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Research article

Effects of Sand-Based Plyometric-Jump Training in Combination with Endurance Running on Outdoor or Treadmill Surface on Physical Fitness in Young Adult Males

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Abstract

This study aimed at examining the effects of nine weeks of sand-based plyometric-jump training (PJT) combined with endurance running on either outdoor or treadmill surface on measures of physical fitness. Male participants (age, 20.1 ± 1.7 years) were randomly assigned to a sand-based PJT combined with endurance running on outdoor surface (OT, n = 25) or treadmill surface (TT, n = 25). The endurance running intervention comprised a mixed training method, i.e., long slow distance, tempo, and interval running drills. A control group was additionally included in this study (CG, n = 25). Participants in CG followed their regular physical activity as OT and TT but did not receive any specific intervention. Individuals were assessed for their 50-m linear sprint time, standing long jump (SLJ) distance, cardiorespiratory fitness (i.e., Cooper test), forced vital capacity (FVC), calf girth, and resting heart rate (RHR). A three (groups: OT, TT, CG) by two (time: pre, post) ANOVA for repeated measures was used to analyze the exercise-specific effects. In case of significant group-by-time interactions, Bonferroni adjusted paired (within-group) and independent (between-group comparisons at post) t-tests were used for post-hoc analyses. Significant group-by-time interactions were found for all dependent variables ($p < 0.001 – 0.002$, $\eta_p^2 = 0.16 – 0.78$). Group-specific post-hoc tests showed improvements for all variables after OT ($p < 0.001$, Hedges´g effect size [g] = 0.05 – 1.94) and TT ($p < 0.001$, $g = 0.04 – 2.73$), but not in the CG ($p = 0.058 – 1.000$, $g = 0.00 – 0.34$). Compared to CG, OT showed larger SLJ (p = 0.001), cardiorespiratory fitness ($p = 0.004$), FVC ($p = 0.008$), and RHR ($p < 0.001$) improvements. TT showed larger improvements in SLJ ($p = 0.036$), cardiorespiratory fitness ($p < 0.001$), and RHR ($p < 0.001$) compared with CG. Compared to OT, TT showed larger improvements for SLJ ($p = 0.018$). In conclusion, sand-based PJT combined with either OT or TT similarly improved most measures of physical fitness, with greater SLJ improvement after TT. Coaches may use both concurrent exercise regimes based on preferences and logistical constrains (e.g., weather; access to treadmill equipment).

Key words: Muscle strength, musculoskeletal and neural physiological phenomena, movement, resistance training, high-intensity interval training, exercise.

Introduction

Physical fitness is an important marker of health and is related for instance to psychological well-being (Rodriguez-Ayllon et al., 2018), and cardiovascular as well as metabolic health-related parameters (Zaqout et al., 2016). Endurance running exercise has positive effects on various indices of physical fitness, such as body composition (e.g., body mass management) (Idrizovic et al., 2021; Swift et al., 2014), cardiorespiratory fitness (Willoughby et al., 2016), and muscular endurance (Menz et al., 2019) as well as mental well-being (e.g., improved mood state) (Oswald et al., 2020; Thompson Coon et al., 2011), and exercise adherence (Oswald et al., 2020). The beneficial effects of endurance running may be attributed to its positive effects on the cardiovascular and respiratory systems (Delgado-Floody et al., 2019).

In addition, combining training of cardiorespiratory fitness and muscle strength (i.e., concurrent training) within a training cycle may increase athletic performance compared to single-mode training (Gäbler et al., 2018). In this regard, plyometric jump training (PJT) is a high-intensity short-duration training method that has the potential to improve muscular strength (Markovic and Mikulic, 2010). PJT may also improve physical fitness in various sports such as soccer, volleyball, and basketball (Ahmadi et al., 2021; Ramirez-Campillo et al., 2020a; Ramirez-Campillo et al., 2020b), including healthy college-aged participants (Torres-Banduc et al., 2020). The performance of PJT exercises stimulates high rates of force development, muscle strength and power (Ramirez-Campillo et al., 2020c), and force absorption muscle capacities (i.e., eccentric force) through tissue-related adaptations, such as muscle hypertrophy (Grgic et al., 2021) and neural adaptations such as improved motor unit recruitment and/or firing strategies (Ramirez-Campillo et al., 2021b). Additionally, PJT can improve health-related parameters such as body composition (Ramirez-Campillo et al., 2022) and blood pressure (Ramírez-Campillo et al., 2016).

Although endurance running exercise or PJT when applied as single interventions improve health and physical fitness outcomes, concurrent training which is the combination of resistance (e.g., PJT) and endurance training (Gäbler et al., 2018) may even induce greater improvements in physical fitness (Ramirez-Campillo et al., 2021a). Indeed, PJT combined with high-intensity interval training compared to single-mode high-intensity interval training resulted in greater peak oxygen uptake, jump performance, and lean body mass improvements (Racil et al., 2016). Similarly, Ramírez-Campillo et al. (2014) reported that combined PJT and endurance training versus single-mode

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endurance training produced larger effects on performance in a 2.4 km endurance run, 20-m sprint time, countermovement, and drop jump height. A recent meta-analysis confirmed the positive effects of PJT combined with endurance training versus single-mode endurance training on participants' physical fitness (e.g., endurance time-trial performance; sprinting; jumping) (Ramirez-Campillo et al., 2021a). Therefore, the aforementioned studies advocate the combination of endurance running exercise with PJT within a weekly training cycle. Such a combination may offer greater training-induced gains compared with single mode training.

