



Immediate effects of sports massage on muscle strength, power and balance after simulated trail running in the cold

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Abstract

Purpose Despite the efficacy of sports massage as a recovery strategy is still debated and most research suggests minor effects, little is known about the potential effects on recovery after exercise in a cold environment.

Methods A cross-sectional study was performed on 13 male trail runners (30 years, range 23–37) who ran on a treadmill inside a climatic chamber at 5 °C, for 15 min uphill (15%) at 40% of the maximum aerobic velocity (VAM), followed by 15 min downhill (–15%) at 70% of the VAM. After the run, sports massage was performed on a randomized anterior and posterior thigh for 10 min total. Assessments were performed before the run (t0) and after the massage (t2), and results were compared with the non-treated lower limb, including single-leg isometric strength and jump, balance, skin temperature and pain.

Results Sports massage was associated with increased anterior thigh skin temperature ($p = 0.001$, $\eta p^2 = 0.455$) and improved single-leg balance ($p = 0.008$, $\eta p^2 = 0.452$) and pain ($p < 0.001$, $\eta p^2 = 0.509$), whereas a non-significant effect was found for isometric strength and jump.

Conclusions The results from this study suggest that sports massage performed in a cold environment after uphill–downhill running might reduce the effects of fatigue on balance and perceived pain and might be useful to promote recovery after strenuous exercise.

Keywords Musculoskeletal manipulations · Post-exercise recovery · Running · Skin temperature · Sports

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Introduction

Among sports recovery techniques, massage represents one of the most common and present in sports, as the proposed benefits include improved recovery, performance and injury prevention [1]. More in detail, despite the limited scientific literature, it is believed that sports massage can increase blood flow, reduce muscle tension and neurological excitability, and increase the sense of well-being [2]. Concerning blood flow, inconsistent findings have been reported based on the method used to measure it, with some authors suggesting increased blood flow [3, 4], whereas others reported no significant effect of sport massage [5, 6]. Regarding the effects of sport massage on muscle temperature, some authors reported an increase in skin temperature [3, 7], whereas no significant changes were found in muscle temperature, especially at deeper levels [7, 8]. Taken together, previous literature hypothesizes some mechanisms of action on the effects of sport massage on recovery, but scarce and

conflicting results have been found, and meta-analyses suggest no evidence that sports massage improves performance directly, although it may improve flexibility and reduce delayed onset muscle soreness (DOMS) [2]. Among the possible explanations for the mentioned conflicting results, different sports massage techniques might result in different effects. Gliding (effleurage) and kneading (petrissage) are among the most typically performed massage interventions, consisting of (i) strokes delivered with the palm in the direction of lymphatic drainage and venous flow and (ii) lifting tissue away from underlying structures, intending to improve circulation, loosen adhesions between tissues and improve drainage of lymphatics [9], without influencing blood pressure compared to other techniques, such as trigger point therapy [10].

Trail running is defined as any off-road running event and ranges from short distance to ultramarathon distance competitions, and is often associated with harsher and more challenging course topography (e.g., large elevation and descent, irregular running surfaces and obstacles) and environmental conditions (e.g., cold, heat, humidity and altitude) compared with track and road-based endurance running events [11]. Although the effects of hot temperatures on aerobic performance are well known [12], less is known about cold air exposures, despite some authors reporting that cold ambient temperatures impair time to exhaustion [13, 14]. Regarding recovery, the effects of cold ambient temperatures are scarcely investigated [15, 16], with contrasting findings. In trail running, the temperature can range from 2 to 38 °C, depending on the season and setting of the competition [17]. In such sports, massage therapy is well appreciated and commonly used as a post-exercise strategy to improve and obtain recovery [18], despite—as previously reported—conflicting results being present and typically sports massage resulting in poor effects on recovery [19]. However, as most of the research evaluating the effect of sport massage on recovery has been performed in controlled thermoneutral or warm environmental conditions [9], little is known about the potential effects on recovery after exercise in a cold environment, which might be typical of some trail running events.

Therefore, the present study aimed to evaluate the effects of sport massage on lower limb strength, balance and thigh skin temperature, as well as pain perception, after a simulated trail running in a laboratory-controlled cold environment. In particular, lower limb strength and balance were assessed as these have been shown to be predictors of trail running [20] and sport performance [21], whereas skin thigh temperature was monitored as it could be influenced by cold, exercise and massage in different ways and their interaction might support some mechanisms typically evaluated in sports massage studies [3, 7]. As such, considering the potentially involved mechanisms and the wide practice of such recovery strategy, it might be hypothesized that sport

massage performed after a simulated trail running in the cold might improve subjective ratings of pain and fatigue, as well as active markers of neuromuscular performance.

