 ± 31.82	298.92 ± 29.52	−13.22 [−16.04, −10.40]	< .001	—	−2.59 [−4.38, −1.86]
Quadriceps stiffness	MR	228.67 ± 23.50	222.91 ± 26.46	−5.76 [−7.84, −3.67]	< .001	< .001	−1.53 [−2.86, −1.03]
Quadriceps stiffness	AR	252.22 ± 40.54	242.98 ± 38.93	−9.24 [−13.99, −4.49]	< .001	.002	−1.08 [−1.71, −0.80]
Quadriceps stiffness	MAR	263.13 ± 21.14	254.82 ± 22.26	−8.31 [−12.03, −4.59]	< .001	< .001	−1.24 [−2.33, −0.85]
Tibialis anterior stiffness	MR	382.98 ± 63.25	376.40 ± 63.09	−6.58 [−9.55, −3.60]	< .001	< .001	−1.22 [−3.40, −0.55]
Tibialis anterior stiffness	AR	396.18 ± 49.26	385.93 ± 47.48	−10.24 [−14.68, −5.81]	< .001	< .001	−1.28 [−2.13, −0.83]
Tibialis anterior stiffness	MAR	398.47 ± 52.16	381.76 ± 48.40	−16.71 [−24.74, −8.68]	< .001	.001	−1.15 [−2.33, −0.93]
Hamstring stiffness	MR	268.33 ± 47.34	263.16 ± 48.61	−5.18 [−8.00, −2.36]	.001	.003	−1.02 [−1.77, −0.58]
Hamstring stiffness	AR	283.84 ± 29.88	276.44 ± 31.99	−7.40 [−10.30, −4.50]	< .001	< .001	−1.41 [−2.67, −0.90]
Hamstring stiffness	MAR	280.00 ± 40.93	269.62 ± 42.06	−10.38 [−12.54, −8.22]	< .001	< .001	−2.66 [−4.86, −1.78]
Lateral gastrocnemius stiffness	MR	294.47 ± 62.53	293.49 ± 66.44	−0.98 [−6.67, 4.71]	.718	.718	−0.10 [−0.97, 0.36]
Lateral gastrocnemius stiffness	AR	309.29 ± 47.41	299.53 ± 46.55	−9.76 [−13.54, −5.97]	< .001	< .001	−1.43 [−2.37, −1.03]
Lateral gastrocnemius stiffness	MAR	306.98 ± 50.36	289.49 ± 49.93	−17.49 [−24.42, −10.56]	< .001	< .001	−1.40 [−2.87, −0.76]

Note. MR = meditative relaxation; AR = aromatherapy relaxation; MAR = combined meditative aromatherapy relaxation; CI = confidence interval; FDR = false discovery rate. Change = T4 − T3. Cohen's d_z denotes the standardized effect for paired observations. The four-muscle mean is the post hoc primary outcome and is not included in the secondary FDR family. An em dash indicates that secondary-family FDR correction was not applied to that outcome. Muscle-specific q values use Benjamini-Hochberg correction across 27 secondary within-group tests. Standardized-effect intervals use 10,000 bootstrap samples.