PJT exercises can be performed on different surface types such as wooden surface, synthetic floor, concrete, or sand surface (Granacher et al., 2015; Ramirez-Campillo et al., 2020a). For example, Impellizzeri et al. (2008) reported that sand-based PJT is more effective in improving selected sprint and jump outcomes compared to grass-based PJT. The use of sand surface during PJT may enhance neuromuscular performance (Ahmadi et al., 2021; Pereira et al., 2021), and its unstable nature may increase muscle activation (Pereira et al., 2021). There is for instance evidence that running on sand compared with stable ground results in increased muscle activation (Jafarnezhadgero et al., 2022). In addition, sand also reduces shock absorption (i.e., due to its absorptive characteristics) which leads to reduced tissue and joint stress and larger metabolic demands compared to harder surfaces (Impellizzeri et al., 2008). Ahmadi et al. (2021) reported improved cardiorespiratory fitness after sand-based versus rigid surface PJT which is likely due to the high metabolic demand when performing PJT on sand compared to stable ground. Therefore, PJT on sand might be well-suited to be conducted in combination with endurance running exercise.

The type of running surface (e.g., outdoor track versus indoor treadmill) may also affect the outcomes of running exercise due to different mechanical properties. As with sand-based PJT, outdoor running is more unstable and less predictive than for instance treadmill running which is why it affords increased metabolic and neuromuscular demands. In fact, there is evidence that over-ground running at high intensity resulted in greater energy consumption compared with treadmill running (Li et al., 2020). Moreover, Yaserifar and Souza Oliveira (2022) reported higher lower limbs muscle activities (i.e., tibialis anterior, peroneus longus, soleus, gastrocnemius medialis, vastus medialis, and rectus femoris) when running on grass versus treadmill running. Accordingly, greater acute metabolic and neuromuscular demands of outdoor compared with treadmill running may induce larger chronic physical fitness improvements. However, the literature regarding running exercise on different surfaces (i.e., outdoor track; indoor treadmill) and its effect on measures of physical fitness in young male adults is scarce, particularly when endurance running exercise is combined with sand-based PJT in the form of concurrent training. Therefore, this study aimed to compare the effects of nine weeks of sand-based PJT combined with endurance running on either outdoor surface or treadmill surface, versus control, on measures of physical fitness in young adult males. Based on previous findings (Colino et al., 2020; Li et al., 2020; Yaserifar and Souza Oliveira, 2022), we hypothesized larger physical fitness improvements after sand-based PJT when combined with endurance running on outdoor surface versus treadmill surface. We expect higher gains due to larger physiological demands in outdoor running.

Methods

Participants

To calculate the required sample size, a freeware statistical software tool (G*Power; University of Düsseldorf, Düsseldorf, Germany) was used. The following variables were included in the a priori power analysis: number of groups: 3; number of measurements: 2; effect size f: 0.8 based on a previous study that investigated the effects of jumping interval training in recreational runners on countermovement jump performance (Ache-Dias et al., 2016); alpha error: <.01; non-sphericity correction: 1; correlation among repeated measures: .5; desired power (1-ß error): 0.90.

The results of the a priori power analysis indicated that a minimum of 15 participants would be needed per group to achieve statistical significance for jump performance (standing long jump - SLJ). A greater number of participants was recruited considering potential drop outs due to injury, lack of time, or related reasons. A graphical depiction of the study design is shown in Figure 1. A total of 150 college-age male students initially agreed to take part in the study. A relatively low number (n = 4) of female students agreed to participate in the study which is why we used males only for data analyses to obtain a homogeneous sample. Females were of course allowed to exercise as well and future studies should examine this research question in females. To be eligible to be included in this study, participants i) had to be free of lower limbs injuries during the six months prior to the start of the study; ii) had to participate in physical fitness training programs two months before the study started. Moreover, only those participants above the group-based median for cardiorespiratory fitness were eligible to be enrolled. This criterion was based on logistical reasons (e.g., reduced availability of treadmills). To determine the group-based median, a 1,600-meter run-walk test was conducted (Almeida et al., 2010). Five participants did not complete the test and were automatically excluded. The top 75 participants who obtained better performances (i.e., reduced times) were eligible (n = 75, mean ± standard deviation age = 20.13 ± 1.73 years). Subsequently, the participants were randomly assigned to an outdoor running group (OT; n = 25), a treadmill running group (TT; n = 25), or a control group (CG; n = 25) using an online randomization software (www.randomizer.org). The participants of each group possessed similar demographic characteristics (Table 1). Prior to the start of the study, all participants received information on potential risks and benefits of this study. Thereafter, informed consent was obtained from the study participants. The study was approved by local ethical committee (RRU/R&P/RRUEC/6th/187/2021) and the protocol conformed to the Declaration of Helsinki (1964, updated in 2013).

