Effects of Pre-Run Walk Under Load on Reactive Strength Index, Running Economy, and Performance of Recreationally Competitive, Male Runners

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Abstract

Introduction: This study examined the effects of a low-impact external loading warm-up intervention (~25% body mass) on reactive strength index (RSI), running economy (RE), and run to exhaustion (RTE) performance.

Methods: Thirteen recreationally competitive, middle-aged (38±11 years) male runners completed a familiarization session and two counterbalanced trials. Experimental trials began with the same 10-min self-selected warm-up followed by a 15-min treadmill walk (4.02 km/h) at multiple grades without (CON) or with a 19.2 kg weighted vest (VEST). Perceived readiness (PRS) was assessed post warm-up. Participants then completed three, 5-minute RE bouts at a fixed velocity of 11.3 km/h, and 80% and 90% of estimated 5-km race pace followed by a RTE. RSI tests were performed in triplicate before and after the VEST or CON walk and between each RE bout.

Results: PRS (VEST = 76±14 vs CON = 70±14 mm; p = 0.18), heart rate, VO_2, respiratory exchange ratio and metabolic cost did not differ ($p > 0.05$ at every pace). No treatment effect was found for RSI, but there was an effect for time due to a trend of post warm-up RSI favoring VEST. Finishing times for RTE did not differ (p = 0.69) between CON (510±158 s) and VEST (519±141 s).

Conclusions: VEST failed to elicit statistical advantage in RSI, RE, or RTE in recreationally competitive male distance runners. However, examination of individual PRS and immediate post-warm-up RSI outcomes to RTE suggests positive responders are identifiable and may benefit from this novel, low-impact post-activation potentiation enhancement strategy.

Key Words: post-activation potentiation enhancement, warm-up, weight vest

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Introduction

Enhancing running economy (RE) is a principal strategy to improve distance running performance. [1,2] Three investigations have explored the potential benefits of incorporating weight vest warm-up interventions with trained runners. The first by Barnes, Hopkins, McGuigan and Kilding [3] included adding a weight vest (20% of body mass) during a set of 10-s strides (6 strides in total) to the warm-up routine of trained, male runners. The addition of a weight vest resulted in 10 of the 11 participants decreasing their oxygen cost at a standardized treadmill speed of 14 km/h and 1% grade, and simultaneously increasing their duration capacity of a graded exercise test. Likewise, RE but not performance was improved during a run to exhaustion (RTE) using the same protocol by Wei, Yu, Duncan and Renfree [4] in sample of nine female and three male college students that were physically active but not trained runners.

Leg stiffness decreases during extended continuous running. [5] Barnes et al. [3] attributed their runners' improvements to increased leg stiffness as assessed by dividing relative peak force by jump height of 5 consecutive jumps completed as quickly as possible. Wei et al. [4] also found increased leg stiffness versus a control warm-up but no difference versus a plyometric-based warm-up without loading. It is plausible beginning a race with increased leg stiffness or the ability to mitigate loss in leg stiffness across the race duration could lead to better running performance by minimizing metabolic cost via alteration in ground contact time. [6] These findings inspired a third, field-based performance study. The addition of four, 80 m strides while wearing a soft, weighted compression garment failed to improve early, mid, or late performance during a 5-km road time trial of 10 collegiate cross-country runners during an official coach-led practice time trial. [7] The failure to improve performance may have been due to the reduced loading scheme (~10% of body mass) versus the heavier traditional style weight vest used in Barnes et al. [3] and Wei et al. [4].

Striding under heavy load, may not be appealing to recreationally competitive runners, particularly middle-age to older runners that make up a large portion of this population. While the strides were only undertaken for seconds in these studies, the weight vests were worn for considerably longer durations. The current authors developed this study with a hypothesis that perhaps the extended loading period, not necessarily the strides under load, may partially explain some of the positive outcomes [3,4], but this strategic intervention has yet to be examined. The purpose of this study was to determine if walking under load for 15-min prior to an individual's self-selected warm-up could (a) attenuate decline in leg stiffness throughout a ~20 min running protocol as determined by a lower body reactive strength index (RSI) task, (b) enhance RE at multiple paces, and (c) increase duration of a run to exhaustion (RTE). The introduction should be brief and supported with citations and impactful research.