Methods

This cross-sectional study was performed in a controlled laboratory environment, and a climate chamber maintained constant cold temperature throughout the experimental procedure and for all the participants. The outcomes included in the present study aimed to provide an overview of strength and power of the lower limbs, as well as balance and perceived soreness. Infrared skin temperature was measured at different time points. Sports massage was performed by the same experienced sports physiotherapist, on one randomized thigh, and the contralateral lower limb was used as control for each subject. The sports massage protocol was based on previous literature, being well standardized and typically used in sports [1, 22]. The assessed outcomes aimed to understand the translational potential of such technique to improve recovery and performance in trail runners.

Subjects

Thirteen healthy male participants, with mean age of 30.4 years (SD 5.3 range 23–37), mean height: 1.81 m (SD 0.06 range 1.70–1.92), mean body mass 74.2 kg (SD 6.9 range 62–82), mean body mass index (BMI) 22.7 kg/m² (SD 1.5 range 20.2–24.2), and VO₂max: 55.49 mL/kg min (SD 5.49, range 67.3–43.10) were recruited to participate in the study. Inclusion criteria were a BMI between 18.5 and 25, a high level of physical activity according to the International Physical Activity Questionnaire (IPAQ) score (‘vigorous-intensity physical activities’ on at least 3 days/week, totaling at least 1500 MET-min/week). Exclusion criteria were a positive medical history for cardiovascular and/or metabolic diseases, a history of ineligibility for competitive sports, and severe lower limb injuries in the past 12 months (> 28 days of missed activity). All participants provided their written informed consent before commencing the experimental protocol. The study was approved by the ethics committee of the University of Trieste (protocol code 122/2022, 23.05.2022).

Procedures

The experimental protocol involved two sessions, and participants were required to abstain from high-intensity physical exercise 24 h before each session. During the first session, the participants underwent an incremental protocol to exhaustion to determine the VO₂max and the maximal aerobic velocity (VAM). After an appropriate warm-up, the participants were asked to run on a treadmill set at a constant

1% incline, starting at a speed of 8 km/h and increasing the speed by 1 km/h every 3 min. The test concluded upon the voluntary discontinuation of the participant when they could no longer sustain the prescribed effort. Individual maximal speed was calculated according to $VAM = V_f + [(-tT - 1) V_d]$, where V_f is the velocity of the last step completed, t the duration of the final workload, T the duration of the step and V_d the difference between the two final velocities.

The second session was held within 1 month from the first session. The participants were required to wear loose running shorts of a length that left the thigh exposed. The entire experimental session, except for the single-leg height vertical jump, was conducted in a climatic chamber at a temperature of 5 °C and relative humidity approximately 60%. The running protocol was conducted on a treadmill (Technogym Run Race, belt width 50 cm, speed incremented by 0.1 km/h, inclination range +15% to -5%). For the downhill condition, a wooden plank was placed under the rear part of the treadmill to achieve a steeper slope. The subject entered the room and observed a resting period of 10 min, followed by a standardized 5-min warm-up starting from a speed of 5 km/h and increasing the speed by 1 km/h every minute until reaching 9 km/h (Fig. 1).

At the end of the warm-up (t_0), baseline measurements were collected for each limb including the rate of pain (Numerical Pain Rating Scale, NPRS), lower limb skin temperature (Tsk), single-leg balance maximum voluntary contraction force (MVC), and rate of force development (RFD) of knee extensors, as well as single-leg countermovement jump height (CMJ). The rate of perceived exertion (RPE) was also collected. The participants then commenced a treadmill running exercise designed to induce muscle fatigue, structured to simulate a segment of a trail

running race. The protocol involved 15 min of uphill running at a +15% incline, with a speed set at 40% of the VAM obtained during the incremental test. This was followed by 15 min of downhill running at a -15% incline and at a speed of 70% of the VAM. The running protocol was designed to represent the slope and speed characteristics of section of a trail run. In particular, the downhill section was chosen to simulate conditions that have been demonstrated to induce losses in knee and hip extensor muscles [23]. Immediately after completing the running task, the participants received a 10-min massage treatment on one randomly selected lower limb thigh, while the control limb was kept at rest in a passive state. Following the treatment (t_2), all measurements conducted during the initial assessment (t_0) were repeated. The data relating to NPRS, Tsk and RPE were also collected after completing downhill running before the massage treatment (t_1).