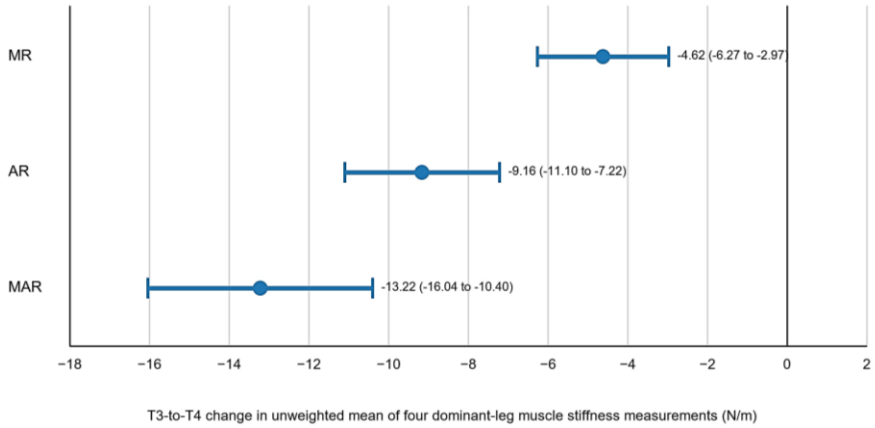

Figure 2. Immediate T3-to-T4 change in the unweighted mean of four dominant-leg muscle stiffness measurements. Points show group means and bars show 95% confidence intervals; numerical labels provide the mean change and interval. Negative values indicate lower measured stiffness. MR, meditative-relaxation package; AR, topical-aromatherapy/rest package; MAR, combined topical-plus-meditation package.

Unadjusted T3-to-T4 changes were −4.62 N/m in MR, 95% CI [−6.27, −2.97]; −9.16 N/m in AR, 95% CI [−11.10, −7.22]; and −13.22 N/m in MAR, 95% CI [−16.04, −10.40]. These correspond to reductions of approximately 1.6%, 3.0%, and 4.2% from T3, respectively (Table 3; Figure 2). Cohen's d_z estimates were −1.55, bootstrap 95% CI [−2.63, −1.07]; −2.61, bootstrap 95% CI [−5.43, −1.79]; and −2.59, bootstrap 95% CI [−4.38, −1.86], respectively. The study did not estimate protocol-specific measurement error or minimal detectable change for the unweighted four-muscle mean. Published Myoton reliability findings from other devices, muscles, and protocols do not establish an applicable minimal detectable change for this composite (Lee et al., 2021; Trybulski et al., 2024). The physiological and performance importance of the approximately 3–8 N/m adjusted differences is therefore uncertain. Individual T3 and T4 responses are shown in Supplementary Figure S1.

Table 4. ANCOVA of immediate T3-to-T4 changes.

Outcome	Adjusted group effect	Raw p	FDR q	Adjusted contrasts, estimate (95% CI)	Interpretation
Four-muscle mean stiffness, N/m	F(2, 39) = 15.30	<.001	—	AR vs MR: −4.99 [−8.08, −1.90], raw p = .002, Holm p = .005; MAR vs MR: −8.01 [−10.95, −5.08], raw p ≤ .001, Holm p < .001; MAR vs AR: −3.02 [−5.87, −0.18], raw p = .038, Holm p = .038	Primary post hoc comparison
Heart rate, beats/min	F(2, 39) = 3.53	.039	.088	AR vs MR: −0.06 [−1.36, 1.24], raw p = .922, Holm p = .922; MAR vs MR: −1.39 [−2.61, −0.17], raw p = .027, Holm p = .081; MAR vs AR: −1.32 [−2.54, −0.10], raw p = .034, Holm p = .081	Secondary omnibus effect did not retain FDR significance
SDNN, ms	F(2, 39) = 0.09	.918	.918	AR vs MR: −0.22 [−1.90, 1.45], raw p = .791, Holm p = 1.000; MAR vs MR: −0.42 [−2.45, 1.62], raw p = .681, Holm p = 1.000; MAR vs AR: −0.20 [−1.87, 1.48], raw p = .814, Holm p = 1.000	Secondary omnibus effect did not retain FDR significance
High-frequency power (device units)	F(2, 39) = 0.43	.656	.761	AR vs MR: 0.09 [−0.10, 0.27], raw p = .362, Holm p = 1.000; MAR vs MR: 0.06 [−0.19, 0.30], raw p = .633, Holm p = 1.000; MAR vs AR: −0.03 [−0.25, 0.19], raw p = .802, Holm p = 1.000	Secondary omnibus effect did not retain FDR significance
Low-frequency power (device units)	F(2, 39) = 0.46	.636	.761	AR vs MR: −0.07 [−0.30, 0.15], raw p = .508, Holm p = 1.000; MAR vs MR: −0.10 [−0.30, 0.11], raw p = .352, Holm p = 1.000; MAR vs AR: −0.02 [−0.22, 0.18], raw p = .823, Holm p = 1.000	Secondary omnibus effect did not retain FDR significance
LF/HF ratio	F(2, 39) = 5.26	.010	.029	AR vs MR: −0.01 [−0.04, 0.02], raw p = .554, Holm p = .554; MAR vs MR: 0.03 [0.00, 0.06], raw p = .023, Holm p = .046; MAR vs AR: 0.04 [0.01, 0.07], raw p = .005, Holm p = .014	Secondary omnibus effect retained after FDR control
Quadriceps stiffness, N/m	F(2, 39) = 0.40	.676	.761	AR vs MR: −2.45 [−8.43, 3.52], raw p = .411, Holm p = 1.000; MAR vs MR: −0.79 [−6.82, 5.24], raw p = .792, Holm p = 1.000; MAR vs AR: 1.66 [−3.57, 6.90], raw p = .524, Holm p = 1.000	Secondary omnibus effect did not retain FDR significance
Tibialis anterior stiffness, N/m	F(2, 39) = 3.04	.059	.107	AR vs MR: −4.54 [−12.60, 3.51], raw p = .261, Holm p = .431; MAR vs MR: −9.21 [−16.80, −1.62], raw p = .019, Holm p = .056; MAR vs AR: −4.67 [−12.17, 2.83], raw p = .215, Holm p = .431	Secondary omnibus effect did not retain FDR significance
Hamstring stiffness, N/m	F(2, 39) = 5.32	.009	.029	AR vs MR: −3.78 [−7.65, 0.09], raw p = .056, Holm p = .111; MAR vs MR: −5.84 [−9.47, −2.21], raw p = .002, Holm p = .007; MAR vs AR: −2.06 [−5.64, 1.52], raw p = .252, Holm p = .252	Secondary omnibus effect retained after FDR control
Lateral gastrocnemius stiffness, N/m	F(2, 39) = 8.56	<.001	.007	AR vs MR: −10.04 [−18.61, −1.46], raw p = .023, Holm p = .046; MAR vs MR: −16.42 [−24.45, −8.39], raw p ≤ .001, Holm p ≤ .001; MAR vs AR: −6.38 [−14.29, 1.54], raw p = .111, Holm p = .111	Secondary omnibus effect retained after FDR control