Scientific Methods

Participants

Recruitment efforts were made to match or exceed the n of similar studies. [3] [4] [7] Thirteen recreationally competitive male runners (38±11 years; 76.4±8.1 kg; 178±4 cm; VO_{2peak} 49.7±4.2 ml/kg/min) free from injury that reported training four or more times per week participated in this study. Participants self-reported capacity to complete a 5-km run between 18-22 min (15±1 km/h pace). A technical difficulty concerning treadmill grade resulted in an invalid RTE performance test for one participant. All participants provided written informed consent prior to any experimental procedures. This study was approved by the local institutional review board and all procedures conformed to the standards of the Declaration of Helsinki.

Protocol

Participants reported to the laboratory on three separate occasions. The initial visit allowed anthropometric assessments and served as a familiarization trial. Participants were assessed for body mass (BWB-800, Tanita Corporation, Japan), height (Invicta Plastic Limited, Leicester, England, 1990) and screened for apparent health risk associated with a physical activity questionnaire (PAR-Q) [8]. A training history questionnaire was then completed by participants. The questionnaire included sections on training modalities, training frequency and duration, and a detailed description of each participant's customary warm-up activities.

Two experimental trials were conducted and separated by at least five but no more than 14 days apart. Trials were conducted at approximately the same time of day (±1 h) for each individual. Participants were asked to wear the same clothing and shoes for each session to keep body mass with clothing as close as possible between trials. Early morning participants were asked to report after an overnight fast. For trials commencing after 10:00 am, participants were asked to report at least 4-h post-prandial. Participants recorded food and beverage intake 24-h prior to their first trial and were instructed to duplicate the 24-h dietary pattern for the second trial. Participants were instructed to consume a 500 ml bottle of water prior to bed the night before trials and an additional 500 ml prior to reporting to the laboratory. Instructions were given to avoid alcohol and caffeine consumption and strenuous exercise for 24-h before sessions.

Following anthropometric measurements and questionnaires in the initial session, participants were asked to warm-up as they would prior to a competitive racing event but with a 10-min time restriction. The warm-up protocol and activities were recorded for replication in subsequent sessions. Participants then completed a lower body RSI task on a validated[9] contact time mat (Just Jump! Probotics Inc. Huntsville, AL). The RSI required participants to keep their hands on their hips, and from an upright starting position, complete 4 consecutive jumps. Participants were given specific instructions to "jump as high as possible while also attempting to minimize ground contact time between jumps". RSI was calculated by dividing average jump height (cm) by ground contact time (s). Three practice attempts were made with 30-s recovery intervals between attempts. If participants did not feel confident that they had sufficiently mastered the RSI task, additional attempts were allowed until the participant felt prepared. No participants exceeded more than four attempts. Next, a continuous, single-intensity, multi-grade treadmill (PRO 27, Woodway, Waukesha, WI) $VO_{2peak60}$ test was conducted with all participants reaching volitional exhaustion between 6-12 min. Data from our laboratory has previously confirmed that both male[10] and female[11] runners reach ≥ 95% of their VO_{2peak} in 5-min when running at a competitive 5-km pace with the treadmill grade set to 1%. Based on these factors, the $VO_{2peak60}$ test incorporated a treadmill pace equal to that of the participant's estimated 5-km pace conservatively rounded to the closest 0.16 km/h (smallest increment of adjustment allowed by treadmill). Treadmill grade was initially set at 0% and increased by 1% each 3-min. To help ensure the duration of the test was not too short, velocity was decreased by 0.8 km/h if respiratory exchange ratio (RER) in the third minute of the first stage was > 0.95 and/or rate of perceived exertion (RPE) was 8 or greater on a 10-point scale for stage 1. Likewise, if RER was less than 0.90 or RPE was 5 or less at the end of the first stage, treadmill velocity was increased by 0.8 km/h. Indirect calorimetry (TrueOne 2400, Parvo Medics, Salt Lake City, UT) data was collected and VO_2 test data was then manually searched for highest 60-s VO_2 average during the final 2-min of the test preceding volitional exhaustion to determine $VO_{2peak60}$.