Massage protocol

The selection of the limb on which to perform the treatment was done through randomization (6 dominant, 7 non-dominant) using the online software RANDOM.ORG98. The treatment involved 10 min of thigh massage, evenly divided between the posterior and anterior regions (Video 1). At the same time, the contralateral limb serving as the control was left to rest passively. The massage was administered to all participants by the same therapist (an expert sports physiotherapist with a 1-year university specialization course and more than 5 years of experience with professional athletes) to standardize the pressure and technique. The duration of the massage was chosen based on the review by Poppendieck, which suggests an intervention ranging from 5

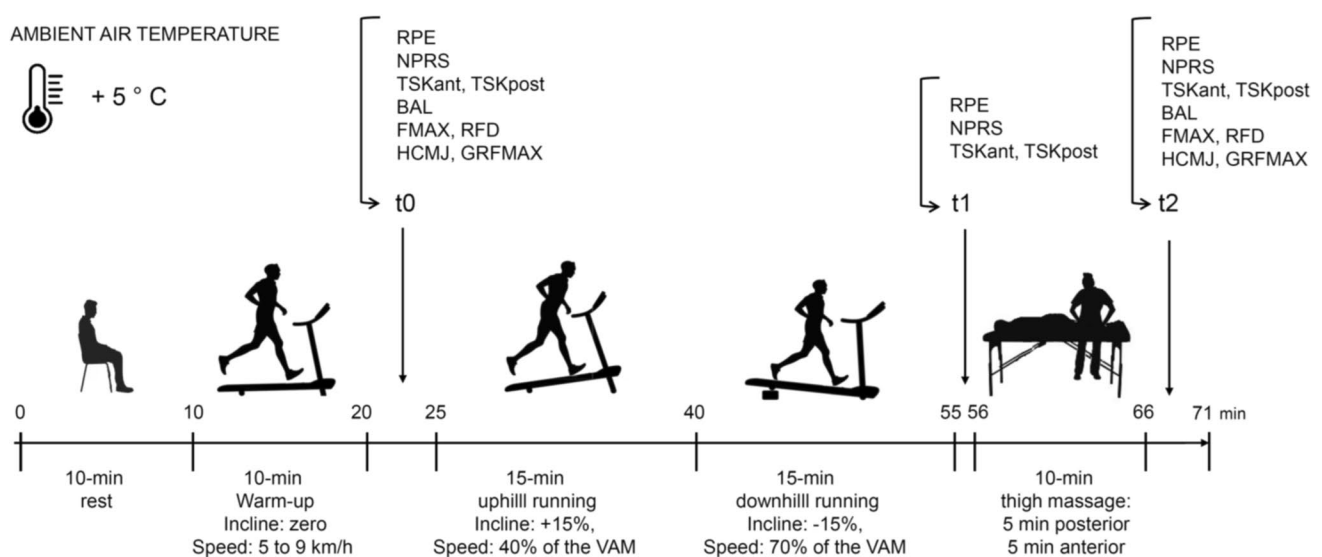


Fig. 1 Schematic representation of the experimental protocol

to 12 min to maximize potential effects [1]. The techniques of effleurage (superficial gliding, at a rate of 20/30 strokes per minute) and petrissage (kneading, 50/60 strokes per minute) were employed, following previous protocols [22]. Effleurage and petrissage were alternated every minute. The treatment began with the participants in a prone position on a treatment bed for the massage of the posterior thigh compartment and, after 5 min, continued with them in a supine position for the anterior compartment. A neutral oil was applied for the execution and carefully removed with absorbent paper at the end of the massage.

Outcomes

Pain perception rate was evaluated through the NPRS which assesses pain intensity on a scale from 0 (no pain) to 10 (worst pain imaginable) [24], as previously proposed to evaluate the effects of recovery techniques [25]. The RPE was determined using a printed Borg CR100 scale [26], which was presented in front of the subject.

The skin temperature (T_{sk}) of the anterior and posterior thigh was measured using an infrared thermal camera (model: R300W2 R15; year: 12/2011; company: NEC Avio Infrared Technologies Co), positioned 5 m away from the subject standing in a standardized position [27]. The skin temperature for TR and NTR side, as well as for the anterior and posterior regions, was calculated as an average over a region of interest (ROI). Following the methodology of previous investigations, the ROIs were determined as the largest possible area, corresponding to the knee flexors [27] and extensor [28] muscles for the anterior and posterior regions,

respectively. The ROIs were manually defined as six vertex polygonal shapes using a custom-written Matlab script (Matlab R2020b, MathWorks, Inc., Natick, MA, USA) by the same operator to reduce inter-operator variability [27]. The polygon was designed with the upper side horizontal, with the internal vertex coinciding with the pubic line, the lateral and medial margins following the contour of the thigh and the lower side horizontal, positioned 5 cm above the upper pole of the patella on the front side, whereas it was delimited by the popliteal fossa on the posterior side (Fig. 2).