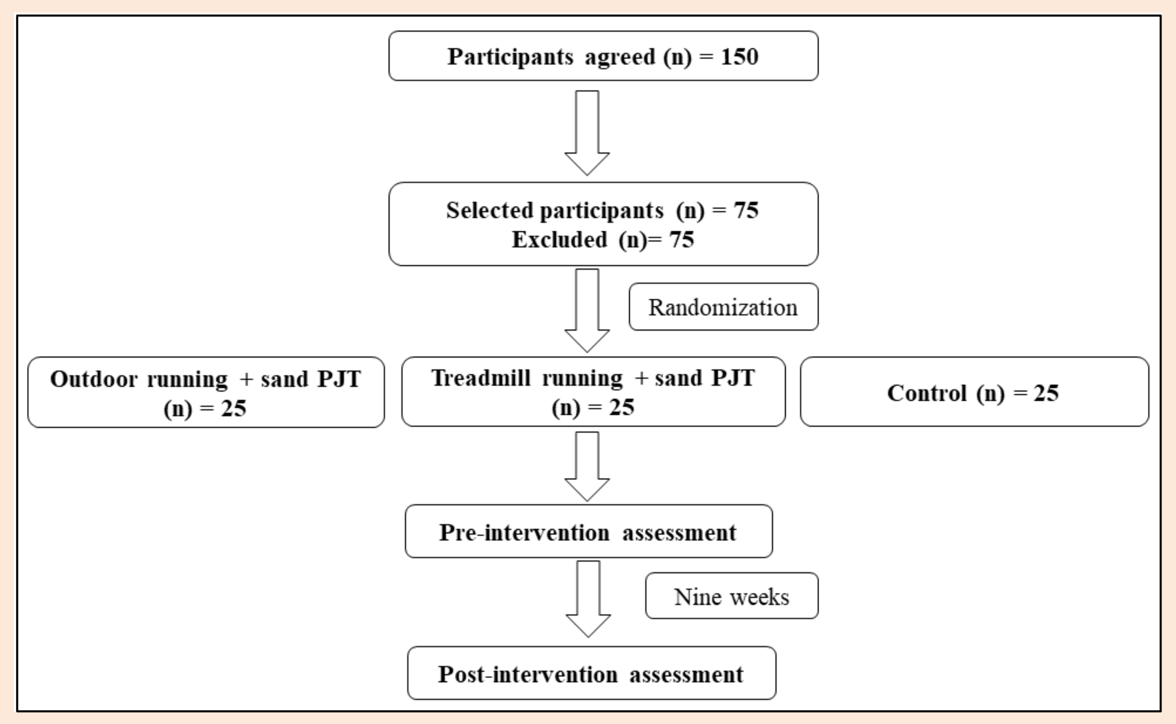

Figure 1. **Schematic of the study design. PJT: plyometric-jump training.**

Table 1. Demographic characteristics of the study participants. Data are means ± SD.

	Outdoor training group	Treadmill training group	Control group	*P*-value
Age (years)	20.1 ± 2.2	20.2 ± 1.5	20.1 ± 1.4	0.970
Height (cm)	174.6 ± 5.3	172.4 ± 5.5	172.3 ± 5.1	0.223
Body mass(kg)	63.1 ± 6.8	61.2 ± 7.9	62.5 ± 7.5	0.653
1,600 m time (min)*	6.8 ± 0.7	7.0 ± 0.5	6.9 ± 0.6	0.322

*: Participants' pre-intervention performance in the *1-mile test* was used as an inclusion criterion. Details are provided in the main text.

Procedure

One week before baseline assessment, the participants performed two familiarization sessions to become acquainted with the fitness tests. Demographic data were collected during the familiarization sessions. Participants were asked to refrain from any strenuous activity and alcohol consumption 24 hours prior to testing. A randomized longitudinal design was used to compare the effects of exercise intervention (i.e., OT, TT) on 50-m linear sprint speed, SLJ, cardiorespiratory fitness (12-min Cooper test), forced vital capacity (FVC), calf girth, and resting heart rate (RHR). Measurements were performed during similar daily hours before and after the intervention, across three consecutive days, with the 50-m sprint and SLJ tests recorded on day one, FVC, calf girth, and RHR recorded on day two, and the Cooper test recorded on day three. Upon arrival for testing on days one and three, participants underwent a 10 minutes general warm-up procedure. For the outdoor assessments, the temperature (27 – 31° C), humidity (24 – 27%), and wind velocity (8 km·h^{-1}) were similar before and after the intervention.

Training intervention

During the nine weeks intervention program, the OT and TT groups completed 14 endurance running training sessions and 13 sand-based PJT sessions. CG followed their regular physical activity behavior (similar to OT and TT) and did not receive any additional intervention. The PJT and running training sessions were scheduled on separate days of the week, with ≥24 h of inter-session recovery (i.e., to minimize potential interference effects). The participants in the OT and TT groups conducted an endurance running program. The two exercise programs were continuously supervised and matched for training intensity during the running sessions using heart rate monitors (Polar H10, Kempele, Finland) (Table 2). Training volume expressed as total distance or duration was similar between the exercise groups (Table 2). Additionally, both intervention groups were exposed to sand-based PJT which occurred in a 5 m wide and ~60 m long sandpit. More information on the sand-based PJT training program can be found in Table 3.