Each experimental trial began with an assessment of participant's clothed body mass plus a forearm heart rate monitor (Polar Electro Oy, Professorinite 5, FI-90440 Kempele, Finland). The runner then completed their personalized 10-min warm-up protocol with a short recovery period of ~3 min, followed by three RSI separated by 30s. After the RSI testing, participants completed a 15-min treadmill walking (4 km/h) protocol. The protocol consisted of five repeated bouts of 1 min at 2% grade, 1 min at 1% grade, and 1 min at 0% grade. The only difference between experimental sessions were that in the experimental trial a 19.2 kg weight vest (RUNMax Adjustable Weighted Vest) (VEST) was worn during the walking protocol and no weight vest was worn during control (CON). Weight vest application equaled 25.2±2.9% of participants' body mass across the cohort. An a priori decision was made during study design stages that the VEST mass selection should exceed the ≤ 20% body mass used during the higher intensity striding protocols of [3] [7] [4]. The vest chosen was one of the most highly purchased weight vests on the digital marketplace when acquired for use in this study. The vest had 5 anterior and 5 posterior pockets for inserts. Each insert was ~1.7 kg. Because of this design, all insert pockets were used to keep the load symmetric (anterior/posterior and laterally) while also meeting minimum body mass % requirements. Five minutes after the walking protocol, participants completed three RSI, each followed by a 30-s recovery period. At 8 min post-walk, runners used a modified perceived readiness scale (PRS) implemented in past running studies that have used warm-up protocol manipulation[12]. The original PRS consisted of a Likert scale of 1 (not effective at all) to 10 (extremely effective). The descriptors remained the same, but participants were asked to make a vertical mark on a 100-mm line after being asked how ready they felt from the warm-up to perform graded exercise and RTE assessments.

At 10-min post walk, participants donned a soft malleable face mask (Hans Rudolph Inc., V2 Mask, Shawnee, KS) for indirect calorimetry data collection procedures to assess RE and began the first RE bout. The pace for all participants during this trial was 11.3 km/h at 1% grade for 5 min. As soon as the treadmill was safely stopped, the facemask was removed and three RSI were immediately completed, each separated by 30 s of standing rest, before returning to the treadmill. This protocol was repeated for two more 5-min bouts at 80 and 90% of the participant's estimated 5-km race pace. These paces were selected to induce fatigue and be as close to 5-km race intensity as possible but still low enough intensity that metabolic cost could be calculated (i.e. produce an RER of < 1.00). RSI was collected between each bout and participants returned to treadmill running within 1 min of the final RSI. VO_2, metabolic cost (calculated using non-protein-based stoichiometry formulas[13], RER and heart rate were analyzed from each RE bout using the average of the final 2 min of each 5 min bout.

Following the last RSI bout, runners returned to the treadmill without the mask to complete the RTE. The treadmill began from the stop position and was pre-set to the same pace used in the $VO_{2peak60}$ test. Treadmill grade was set to 1% lower than grade achieved during the final full stage completed during the $VO_{2peak60}$ test. The goal of the RTE pace was to elicit exhaustion in ~6-9 min. Figure 1 provides an illustrated and detailed explanation of the experimental trials and description of when dependent variables were collected.