Balance capacity (BAL) was measured during 30-s single-leg stabilometric tests [29]. During the single-leg stance, the participants maintained their eyes open, hands fixed on the hips and the unloaded leg flexed at 90° while standing on the platform with vertical load data acquired at a sampling frequency of 80 Hz. Single-leg balance (BAL) was considered as the ellipse area with axes defined by the standard deviation of lateral (SD_{LAT}) and anteroposterior displacements (SD_{AP}) of the center of pressure location on the horizontal plane and then calculated by the formula

$$BAL = (\pi SD_{LAT} SD_{AP}) / 4.$$

Maximal isometric knee extensor strength and rate of force development of both limbs were assessed with a strain gauge load cell (model: P155.B-S-A/1500N; year: 2010; company: Deltatech Italy, Sogliano al Rubicone, Italy), from which signals were acquired at 500 Hz using 16-bit a data acquisition board (NI-DAQ-6016, National Instruments). The subject was seated on a custom-built chair with knee and hip joints at a 90° angle, and instructed to push against a

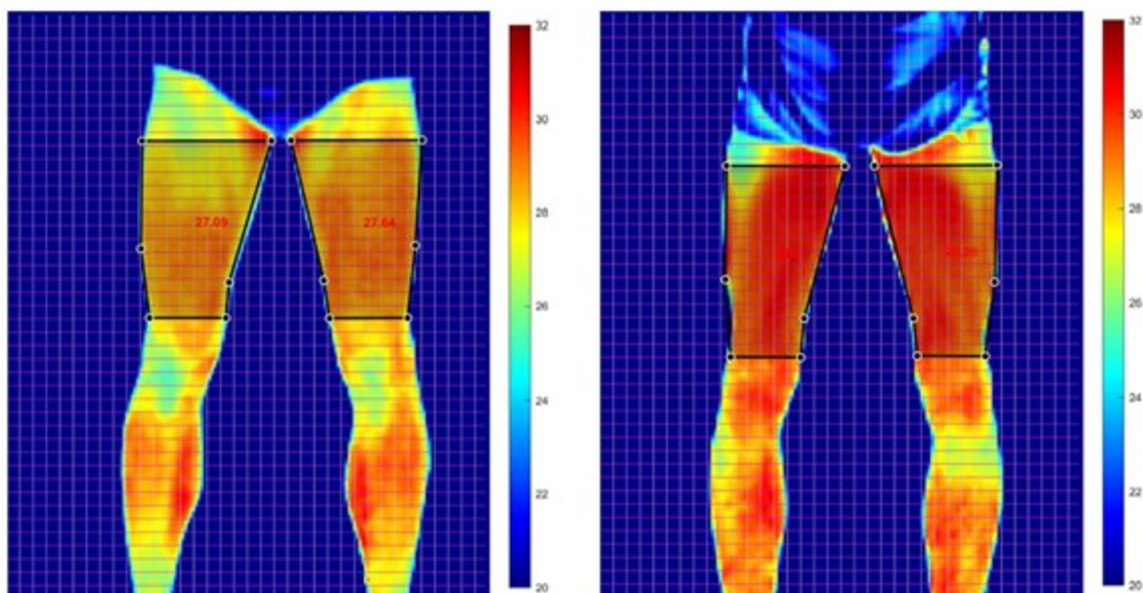


Fig. 2 Example of determination of the ROIs for the anterior (left panel) and posterior (right panel) side

fixed frame positioned in front of the lower leg level, approximately 35 cm distally from the knee's center of rotation. The subject was directed to exert force as quickly and forcefully as possible. Each test was performed two times alternating between TR and NTR legs, with a 1-min rest between each repetition, and the maximal value was considered for further analysis. Maximal force (FMAX) was calculated as the highest value displayed by the force signal during the contraction, and the rate of force development (RFD) was obtained as the highest value of the force–derivative curve.

The maximum height during a single-leg countermovement jump was obtained using a force platform. The platform (dimension 0.6×0.4 m) was instrumented with a monoaxial load cell (model: P229.B-S-A_5000N_01_A; year: 2016; company: Deltatech Italy, Sogliano al Rubicone, Italy) and the force signal was acquired at 500 Hz using a microcontroller (Adalogger M0, Adafruit, New York City, USA). Due to technical difficulties in transporting the platform into the climatic chamber, the test was conducted in a nearby room at a temperature of 21 °C, to which participants had access for a brief necessary period. The subject was asked to jump as high as possible starting from the single-leg position, with their hands on their hips and performing a quick countermovement [30]. The test was repeated three times for each leg alternating between TR and NTR. The jump height (HCMJ) was calculated using the formula:

$$\text{HCMJ} = \frac{1}{2}g\left(\frac{t}{2}\right)^2,$$

where g is the gravity acceleration and t is the flight time, determined as the time when the force was acquired by the platform nulls. Maximal vertical ground reaction force (GRFMAX) was calculated as the maximal force value achieved during the pushing phase. Maximal values for HCMJ and GRFMAX over the trial were considered for further analysis.