Note. ANCOVA = analysis of covariance; CI = confidence interval; FDR = false discovery rate; MR = meditative relaxation; AR = aromatherapy relaxation; MAR = combined meditative aromatherapy relaxation; SDNN = standard deviation of normal-to-normal intervals; LF = low-frequency power; HF = high-frequency power. Models adjust for the T3 value, height, and body mass. The nine secondary omnibus tests use Benjamini-Hochberg FDR correction; each outcome's three pairwise contrasts use Holm correction. An em dash indicates that the primary outcome is not included in the secondary FDR family.

The four muscle-specific T3 values showed standardized Cronbach's α = .745 and a mean inter-item correlation of .421. These exploratory values indicate moderate covariation but do not establish a unidimensional or clinically meaningful latent construct; the outcome remains a descriptive unweighted mean. In the secondary ANCOVA family, hamstring (raw p = .009, FDR q = .029) and lateral-gastrocnemius stiffness (raw p < .001, q = .007) retained FDR significance, whereas quadriceps (q = .761) and tibialis anterior (q = .107) did not. Detailed longitudinal models are reported in Supplementary Table S2.

Exploratory autonomic responses

Heart rate decreased from T3 to T4 in all three groups; the largest mean reduction occurred in MAR (−2.60 beats/min, 95% CI [−4.12, −1.08]). The adjusted group effect was $F(2, 39) = 3.53$, raw p = .039, but it did not

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retain significance after correction across the nine secondary ANCOVAs (FDR q = .088). The previously nominal MAR-versus-MR and MAR-versus-AR contrasts also did not remain significant after within-outcome Holm correction (both adjusted p = .081).

The remaining HRV pattern was mixed. In MAR, SDNN decreased by 1.87 ms, HF by 0.26 device units, LF by 0.15 device units, and LF/HF increased by 0.05. The adjusted LF/HF group effect retained secondary-family FDR significance, $F(2, 39) = 5.26$, raw p = .010, q = .029. Holm-adjusted contrasts were 0.031 for MAR versus MR, 95% CI [0.005, 0.058], p = .046, and 0.040 for MAR versus AR, 95% CI [0.013, 0.067], p = .014. Because respiration was not recorded and spectral values came from proprietary scaling, these changes do not demonstrate increased parasympathetic activity, improved recovery, calm, or readiness. Detailed longitudinal results are shown in Supplementary Table S1.