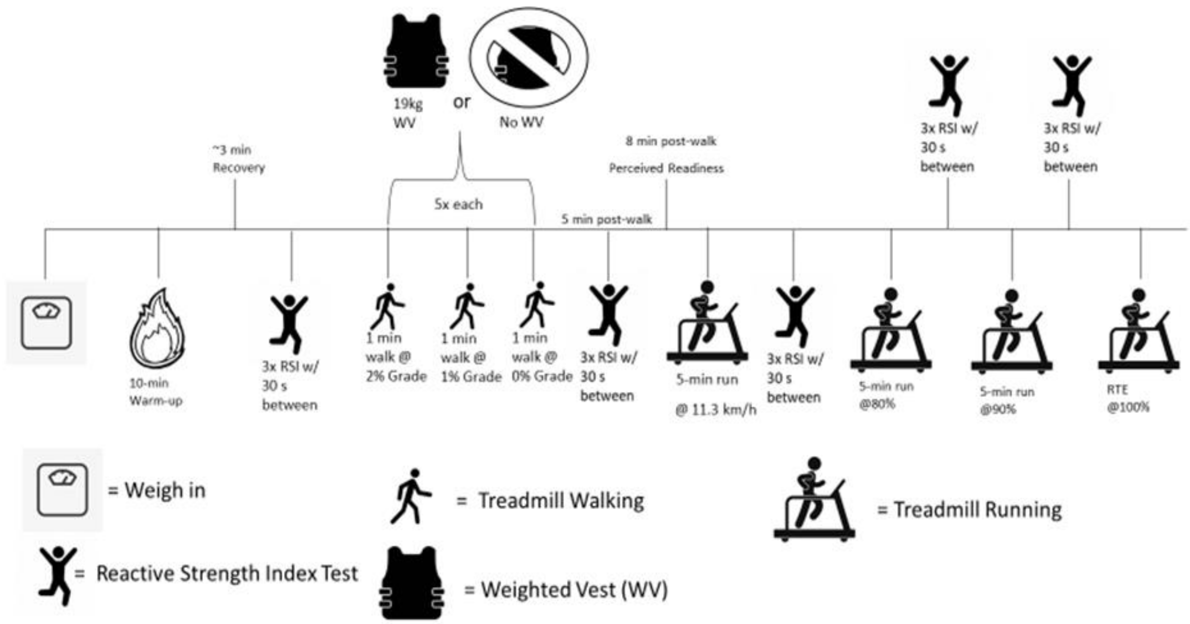

Figure 1. Illustrated representation of methodology. RSI = Reactive Strength Index; RTE = Run to Exhaustion.

Statistical Analysis
Data were assessed for normality using the Shapiro-Wilk test. Dependent variable analyses excluding RSI were analyzed using paired *t*-tests. For RSI, the average of the two highest scores at each timepoint was used for statistical analyses in a 2 (condition) by 5 (time point) repeated measures ANOVA. Data were assessed for sphericity using Mauchly's Test. Greenhouse-Geiser adjustments were used if sphericity was violated. Bonferroni adjustments were implemented for *post hoc* comparisons if main or interaction effects were significant. All data are reported as mean and standard deviation. An alpha level of ≤ 0.05 was used to determine significance.

Results
The walking protocol produced only modest cardiovascular challenge, but VEST (87±10 beats/min) heart rate was elevated ($p < 0.001$) compared to CON (82±10 beats/min). Perceived readiness following the participants' habitual warm-up routine plus walking treatments did not differ (VEST = 76±14 vs CON = 70±14; $p = 0.18$). Significant effects for RSI were discovered for time ($p < 0.001$) and interaction ($p = 0.01$), but not for treatment ($p = 0.82$). Post hoc analyses revealed that post-walk RSI performance was lower than all three post-running economy bouts (Figure 2). Based on the lack of main effect for treatment and large amount of between-subject variance, no pairwise comparisons for individual time points were made. There was no indication that RE was altered by VEST as heart rate, VO_2, RER, and metabolic cost did not differ at the standardized running pace or at 80 or 90% of 5-km pace (Table 1). RTE performance also failed ($p = 0.69$) to be impacted by VEST (Figure 3). However, examination of individual RSI and RTE outcomes suggested potential for a sub-group level responsiveness. Individual RTE responses and RSI scores following the warm-up for CON and VEST are displayed in Figures 3 and 4 for more nuanced discussion of positive and negative individual responders, respectively.