Statistical analyses

To estimate sample size, G^* Power was used considering the results from previous literature [31], suggesting a minimum sample size of six participants based on the reported effect size (Cohen's d of 0.6 and 1.5) and set power of 0.80. We decided to recruit 13 participants to increase the statistical power and considering the risk of participants not completing the experimental procedure and achieved a power calculated a posteriori as >0.99 . Calculation of parameters for BAL, FMAX, RFD and HCMJ was done as described above with custom-written Matlab scripts (Matlab R2020b, MathWorks, Inc., Natick, MA, USA). All statistical analyses were performed with SPSS version 23 (IBM). This is the primary analysis of these data. Data are reported as the means,

standard deviation, counts and proportions (%) as appropriate. Two-tailed testing was performed. Normality testing using the Shapiro–Wilk test was performed for all datasets. A within–within analysis of variance (ANOVA) was performed considering the within-factor “limb” (treated vs non-treated) and within-factor time. In the interaction effect, simple main effects were determined. Greenhouse–Geisser correction was applied in case of lack of sphericity. The effect size was determined by η^2 . Significance was set for $p < 0.05$.

Results

All the participants completed the protocol and assessments and were included in the final analyses. During the running protocol, the mean uphill velocity was 6.8 km/h (SD 0.7, range 5.7–8.9) and the mean downhill velocity was 11.9 km/h (SD 1.2, range 10.0–14.0). The ambient temperature and humidity remained constant during the experimental procedures.

Perception

Pain intensity exhibited a significant effect of time and a time × treatment interaction (Table 1 and Fig. 3). Pain perception increased at t1 compared to baseline and subsequently decreased after treatment, reaching a value significantly lower on the TR side compared to the NTR side (-1.538 , 95% CI [-2.173 , -0.904], $p < 0.001$). The rate of perceived exertion exhibited a significant effect of time, increased at t1 and then decreased at t2 (Table 1).

Skin temperature

The temperature in both the anterior and posterior regions demonstrated a significant overall increase over time (Table 1). A significant interaction between treatment and time was observed for TSKant, showing a larger, albeit not statistically significant, increase from t1 to t2 on the TR side (0.73 °C, 95% CI [-0.21 , 1.68], $p = 0.16$) than on the NTR side (0.15 °C; 95% CI [-0.73 , 1.05], $p = 1.00$).

Balance

The BAL parameter is influenced by the time–treatment interaction effect (Table 2 and Fig. 3). The BAL value for NTR limb at t2 shows a significant worsening compared to t0 ($+24\%$, 35.42 mm², 95% CI [2.32 , 68.62], $p = 0.04$), while in the TR limb, at t2, the deterioration is minimal and not statistically significant ($+3.15\%$, 4.39 mm², 95% CI [-14.64 , $+23.42$], $p = 0.62$). As a result, starting from a t0 condition where the two groups were comparable ($p = 0.52$),

Table 1 Infrared skin temperature and pain perception during the experimental protocol in the non-treated and treated lower limb of the participants ($n = 13$)

		Mean \pm SD 95% CI			$F(1,12)$ p ηp^2		
		t0	t1	t2	Treatment \times time	Treatment	Time
TSKant (°C)	NTR	24.1 \pm 1.4 [23.1, 25.0]	25.8 \pm 1.7 * [24.7, 26.8]	25.9 \pm 1.0 [25.3, 26.7]	10.023 0.001	0.236 0.636	14.389 < 0.001
	TR	23.9 \pm 1.3 [23.0, 24.7]	25.5 \pm 1.7 [24.3, 26.6]	26.2 \pm 0.9 [25.6, 26.8]	0.455	0.019	0.545
TSKpost (°C)	NTR	24.9 \pm 1.4 [24.0, 25.8]	26.1 \pm 1.3 [25.2, 26.8]	27.1 \pm 1.0 * [26.5, 27.8]	0.705 0.504	1.110 0.313	19.058 < 0.001
	TR	24.9 \pm 1.3 [24.1, 25.8]	26.1 \pm 1.1 [25.4, 26.8]	27.4 \pm 0.9 * [26.8, 28.0]	0.055	0.085	0.614
NPRS	NTR	0.38 \pm 0.60 [-0.008, 0.778]	5.31 \pm 1.38 * [4.405, 6.210]	3.23 \pm 1.20 *,§ [2.445, 4.017]	12.464 < 0.001	14.344 0.003	52.275 < 0.001
	TR	0.69 \pm 0.96 [0.069, 1.316]	5.08 \pm 1.53 * [4.076, 6.078]	1.69 \pm 1.33 * [0.824, 2.560]	0.509	0.544	0.813
RPE	–	8.15 \pm 4.22 [5.40, 10.91]	33.62 \pm 16.32* [22.96, 44.26]	2.92 \pm 3.06 * [0.93, 4.92]	–	–	37.120 < 0.001 0.756

Notes: Skin temperature (TSK, °C) of the anterior (ant) and posterior (post) thigh, numeric pain rating scale (NPRS) and rate of perceived exertion (RPE) on the non-treated (NTR) and treated (TR) limb, before the run (t0), after the run (t1) and after the treatment (t2) Significance for the within–within analysis of variance (ANOVA), bold values for $p < 0.05$. Post hoc analysis suggests a significant within-limb difference from T0 (§) and a within-time difference between NTR and TR (*)

the difference between the two limbs, TR and NTR, was significant at t2 (40.14 mm², 95% CI [10.20, 70.09], $p = 0.01$).