Adverse events

No skin irritation, dizziness, respiratory symptom, discomfort, withdrawal, or other adverse event was reported during the intervention, after T4, or in post-competition follow-up. The absence of a standardized checklist and defined delayed-monitoring window limits the precision of this safety observation.

DISCUSSION

The most defensible finding is that three pragmatic 16-minute packages were associated with different immediate changes in an unweighted mean of four dominant-leg stiffness measurements. The ordering of reductions remained after post hoc adjustment for T3 stiffness, height, and weight. Complete retention, implementation within an applied tournament schedule, and successful repeated measurement support the feasibility of a larger trial. These data do not show that any package outperformed natural change or quiet sitting because every group received an intervention and no neutral control was included.

The results cannot be attributed specifically to cedarwood essential oil or interpreted as synergy. The AR package combined an aromatic product, carrier oil, touch, provider attention, prone positioning, and seated rest; MAR added guided meditation. Without a factorial design and component-matched controls, contrasts quantify package differences only. Expectancy may also contribute to response, particularly because participants had prior exposure to meditation and aromatherapy and no credibility or expectancy measure was collected (Beedie et al., 2018).

The direction and magnitude of stiffness change should not be labelled mechanical relaxation or improved readiness. Localized stiffness may influence force transmission and stretch-shortening-cycle behaviour, and higher resting calf stiffness has been associated with some drop-jump outcomes (Ando et al., 2021). Conversely, evidence that manual massage improves sport performance is inconsistent (Davis et al., 2020). In this trial, no jump, sprint, change-of-direction, shooting, perceived-readiness, or competition-performance outcome was measured. A larger reduction could therefore be beneficial, neutral, or detrimental depending on the athlete, muscle, task, and timing.

The autonomic dissociation is also informative. MAR showed a lower heart rate together with lower SDNN, HF, and LF and higher LF/HF. This pattern does not support a simple vagal-enhancement interpretation. Short-term spectral HRV is sensitive to respiration and analytic choices, and LF/HF is not a validated linear index of sympathovagal balance (Billman, 2013; Laborde et al., 2017). The present results are best described as device-recorded autonomic changes of uncertain physiological meaning.

The study has major limitations. It was small, unregistered, lacked a public protocol and formal sample-size calculation, and used simple randomization without concealment, resulting in height and weight imbalance. Participants and providers were unblinded, assessor blinding was not implemented, and statistical blinding was undocumented. The single-institution, male, previously exposed sample restricts generalizability. Intervention dose and cedarwood chemistry were incompletely standardized. HRV processing and respiration were not controlled. Myotonometry posture and landmark details were incompletely recorded, and the four-muscle mean lacks validation and study-specific reliability or minimal-detectable-change estimates. The analytic hierarchy, covariates, composite, multiplicity procedures, and marginal models were specified after data collection. Although FDR and Holm corrections reduce false-positive risk, these analyses remain exploratory. Functional performance and manipulation checks were absent.

Practitioners should not interpret these preliminary data as support for routine cedarwood use or as a replacement for individualized warm-up and evidence-based psychological preparation. If a topical aromatic procedure is considered in research or practice, athlete consent, allergy and skin screening, patch testing, institutional medical approval, product quality, ventilation, and competition rules should be addressed. The present safety finding covers only this small, monitored sample.

Future work should preregister one primary outcome, use a sufficiently powered factorial or component-control design, stratify or minimize allocation by playing position and baseline stiffness, standardize topical dose and exposure, record respiration and raw electrocardiographic processing, estimate protocol-specific Myoton reliability, and collect expectancy, anxiety, perceived readiness, and sport-specific performance. A crossover design may be useful for evaluating individual preference and response, provided carryover is controlled.