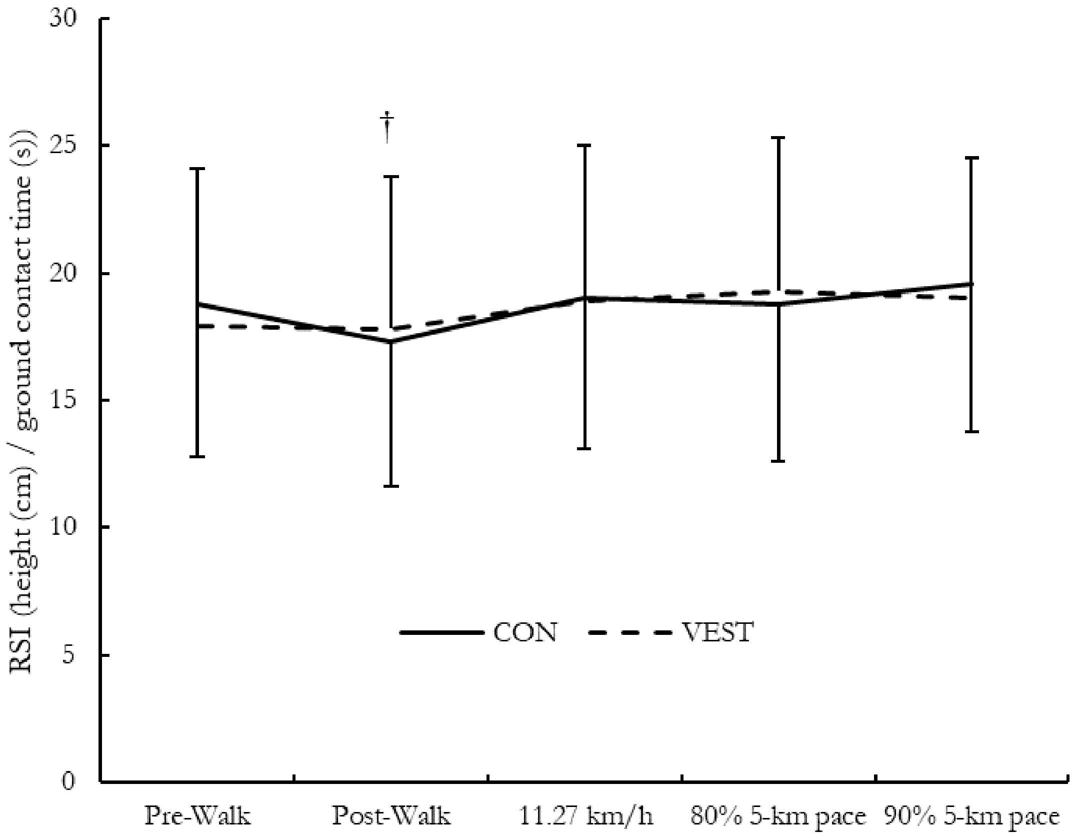

Figure 2. Reactive strength index (RSI) across experimental trial sessions. (n = 13; mean ± standard deviation). CON (Control), VEST (Load trial), GCT (Ground contact time).
† = main effect ($p < 0.05$) for time at post-walk period differed versus each running bout.

Table 1. Physiological and metabolic responses during 5-min running economy bouts at varying intensities (n = 13*; mean ± standard deviation).

	11.27 km/h		80% PB		90% PB	
	CON	VEST	CON	VEST	CON	VEST
HR (beats/min)	147 ± 11	146 ± 10	151 ± 16	152 ± 15	164 ± 15	164 ± 15
VO_2 (ml/kg/min)	35.5 ± 2.5	35.7 ± 3.4	36.7 ± 3.7	37.2 ± 3.8	41.6 ± 4.2	41.8 ± 3.6
VO_2 (L/min)	2.73 ± 0.35	2.75 ± 0.37	2.81 ± 0.32	2.87 ± 0.37	3.19 ± 0.38	3.22 ± 0.37
RER	0.89 ± 0.04	0.89 ± 0.04	0.88 ± 0.03	0.89 ± 0.04	0.93 ± 0.05	0.93 ± 0.05
Metabolic cost						
(Kcal/L/min)	13.8 ± 1.8	13.9 ± 1.9	14.2 ± 1.6	14.5 ± 1.9	15.9 ± 1.3	16.0 ± 1.3*
(kJ/L/min)	57.9 ± 7.4	58.3 ± 7.8	59.4 ± 6.8	60.8 ± 8.1	66.4 ± 5.5	67.0 ±5.4*

CON (control), VEST (load trial), 80% PB (80% of personal best 5-k time), 90% PB (90% of personal best 5-k time). * (n = 12) One participant had an RER > 0.99 prohibiting calculation.