Isometric strength

Compared to t0, the FMAX at t2 exhibited a slight decrease of approximately 8%, with no significant difference observed between the two limbs, on average by 41.44 N (95% CI [23.35, 59.52], $p < 0.001$). There is a minimal tendency for the TR limb to decrease and become less than the NTR limb (–36 N compared to –46), with the difference between the two limbs being 10 N at t0 and increasing up to 22 N at t2. However, the difference is not significant, and the two sides remain comparable (Table 2). Similarly to FMAX, the RFD also decreased at t2 (216.28 N/s, 95% CI [42.198, 389.54]), with no significant difference observed between NTR and TR.

Countermovement jump

The GRFMAX does not undergo significant changes, either due to the fatigue protocol, the intervention, or the interaction of the two factors (Table 2). On the other hand, HCMJ decreases after fatigue, with no significant differences between the two limbs (TR and NTR). In the second evaluation, the jump height decreases by an average of 1.25 cm (95% CI [–0.02, +2.50], $p = 0.05$), approximately 8%. Limb

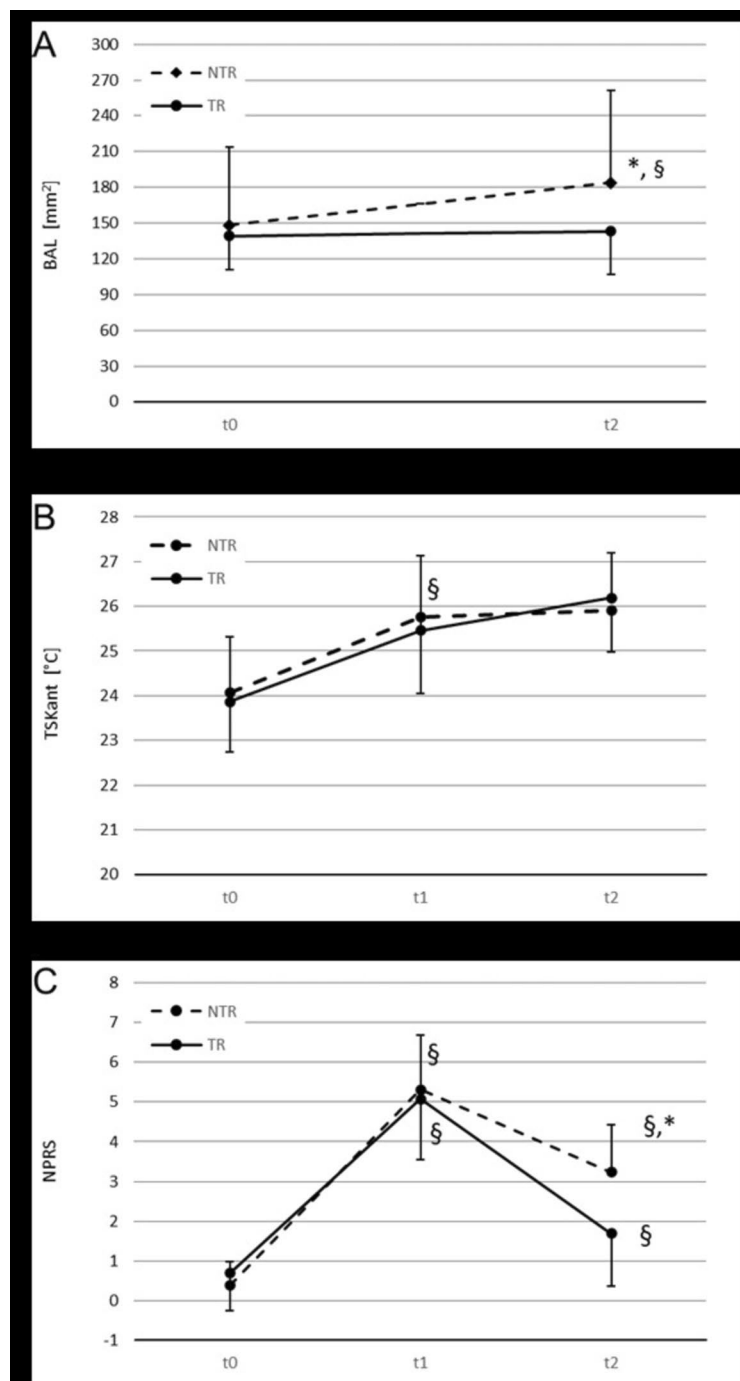
TR shows a trend to decline less than the non-treated limb (TR = –0.88 cm, i.e., 6%; NTR = –1.62 cm, i.e., 10%), but not enough to be statistically significant ($p = 0.19$).