CONCLUSIONS

In this preliminary unregistered trial, all three pre-competition packages were followed by small immediate reductions in an unweighted mean of four dominant-leg stiffness measurements. The combined topical-plus-meditation package was associated with a larger adjusted reduction than the two other tested packages. Because there was no passive or component-matched control, the active component and the extent to which changes exceeded natural variation or measurement error remain uncertain. The mixed autonomic findings do not establish parasympathetic recovery, and no conclusion can be drawn about readiness, benefit, injury risk, or basketball performance.

AUTHOR CONTRIBUTIONS

All authors meet the established criteria for authorship. Contributions are reported according to the CRediT taxonomy as follows:

Conceptualisation: Li-Ying Wei. Methodology: Li-Ying Wei, Ming-Yi Liu, and Chin-Li Lin. Formal analysis: Ming-Yi Liu. Investigation: Li-Ying Wei and Chin-Li Lin. Data curation: Li-Ying Wei. Writing – original draft: Li-Ying Wei. Writing – review & editing: Ming-Yi Liu and Chin-Li Lin. Supervision: Ming-Yi Liu and Chin-Li Lin.

All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

ETHICS APPROVAL

The study complied with the Declaration of Helsinki and received approval from the Institutional Review Board of National Taiwan Sport University (approval No. NTSUIRB-113-011; 16 April 2024). Written informed consent was obtained from all participants before enrolment.

DATA AVAILABILITY STATEMENT

De-identified participant-level data are available from the corresponding author on reasonable request, subject to ethics approval and institutional data-sharing restrictions.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, ChatGPT (OpenAI) was used as an AI-assisted tool to support English-language editing and formatting consistency during manuscript preparation. It was not used to generate research data or independently determine scientific conclusions. All numerical results, analyses, references, interpretations, and final content were checked and approved by the authors. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

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SUPPLEMENTARY MATERIAL

Table S1. Autonomic outcomes across four measurement occasions.

Outcome	Group	T1	T2	T3	T4	Group × time	Raw p	FDR q
Heart rate, beats/min	MR	71.01 ± 2.41	70.64 ± 2.17	71.21 ± 1.69	70.54 ± 1.85	$\chi^2(6) = 25.74$	< .001	< .001
Heart rate, beats/min	AR	70.87 ± 5.11	71.20 ± 4.71	70.93 ± 5.31	69.53 ± 4.41			
Heart rate, beats/min	MAR	70.67 ± 4.67	70.93 ± 3.90	71.87 ± 4.09	69.27 ± 3.51			
SDNN, ms	MR	36.01 ± 2.69	35.95 ± 2.65	36.67 ± 2.70	36.23 ± 2.81	$\chi^2(6) = 26.39$	< .001	< .001
SDNN, ms	AR	39.87 ± 3.93	39.27 ± 3.45	38.87 ± 3.27	37.80 ± 3.45			
SDNN, ms	MAR	42.60 ± 3.50	42.13 ± 3.34	42.80 ± 2.48	40.93 ± 3.01			
High-frequency power (device units)	MR	4.51 ± 0.35	4.46 ± 0.26	4.52 ± 0.23	4.32 ± 0.21	$\chi^2(6) = 14.22$	.027	.031
High-frequency power (device units)	AR	4.91 ± 0.47	4.86 ± 0.41	4.75 ± 0.32	4.64 ± 0.39			
High-frequency power (device units)	MAR	5.41 ± 0.55	5.41 ± 0.61	5.53 ± 0.61	5.27 ± 0.62			
Low-frequency power (device units)	MR	5.41 ± 0.70	5.41 ± 0.56	5.50 ± 0.52	5.38 ± 0.37	$\chi^2(6) = 4.20$	.649	.649
Low-frequency power (device units)	AR	5.25 ± 0.53	5.24 ± 0.43	5.15 ± 0.48	5.05 ± 0.46			
Low-frequency power (device units)	MAR	5.22 ± 0.47	5.29 ± 0.45	5.27 ± 0.43	5.12 ± 0.38			
LF/HF ratio	MR	0.24 ± 0.18	0.23 ± 0.18	0.25 ± 0.18	0.27 ± 0.09	$\chi^2(6) = 18.91$	.004	.006
LF/HF ratio	AR	0.23 ± 0.08	0.24 ± 0.08	0.27 ± 0.09	0.26 ± 0.06			
LF/HF ratio	MAR	0.22 ± 0.09	0.25 ± 0.08	0.24 ± 0.08	0.29 ± 0.07			

Note. Group-by-time tests are from Gaussian generalized estimating equations adjusted for height and body mass, with an exchangeable working correlation and participant-clustered robust standard errors. FDR q values cover nine secondary outcomes.