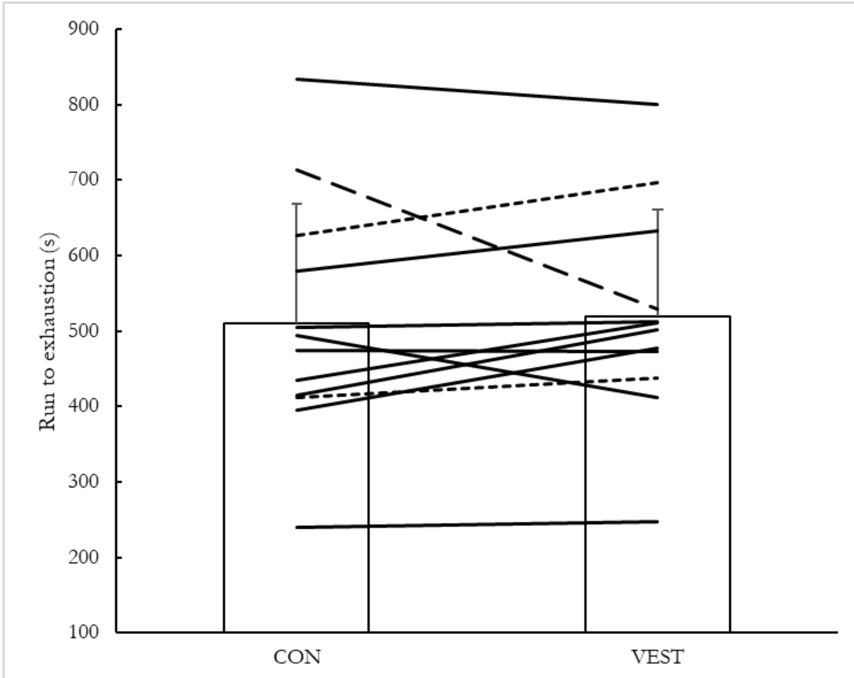

Figure 3. Individual and mean changes in run to exhaustion (RTE) time after a CON (control) and VEST (load trial) trial (n = 12; mean ± standard deviation). Short dashed lines represent runners described in discussion that reported highly favorable VEST perceived recovery scale and improved RTE. Long dashed lines represent participant described in discussion that experienced significant decrease in reactive strength index following VEST and greatest decrement in RTE.

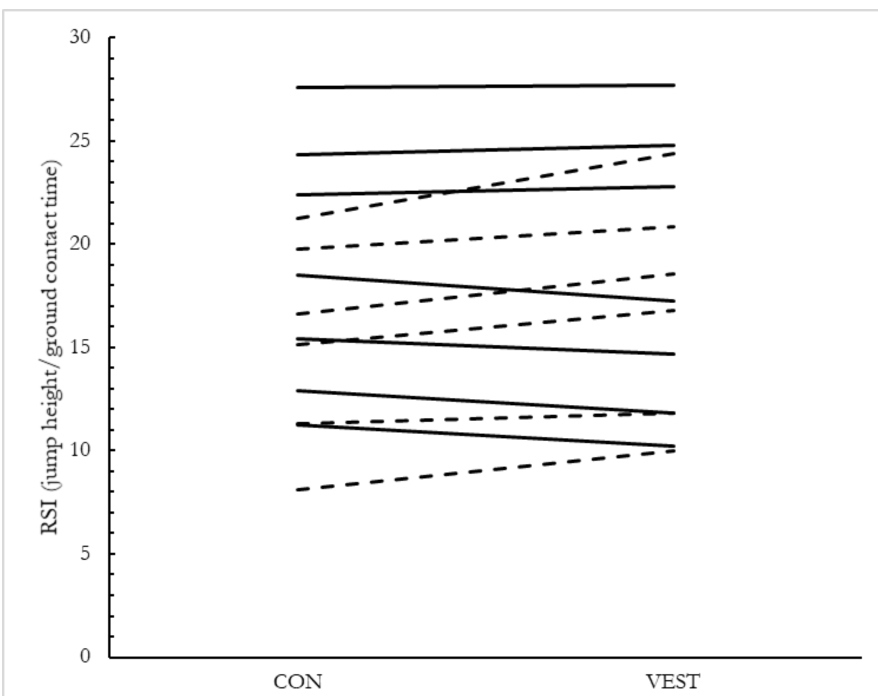

Figure 4. Individual reactive strength index (RSI) scores following treatment interventions and prior to running bouts. Dashed lines represent individuals with ≥ 4% improvement in RSI and ≥ 6% increased run to exhaustion performance following VEST.