Rating of perceived exertion

The rating of perceived exertion for each training session (sRPE) was recorded using the modified Borg scale (0 to 10 point scale) (Foster et al., 2001). Each participant was sent a google form link to their cellphones to rate sRPE with the scores ranging from 0 (i.e., nothing at all) to 10 (i.e., maximal) following 30 min after each plyometric or running training session.

Testing procedures

50-m linear sprint test

Participants were instructed to stand behind a marked line and kindly asked to start the test after the sound of the

Table 2. Description of the training program for the outdoor and treadmill running groups.

	Day	Training methods	Session description
Week 1st	Monday	Long slow distance running	Duration: 30 minutes, Intensity: 60-80% maximal heart rate, Work-rest ratio: 1:0
	Friday	Tempo training	Duration: 15 minutes, Intensity: 140-146 beats/minute Repetition: 1, Work-rest ratio: 1:0
Week 2nd	Wednesday	Interval training	Intensity: 80-85% maximal heart rate, Distance: 400 meters, Repetition: 4, Recovery: heart rate return near basal
Week 3rd	Monday	Long slow distance running	Duration: 30 minutes, Intensity: 60-80% maximal heart rate, Work-rest ratio: 1:0
	Friday	Tempo training	Duration: 15 minutes, Intensity: 140-146 beats/minute Repetition: 1, Work-rest ratio: 1:0
Week 4th	Wednesday	Interval training	Intensity: 80-85% maximal heart rate, Distance: 400 meters, Repetition: 6, Volume: 2,400 meters, Recovery: heart rate return near basal
Week 5th	Monday	Long slow distance running	Duration: 40 minutes, Intensity: 60-80%, Work-rest ratio: 1:0
	Friday	Tempo training	Duration: 20 minutes, Intensity: 140-146 beats/minute Work-rest ratio: 1:0
Week 6th	Wednesday	Interval training	Intensity: 80-85% maximal heart rate, Distance: 400 meters, Repetition: 8, Volume: 3,200 meters, Recovery: heart rate return near basal
Week 7th	Monday	Long slow distance running	Duration: 50 minutes, Intensity: 60-80% maximal heart rate, Work-rest ratio: 1:0
	Friday	Tempo training	Duration: 25 minutes, Intensity: 140-146 beats/min Repetition: 1, Work-rest ratio: 1:0
Week 8th	Wednesday	Interval training	Intensity: 80-85% maximal heart rate, Distance: 400 meters, Repetition: 10, Volume: 4,000 meters, Recovery: heart rate return near basal
Week 9th	Monday	Long slow distance running	Duration: 60 minutes, Intensity: 60-80%, Work-rest ratio: 1:0
	Friday	Tempo training	Duration: 30 minutes, Intensity: 140-146 beats/min, Repetition: 1, Work-rest ratio: 1:0

In addition to sand-based PJT, the intervention groups also performed exercises such as duck walks, shuttle runs, crab walks, ladder drills (e.g., side shuffling), and planks. *: participants were asked to perform exercises with the aim to achieve maximal or near-maximal distance or height (or minimal contact time) per repetition.

Table 3. Sand-based plyometric jump training (PJT) performed by both intervention groups.

Weeks	Exercises	Training description
1st, 2nd, 3rd	Running (warm-up) Bounding Hoping Power skipping	Intensity: high* Duration: 30 seconds Rest between exercises: 30 seconds Rest between sets: 2 minutes Number of sets: 3 Work-rest ratio: 1:1
4th, 5th, 6th		Intensity: high Duration: 45 seconds Rest between exercises: 30 seconds Rest between sets: 2 minutes Number of sets: 3 Work-rest ratio: 1.5: 1
7th, 8th, 9th		Intensity: high Duration: 60 seconds Rest between exercises: 30 seconds Rest between sets: 2 minutes Number of sets: 3 Work-rest ratio: 2:1

In addition to sand-based PJT, the intervention groups also performed exercises such as duck walks, shuttle runs, crab walks, ladder drills (e.g., side shuffling), and planks. *: participants were asked to perform exercises with the aim to achieve maximal or near-maximal distance or height (or minimal contact time) per repetition.

clapper. Two independent coaches who were not part of this study were recruited as timekeepers and assigned to record the time needed for each trial using a hand stopwatch (Casio S053 HF-70W-1DF, Casio Computer Co., Ltd., Tokyo, Japan). The assessors were unaware of group allocation. The average time needed to complete the test from both timekeepers was used for inclusion. Three trials were conducted with a recovery period of ~1 minute between trials, and the fastest trial was selected for analysis.