Table S2. Dominant-leg stiffness across four measurement occasions.

Outcome (N/m)	Group	T1	T2	T3	T4	Group × time	Raw p	FDR q
Four-muscle mean stiffness	MR	291.62 ± 41.10	290.42 ± 38.65	293.61 ± 39.31	288.99 ± 40.74	$\chi^2(6) = 60.88$	< .001	—
Four-muscle mean stiffness	AR	311.73 ± 32.47	311.41 ± 31.74	310.38 ± 31.12	301.22 ± 30.06			
Four-muscle mean stiffness	MAR	310.20 ± 33.95	310.48 ± 33.21	312.14 ± 31.82	298.92 ± 29.52			
Quadriceps stiffness	MR	226.80 ± 25.51	226.07 ± 24.91	228.67 ± 23.50	222.91 ± 26.46	$\chi^2(6) = 22.57$	< .001	.001
Quadriceps stiffness	AR	249.89 ± 38.94	251.89 ± 40.22	252.22 ± 40.54	242.98 ± 38.93			
Quadriceps stiffness	MAR	260.49 ± 24.26	260.82 ± 23.11	263.13 ± 21.14	254.82 ± 22.26			
Tibialis anterior stiffness	MR	380.87 ± 64.17	377.60 ± 61.92	382.98 ± 63.25	376.40 ± 63.09	$\chi^2(6) = 38.71$	< .001	< .001
Tibialis anterior stiffness	AR	395.56 ± 44.65	397.49 ± 47.54	396.18 ± 49.26	385.93 ± 47.48			
Tibialis anterior stiffness	MAR	395.73 ± 53.74	399.02 ± 53.21	398.47 ± 52.16	381.76 ± 48.40			
Hamstring stiffness	MR	265.33 ± 48.58	265.98 ± 44.62	268.33 ± 47.34	263.16 ± 48.61	$\chi^2(6) = 30.83$	< .001	< .001
Hamstring stiffness	AR	288.51 ± 34.65	286.47 ± 32.74	283.84 ± 29.88	276.44 ± 31.99			
Hamstring stiffness	MAR	278.64 ± 43.48	278.22 ± 42.56	280.00 ± 40.93	269.62 ± 42.06			
Lateral gastrocnemius stiffness	MR	293.49 ± 66.93	292.04 ± 64.10	294.47 ± 62.53	293.49 ± 66.44	$\chi^2(6) = 23.06$	< .001	.001
Lateral gastrocnemius stiffness	AR	312.98 ± 47.74	309.80 ± 47.03	309.29 ± 47.41	299.53 ± 46.55			
Lateral gastrocnemius stiffness	MAR	305.93 ± 53.09	303.84 ± 53.02	306.98 ± 50.36	289.49 ± 49.93			

Note. Group-by-time tests are from Gaussian generalized estimating equations adjusted for height and body mass, with an exchangeable working correlation and participant-clustered robust standard errors. The primary four-muscle mean is outside the nine-outcome secondary FDR family.

Table S3. Model-based estimates for four-muscle mean stiffness.