Discussion

The present study aimed to assess the effects of sports massage on balance, muscular strength and power, and soreness, after an uphill–downhill running protocol in the cold, to simulate the characteristics of trail running. In particular, the results showed that while massage reduced muscle pain and soreness after exercise, muscle strength and power were not affected, and single-leg balance was found to improve in the treated lower limb.

Improved muscle soreness after massage is in line with the previous literature, as recent systematic reviews and meta-analyses suggest that it might influence flexibility and DOMS, the latter being reduced up to 13% [1, 9]. The mechanisms that have been proposed to be involved in such improvements depend on the effect of sports massage enhancing local blood flow, reducing edema and the accumulation of noxious substances, as well as decreasing the sensation of pain [32]. Regarding lactate accumulation, no consistent findings have been reported, with some authors suggesting that massage could help reduce blood lactate levels after exercise [33], whereas others did not find any

Fig. 3 Data regarding the changes in **a** single-leg balance (BAL), **b** skin temperature on the anterior thigh (TSKant) and **c** numeric pain rating scale (NPRS) before the run (t0), after the run (t1) and after the massage (t2), comparing the treated (TR) and non-treated (NTR) limb. A mixed-factors analysis of variance (ANOVA) was performed, and post hoc analysis was performed suggesting a significant within-limb difference from T0 (§) and a within-time difference between NTR and TR (*)



significance and active recovery was reported as being a more effective strategy [34]. Although not in a sporting context, some authors also proposed that massage could influence the autonomic nervous system, decreasing sympathetic activity as reported by reduced heart rate variability and cortisol [9].

Regarding the functional measure of muscle recovery, such as isometric strength and vertical jump, the results from this study did not find any significant effect of sports massage. In particular, muscle strength was characterized

by a larger decline after the training protocol, with minor effects on muscle power. The effects of sports massage on muscle strength have generally suggested inconsistent results in the literature, as pre-event massage could decrease isometric strength of the knee, whereas massage had neutral effects or positive effects on muscle strength when administered after exercise [9]. Nevertheless, the meta-analysis of these studies found that massage had no overall effect on strength with low study heterogeneity [9]. Similarly, also jump performance was typically not

Table 2 Neuromuscular and balance performance during the experimental protocol in the non-treated and treated lower limb of the participants ($n = 13$)

		Mean \pm SD 95% CI		$F(1,12)$ p ηp^2	Treatment \times time	Treatment	Time
		t0	t2				
FMAX (N)	NTR	550 \pm 116 [480, 620]	504 \pm 115 [434, 572]	1.003 0.336	1.292 0.278	24.924 < 0.001	
	TR	562 \pm 146 [474, 651]	526 \pm 143 [440, 612]	0.077	0.097	0.675	
RFD (N/s)	NTR	3284 \pm 895 [2743, 3825]	3155 \pm 758 [2696, 3613]	0.982 0.341	2.799 0.120	7.394 0.019	
	TR	3567 \pm 733 [3124, 4011]	3264 \pm 762 [2803, 3725]	0.076	0.189	0.381	
BAL (cm ²)	NTR	148.3 \pm 67.8 [107.3, 189.3]	183.7 \pm 81.0 [134.7, 232.7]	9.895 0.008	3.727 0.078	3.052 0.106	
	TR	139.2 \pm 29.9 [121.1, 157.2]	143.6 \pm 37.8 § [120.7, 166.4]	0.452	0.237	0.203	
GRFMAX (N)	NTR	1300 \pm 143 [1210, 1390]	1318 \pm 160 [1218, 1418]	0.321 0.581	2.545 0.137	3.793 0.075	
	TR	1323 \pm 149 [1230, 1417]	1352 \pm 162 [1250, 1454]	0.026	.175	0.240	
HCMJ (cm)	NTR	15.88 \pm 4.09 [13.41, 18.34]	14.26 \pm 4.14 [11.76, 16.76]	2.761 0.122	0.010 0.924	4.733 0.050	
	TR	15.53 \pm 3.83 [13.22, 17.85]	14.65 \pm 4.22 [12.10, 17.20]	0.187	0.001	0.283	

Notes: Knee extensor isometric strength (FMAX, N), rate of force development (RFD, N/s), single-leg stance area (BAL), maximal value of vertical ground reaction force in CMJ (GRFMAX, N) and jump height (HCMJ, cm), on the non-treated (NTR) and treated (TR) limb, before the run (t0) and after the treatment (t2). Significance for the within–within analysis of variance (ANOVA), bold values for $p < 0.05$. Post hoc analysis suggests a significant within-limb difference from t0 (§)

influenced by massage, as suggested in most of the studies [9].