Standing long jump test

The SLJ was conducted in an indoor gym. Participants were instructed to stand behind a marked line with their feet shoulder-width apart, and to take off with both legs and land on both legs. Arm-swing and countermovement were allowed. Standardized verbal instructions were provided by asking the participants to jump as far as possible. The assessors were blinded to group allocation. The measurement was recorded from the take-off line to the nearest point of contact on the landing (i.e., back of the heels). Three jumps were recorded with the longest jump used for the analysis.

Cooper 12-minute run test

The Cooper 12-minute run test was selected as a measure of cardiorespiratory fitness. Following a general warm-up, the participants were instructed to run for 12 minutes and cover the maximum possible distance. The test was conducted on a 400 meters athletic track with flags placed after every 25 meters. Participants were asked to complete the test at a steady state but maximal velocity across the 12 minutes to achieve a maximal possible running distance.

Forced vital capacity (FVC)

The FVC was measured using a computerized spirometer (Helios 401, Recorders & Medicare Systems Pvt Ltd, Chandigarh, India). The participants were instructed to hold the spirometer and then inhale as much air as possible followed by a forceful exhale inside the spirometer without blowing the air outside. During exhalation, the nose was closed with a nose clip by the assessor. The reading was recorded in litres. Two trials were allowed, with the best trial selected for further analysis.

Calf girth

Following international recommendations, participants were instructed to stand with their feet shoulder-width apart. The greatest calf circumference region was determined and marked with an ink pen. A Gulick tape was then used to measure the marked region to the nearest 0.1 cm. The same assessor recorded the measurements during pre- and post-assessments.

Resting heart rate

The RHR was measured using a fingertip pulse oximeter (Dr Trust-210, New York, USA) following the instructions of the manufacturer. The participants were instructed to lie in supine position for ~10 minutes. The assessor then placed the pulse oximeter in the middle finger of the right hand and RHR was recorded after one minute in beats per minute.

Statistical analysis

The statistical analyses were conducted using IBM SPSS version 20.0.0 (IBM, New York, USA). Data normality were confirmed using the Shapiro-Wilk test. Accordingly, data are presented as means and standard deviations. A one-way ANOVA was used to analyze baseline between group differences for all dependent variables. A three (groups: OT, TT, CG) by two (time: pre, post) ANOVA for repeated measures was used to analyze the exercise-specific effects. In addition, in case of significant group-by-time interactions, Bonferroni adjusted paired (within-group) and independent (between-group comparisons at post) t-tests were used for post-hoc analyses. Independent t-tests were applied to find out the differences between the three groups at post. Effects sizes (ES) in the form of partial eta squared (η_p^2) were used from ANOVA output. Hedge's *g* derived from paired t-test and independent t-test was calculated to assess changes between pre-post measurements testing for each group as well as between group differences at post measurements. The magnitude of effects for η_p^2 was interpreted as small (<0.06), medium (≥0.06 - 0.13), and large (≥0.14) (Cohen, 1988), while Hedge's *g* was interpreted as trivial (<0.2), small (0.2 - 0.6), moderate (>0.6 - 1.2), large (>1.2 - 2.0), very large (>2.0 - 4.0) and extremely large (>4.0) (Hopkins et al., 2009). The intraclass correlation coefficient (ICC) between trials was interpreted as poor (<0.5), moderate (0.5 - 0.75), good (0.75 - 0.9), and excellent (>0.9) reliability based on the lower bound of the 95% confidence interval (CI; $ICC_{95\%CI\ lower\ bound}$) (Koo and Li, 2016). Statistical significance was set at $p \leq 0.05$.

Results

All participants received treatment as allocated. There were no test or training-related injuries during the study. In addition, all participants attended all training sessions. None of the participants dropped out from the study.

Rating of perceived exertion

The sRPE values are depicted in Figure 2. The mean sRPE was greater in OT (94.76 ± 2.98) compared to TT (85.16 ± 4.11) for endurance running sessions ($p < 0.001$, $g = 2.63$), and in OT (91.88 ± 2.80) compared to TT (83.76 ± 2.45) for sand-based PJT sessions ($p < 0.001$, $g = 2.93$).