Estimate type	Group or contrast	Time	Estimate, N/m	Robust SE	95% CI low	95% CI high	*p*
Estimated marginal mean	MR	T1	293.376	10.540	272.135	314.617	
Estimated marginal mean	MR	T2	292.176	9.888	272.248	312.104	
Estimated marginal mean	MR	T3	295.365	10.118	274.973	315.758	
Estimated marginal mean	MR	T4	290.743	10.403	269.778	311.708	
Estimated marginal mean	AR	T1	309.441	9.155	290.989	327.892	
Estimated marginal mean	AR	T2	309.118	8.987	291.006	327.231	
Estimated marginal mean	AR	T3	308.091	8.877	290.200	325.981	
Estimated marginal mean	AR	T4	298.929	8.590	281.618	316.241	
Estimated marginal mean	MAR	T1	310.738	9.073	292.453	329.024	
Estimated marginal mean	MAR	T2	311.016	8.854	293.173	328.859	
Estimated marginal mean	MAR	T3	312.683	8.546	295.460	329.906	
Estimated marginal mean	MAR	T4	299.461	7.931	283.477	315.445	
Model-based T3-to-T4 change	MR	T4−T3	-4.622	0.781	-6.196	-3.049	< .001
Model-based T3-to-T4 change	AR	T4−T3	-9.161	0.918	-11.012	-7.310	< .001
Model-based T3-to-T4 change	MAR	T4−T3	-13.222	1.335	-15.913	-10.532	< .001
Difference in T3-to-T4 change	AR vs MR		-4.539	1.205	-6.968	-2.110	< .001
Difference in T3-to-T4 change	MAR vs MR		-8.600	1.547	-11.717	-5.483	< .001
Difference in T3-to-T4 change	MAR vs AR		-4.061	1.620	-7.327	-0.795	.016

Note. Gaussian GEE adjusted for height and body mass; exchangeable working correlation $\rho = 0.992$; participant-clustered robust standard errors. Overall group-by-time Wald $\chi^2(6) = 60.88$, $p < 0.001$.

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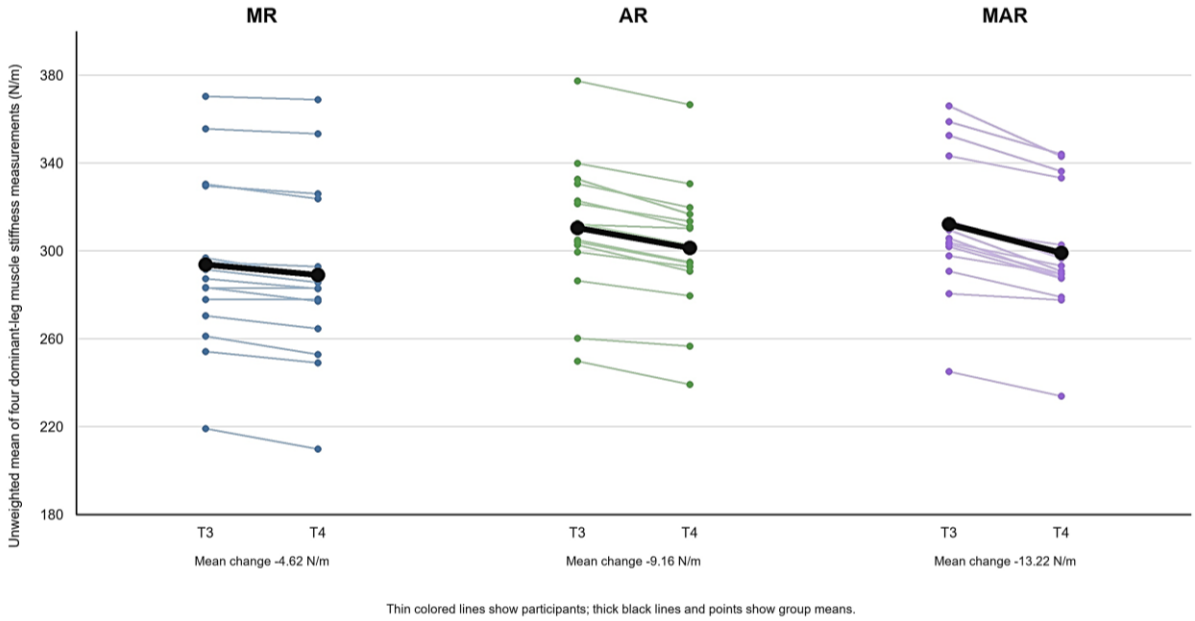

Figure S1. Individual T3 and T4 values for the unweighted mean of four dominant-leg muscle stiffness measurements. Each thin line represents one participant; thick lines and points show group means. Participant identifiers are deidentified.

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