Several factors such as proprioceptive deficits, muscle weakness, muscle strain and sports participation can affect balance, and muscle damage following eccentric exercises can change the kinesthetic sense, therefore leading to the hypothesis that DOMS—as found after running—could alter balance ability [35, 36]. To the best of the authors' knowledge, this is the first study reporting the effects of sports massage on static balance, and we found that while exercise worsened balance performance, massage could help maintain the pre-exercise balancing capacity. In general, functional losses are typically observed immediately after the cessation of exercise, while the peak of perceived soreness can occur also 24 h following exercise [9]; as such, together with a possible placebo effect, it might explain the discrepancies between the reported effects on the subjective measures of recovery (NPRS) and muscular function.

Skin temperature has recently been assessed in sports science and medicine as an estimate of some thermo-physiological processes, and it might be useful to detect injuries and inflammation [37]. During exercise, it typically decreases reflecting the balance between increased muscle activation and intensified heat transfer to the environment [38]. To the

best of the authors' knowledge, few studies have investigated skin temperature responses to running in the cold. When performing at maximal intensity in a cold environment, skin temperature has been suggested to decrease proportionally to the severity of the cold ambient temperature [39]. Also, skin temperature has been historically used as a surrogate of peripheral circulation to determine the local effect of massage. Indeed, massage was suggested to increase skin and thigh intramuscular temperature, but only up to 2.5 cm depth, suggesting it might have a limited effect on deep muscle temperature [8]. In this study, running in the cold (5 °C) resulted in a small, despite significant, increase in thigh skin temperature, and we found that sports massage significantly further increased the skin temperature of the anterior treated thigh concerning the non-treated thigh. It is hypothesized that skin temperature decrease during exercise might be associated with cutaneous vasoconstrictor response and that continuous increase in load intensity may further reduce skin temperature. In contrast, constant load running is suggested to promote the attainment of a relative minimum of skin temperature, followed by a gradual little rise over time, related to thermoregulatory vasodilation [40]. If a complete understanding of skin temperature response to the training protocol is beyond the objectives of this study

and should be further investigated, the reported increase in skin temperature of the treated thigh suggests that vasodilation might have occurred reflecting increased blood flow following massage. However, it should be also considered that consensual responses have been previously reported when comparing two limbs within the same subjects and could partially affect the findings [41, 42].

Taken together, the present findings are in line with the recent systematic reviews and meta-analyses on the effectiveness of sports massage on recovery after exercise, suggesting the improvement of muscle soreness and pain measures. In addition, improved balance was also observed, leading to the hypothesis that massage, decreasing soreness and pain might improve neuromuscular control during single-leg stance. Among the novelties of this study, the exercise protocol consisted of an uphill and downhill running bout performed in a controlled cold environment (5 °C), simulating a trail running event.

Among the main limitations of this study, pain was only assessed with a numerical scale; therefore, future studies using other more reliable methods to evaluate pain perception (e.g., algometers) should be encouraged. Blood lactate was not collected during the running protocol, and assessments were performed only immediately after the exercise and massage; therefore, it is not possible to conclude the effects of massage on blood lactate removal and the trajectory of recovery. However, it should be considered that in this study, we compared the two limbs in the same participants, and blood lactate would have reflected a more systemic response rather than local. In addition, it is not possible to exclude that the treatment performed on a lower limb might have elicited some general responses (e.g., reduced sympathetic activity) that have influenced muscle performance bilaterally. Since the contralateral limb was used as a control, this could also represent a possible limitation as some effects of sports massage (e.g., vascular) might have induced a consensual reaction in the other; at the same time, it can be speculated that such protocol might have mitigated the possible influence of a placebo effect. As a further limitation, this study was performed only on male athletes, and therefore it could be poorly generalizable to female athletes.

Future perspectives

From a future perspective, since the interest in trail running is a peculiar type of running that takes place on outdoor trails, the influence of different environmental conditions should be evaluated as well as different clothing and terrains. Finally, the science of post-exercise recovery is emerging, and many strategies have been investigated in different sports (e.g., cold water immersion, percussive massage therapy, foam rolling, etc.); as such, future studies are encouraged to

evaluate the effectiveness of such strategies and techniques in the specific context of trail running.

Conclusions

Trail running represents a strenuous running activity that impairs lower limbs' neuromuscular performance and balance, and increases pain and fatigue sensation after exercise. In this study, the main findings with a practical application for athletes, trainers and physiotherapists were:

- Trail running in the cold impairs muscle strength, power and balance.
- Sports massage can mitigate the effects of fatigue on monopodal balance.
- Sports massage can reduce pain perception after trail running in the cold.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no competing interests. The figures are original and not previously published.

Ethical approval and informed consent The study was approved by the University of Trieste ethics committee (code 122/2022) and an informed consent was signed by all the participants. All the procedures were performed according to the principles of the Declaration of Helsinki.

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