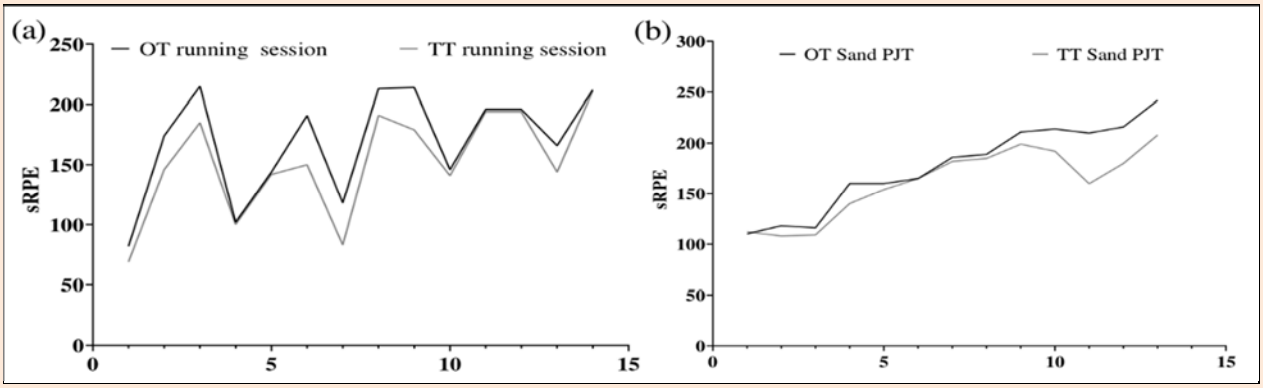

Figure 2. Graphical representation of total session rate of perceived exertion (sRPE; Y axis) of the intervention groups during (a) endurance running and (b) sand-based PJT sessions (X axis). Note: OT – outdoor training group, TT – treadmill training group, PJT – plyometric-jump training.

Table 4. Statistical comparisons for changes in physical fitness in the experimental and control groups.

Variable	Outdoor training group (n=25)			Treadmill training group (n=25)				Control group (n=25)			Time × group
	Pre	Post	p-value [g] Magnitude	Pre	Post	%Δ	p-value [g] Magnitude	Pre	Post	p-value [g] Magnitude	p-value [ηp^2] Magnitude
	Mean±SD			Mean±SD				Mean±SD			
50 m sprint (s)	7.56±0.48	7.49±0.46	<0.001* [0.15] Trivial	7.63±0.34	7.40±0.34	3.0	<0.001* [0.67] Moderate	7.45±0.59	7.46±0.57	0.538 [0.02] Trivial	<0.001# [0.78] Large
SLJ (m)	1.92±0.14	2.07±0.13***ac***	<0.001* [1.09] Large	1.91±0.09	2.17±0.09***bc***	13.6	<0.001* [2.73] Large	1.93±0.15	1.94±0.15	0.358 [0.07] Trivial	<0.001# [0.83] Large
Cooper's test (m)	2,452±223	2,610±224***a***	<0.001* [0.70] Moderate	2,434±189	2,678±132***b***	10.0	<0.001* [1.47] Large	2,396±303	2,403±282	0.564 [0.02] Trivial	<0.001# [0.73] Large
FVC (L)	3.87±0.40	4.12±0.43***a***	<0.001* [0.59] Moderate	3.86±0.41	4.01±0.44	3.9	<0.001* [0.35] Small	3.80±0.25	3.78±0.26	0.710 [0.08] Trivial	<0.001# [0.31] Large
Left calf girth (cm)	33.78±2.71	33.97±2.59	<0.001* [0.07] Trivial	35.62±3.56	35.78±3.56	0.4	<0.001* [0.04] Trivial	34.26±2.79	34.26±2.78	1.000 [0.00] Trivial	0.002# [0.16] Large
Right calf girth (cm)	33.68±2.70	33.83±2.68	<0.001* [0.05] Trivial	35.59±3.50	35.81±3.52	0.6	<0.001* [0.06] Trivial	34.16±2.77	34.14±2.74	0.479 [0.01] Trivial	<0.001# [0.23] Large
RHR (beats/min)	69.28±1.54	66.04±1.74***a***	<0.001* [1.94] Large	69.00±1.47	65.92±2.16***b***	4.5	<0.001* [1.64] Large	69.16±1.49	68.6±1.73	0.058 [0.34] Small	<0.001# [0.43] Large

a: significant difference at follow-up between outdoor training group and control group; ***b***: significant difference at follow-up between the treadmill training and the control group; ***c***: significant difference at follow-up between the outdoor and treadmill training group; **FVC:** forced vital capacity; ***g***: Hedges' *g* effect size; **η_p^2**: partial eta squared; **RHR**: resting heart rate; **SD**: standard deviation; **SLJ**: standing long jump; *: significant difference between baseline and follow-up measures; $^{\#}$: significant time by group effect.

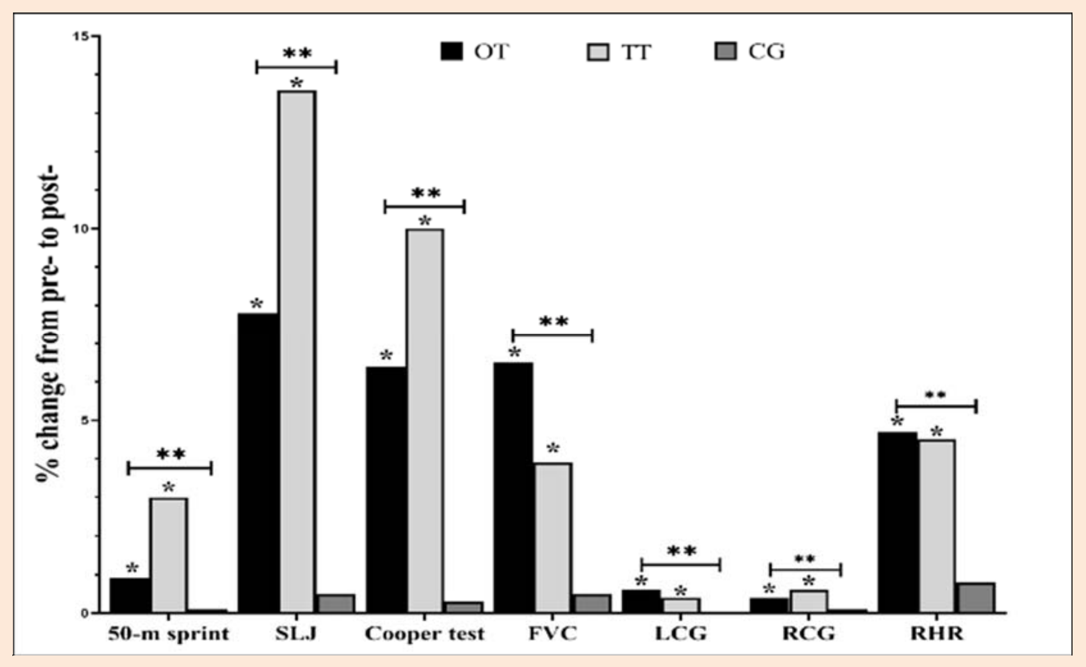

Figure 3. **Percentage (%) change from pre- to post-measurements for (i) 50-m sprint, (ii) standing long jump (SLJ), (iii) Cooper's test, (iv) forced vital capacity (FVC), (v) left calf girth (LCG), (vi) right calf girth (RCG), and (vii) resting heart rate (RHR) prior to and following a nine weeks study protocol including outdoor running training (OT), treadmill running training (TT) and a control group (CG).** * significant difference from pre- to post-measurement, ** significant group-by-time interaction.

Intraclass correlation coefficient

An excellent ICC was found between timekeepers for the 50-m linear sprint test (ICC = 0.97). The between trials ICCs for the 50-m sprint test, the SLJ and Copper test, FVC, calf girth (right), calf girth (left), and RHR were 0.82, 0.76, 0.77, 0.93, 0.99, 0.99, and 0.45, respectively.

Dependent variables

Results for all dependent variables are illustrated in Table 4, with a graphical representation of pre-post percentage change in Figure 3. No baseline differences (one-way ANOVA p = 0.073 – 0.939) were observed between the three groups in any of the dependent variables.

Significant group-by-time interactions were found for SLJ, Cooper test, FVC, and RHR. Post-hoc tests showed larger improvements for OT compared to TT and CG. Furthermore, post-hoc tests revealed larger SLJ improvements for TT compared to OT.

Discussion

The aim of this study was to compare the effects of nine weeks of sand-based PJT combined with either OT or TT versus control on measures of physical fitness in young adult males. We hypothesized that PJT in combination with OT would be more effective than PJT and TT, due to larger metabolic and neuromuscular demands in combined PJT and OT. The results of this study were not in line with our study hypothesis. In fact, we observed similar training gains in both intervention groups for most measures of physical fitness (i.e., 50-m linear sprint; cardiorespiratory fitness; FVC, calf girth, RHR). In contrast to our study hypothesis, TT showed even better results than OT for SLJ performance. Therefore, nine weeks of sand-based PJT combined with either OT or TT are both effective concurrent training modalities. The two exercise regimens similarly improve most measures of physical fitness in young adult males. Greater SLJ improvements were found after TT compared with OT.

In this study, we compared the effects of PJT combined with either OT or TT on 50-m sprint performance in young adult males and observed a moderate effect after PJT with TT ($g = 0.67$; $\Delta = 3.0\%$) and a trivial effect after PJT with OT ($g = 0.17$, $\Delta = 0.9\%$). Of note, Yaserifar and Souza Oliveira (2022) reported increased lower limbs muscle activity when running on grass (i.e., tibialis anterior, peroneus longus, soleus, gastrocnemius medialis, vastus medialis, and rectus femoris) and concrete (i.e., gastrocnemius lateralis, semitendinosus, gluteus maximus) versus treadmill running. Moreover, leg swing amplitude, vertical displacement, and vertical and horizontal velocity variance was lower in treadmill compared to synthetic surface running (i.e., lower external work during treadmill running) because of a lower vertical lift of the centre of mass per step and lower range in cyclic re-acceleration (Wank et al., 1998). Further, outdoor surfaces are associated with a greater impact during ground contact compared with treadmill running (Colino et al., 2020). The aforementioned differences between running on a treadmill compared to outdoor running may explain the reduced sRPE reported after PJT with TT compared to PJT with OT (Figure 2). Reduced sRPE after TT running exercise may be related to reduced residual fatigue and substrate depletion (Gäbler et al., 2018), potentially favoring the quality (e.g., intensity) of subsequent sand-based PJT sessions, and its effect on sprint performance (Ramirez-Campillo et al., 2021a). Whether these theory-based but admittedly speculative explanations explain the greater 50-m linear sprint improvement after PJT with TT compared to OT, needs to be verified in future studies.

In line with the greater magnitude of improvement in 50-m linear sprint time after PJT with TT compared to PJT with OT, a larger SLJ improvement was noted in the PJT with TT group compared to the PJT with OT group. Similar to our findings, a study of Granacher et al. (2015) reported a greater countermovement jump improvement after PJT performed on stable (i.e., firm gym floor) versus unstable (e.g., balance pads) surface (12.9% and 4.5%, respectively). Although SLJ improvement was larger after PJT with TT, both intervention groups achieved large-magnitude improvements compared to the control group which can likely be attributed to neuromuscular adaptations primarily induced through PJT (Pereira et al., 2021), including enhanced motor unit recruitment and/or firing frequency (Ramirez-Campillo et al., 2021b). In addition, our results also reported an increase in calf girth (i.e., left and right calf) in both experimental groups undergoing PJT. Ramirez-Campillo et al. (2022) reported increased calf girth following PJT which is in support of our findings. The absorptive qualities of sand surface likely prolongs ground contact time (i.e., force), thus increasing the contraction time (i.e., time under tension) (Pereira et al., 2021), which could be a factor triggering muscle hypertrophy (Grgic et al., 2021). The reason for the increase in calf girth also may have been possibly due to the increased muscle tension (i.e., greater eccentric stimulus) during the performance of PJT exercises. However, the compliant nature of sand may have reduced the eccentric overload stimulus, which could have reduced the hypertrophic effect. This may explain the significant although trivial magnitude improvement in calf girth. As a limitation, it should be noted that calf girth measurements involve the assessment of different tissues and not just muscle volume. Previous studies reported effects on muscle hypertrophy following PJT using more sophisticated measurement techniques (e.g., magnetic resonance image; muscle biopsies) (Malisoux et al., 2006; Skurvydas and Brazaitis, 2010; Vissing et al., 2008).

Ramírez-Campillo et al. (2014) reported an increased 2.4 km performance in middle- and long-distance runners following a combined PJT with endurance running. Similarly, Ahmadi et al. (2021) postulated improved cardiorespiratory fitness following sand-based PJT versus rigid surface PJT. Our results confirmed previous findings, as cardiorespiratory fitness (i.e., Copper test) improved in both, PJT with TT and OT, when compared to CG. However, PJT plus TT versus PJT with OT showed larger improvements in terms of the examined effect size magnitude ($g = 1.47$ versus $g = 0.70$). The observed improvement in cardiorespiratory fitness can likely be explained by both interventions (i.e., sand-based PJT and endurance running exercise). First, the increase in cardiorespiratory fitness may have been achieved due to increased energetic cost when performing sand-based PJT (Lejeune et al., 1998). Second, both PJT with TT and OT were exposed to aerobic-based running programme (i.e., outdoor or treadmill) during the nine weeks of intervention. A potential mechanism for improved cardiorespiratory fitness may include mitochondrial adaptations (i.e., increase in mitochondrial content), increase in citrate synthase maximal activity, type II fiber activation, and adenosine monophosphate activated protein kinase activity (Kristensen et al., 2015). Another potential reason may be the positive effect of aerobic training on the central adaptation of cardiorespiratory fitness markers (e.g., maximal stroke volume, cardiac output, and blood volume) (Astorino et al., 2012). Indeed, there is evidence that aerobic exercise induces changes in central physiological markers of cardiorespiratory fitness such as FVC and RHR (Fuster et al., 2008; Reimers et al., 2018), which is in line with our findings of improved FVC (i.e., increase) and RHR (i.e., decrease), following PJT with TT and OT. Further, the greater magnitude of cardiorespiratory fitness after PJT with TT compared to PJT with OT may be related to improved stretch-shortening cycle functioning (Coyle, 1995) after PJT with TT and not OT, as reflected by a greater SLJ performance. If such speculative mechanism is corroborated in future studies, it might be related to improved running efficiency, a key element for the improvement of running endurance after PJT (Ramirez-Campillo et al., 2021a).

There are some limitations of our study which should be acknowledged. First, there were no female participants included in this study. Therefore, the results of this study cannot be translated to females. Second, the training intervention was limited to a nine-week duration. A longer study duration may show larger effects. Third, the lack of physiological or biomechanical assessment tools precluded a better understanding regarding the interpretation of our results. Lastly, there was no active control group involved in this study. Future studies should include sand-based PJT or running as active control to elucidate the independent role of both exercise types when introduced in the form of concurrent training.

Conclusion

The current study suggested that concurrent training using sand-based PJT and endurance running exercise enhanced physical fitness in young male individuals. Coaches may use both concurrent exercise regimes (i.e., PJT with OT or TT) based on preferences and logistical constrains (e.g., weather; access to treadmill equipment). However, coaches should note that outdoor running may exhibit greater training loads compared to treadmill running. Therefore, other training loads (e.g., sports activities) should be considered when designing a training cycle. In addition, 48 hours recovery between sand-based PJT and endurance running exercise seems to be an optimal concurrent exercise sequencing to attain the desirable outcomes in young male individuals.

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Key points

- Concurrent training in the form of sand-based plyometric-jump training and endurance running exercise can enhance physical fitness in young individuals;
- Compared to treadmill running, rating of perceived exertion was higher in outdoor running sessions;
- Sand-based plyometric-jump training may induce greater standing long jump performance when combined with endurance running on treadmill surface as compared to outdoor surface.

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