Discussion

The current study was developed based on the hypotheses that spending 15 min under load exceeding 20% of body mass could potentially improve RSI, RE, and RTE. The study's target population, recreationally competitive adult male runners, was considered to be unlikely to incorporate plyometric exercises as part of their warm-up routine and was confirmed. Additionally, the investigators believed this population might be more hesitant to perform strides under load as was undertaken in all 3 previous investigations in which warm-up weight vest interventions were incorporated. Like O'Neal, Albino, Swain, Sharp, Boy and Killen [7] and Wei, Yu, Duncan and Renfree [4], no running performance effect for VEST was exhibited as was found in Barnes, Hopkins, McGuigan and Kilding [3]. Critically, Barnes, Hopkins, McGuigan and Kilding [3] weight vest striding intervention produced RSI and RE improvement in 10 of their 11 male runners. This must be considered when interpreting the current study, as no main effect for treatment was found for RSI. Without RSI improvement, RE or RTE were also unlikely to exhibit following VEST. However, there was a main effect for time, with post-warm-up RSI lower than all three RSI undertaken after RE bouts. A visual inspection of Figure 2 confirms this was due to a trend of CON RSI falling but maintenance of RSI post-VEST. While main effects for treatment were not statistically significant for RSI or RTE, examination of individual data (Figure 4) suggests that likelihood of improved RTE was linked to VEST improving RSI and implications are described in more detail below.

Extensive efforts have been made to characterize neuromuscular alterations and examine the potential of performance enhancement from post-activation potentiation (PAP_E) [14] interventions prior to endurance exercise. In the last decade, two conflicting reviews have been written concerning PAP_E and endurance performance. Boullosa, Del Rosso, Behm and Foster [15] supported PAP_E and concluded that regulatory myosin light chain phosphorylation magnification and increased Ca^{++} sensitivity[16,17] remain the strongest explanations for the potential of PAP_E. However, of the 22 unique studies reviewed[15], only one specifically examined trained runners[18], and no measures of RE or performance outcomes were assessed. A more recent meta-analysis[19] of 35 studies contends that PAP_E does not alter endurance performance. Thirteen studies evaluated included running performance tasks. The PAP_E strategies varied widely and the outcomes within the running modality cohorts are inconsistent. Unfortunately, Vasconcelos and colleagues did not discover or report the positive PAP_E effects on performance of Barnes, Hopkins, McGuigan and Kilding [3]. None of the warm-up protocols excluding the three studies already described used any external loading interventions in attempt to induce PAP_E with one exception. Low, Ahmadi, Kelly, Willardson, Boullosa and Behm [20] included squat jumps with band resistance as a warm-up intervention, producing both RSI and early run (first of 5 x 1-km treadmill time trials) performance improvement. When using a drop jump PAP_E intervention, elite male endurance runners exhibited 5 x 1-km track-based time trial performance improvement, while an elite female cohort found inhibited performance in the same task[21]. It is difficult to compare the remaining studies discovered by [19] to studies incorporating external loading interventions because the PAP_E protocols are of such different modalities and study design[22,23].

PAP_E has been exhibited via loaded squat jumps or striding and with depth jumps. However, the current authors speculated that recreationally competitive male runners were unlikely to incorporate higher-intensity PAP_E activities into their regular training or warm-up routines. When asked if runners participated in plyometric training, only one runner reported "yes". However, that participant did not include any plyometric-based activities in their warm-up. Two participants included A and B skips in their self-selected, pre-competition warm-ups. No other participants included any warm-up drills resembling plyometric exercise. While Vasconcelos et al. [19] meta-analysis did not support PAP_E as a method to improve endurance performance, the efficacy of external loading during warm-up interventions to improve running performance may simply be too multi-faceted to make generalizations to all runners. The current authors contend that a combination of RSI and PRS data analyzed on a case-by-case basis may provide support that blanket statements contraindicating pre-warm-up external loading may be too broad in scope. Additionally, it is important to note that the RTE occurred in a time period meant to mimic a late 5-km competition timeframe, possibly failing to detect early run[21] performance efficacy.

Since blinding was not possible when explaining the purpose of the study, investigators provided a neutral outcome response that VEST might produce increased leg stiffness improving performance, but external loading might also produce fatigue that might hinder RTE. Group PRS did not differ statistically; however, individual evaluations to subjective responses to PRS revealed two participants expressed strong favorable opinions (25+ mm favorability on 100-mm scale) of VEST over CON. These participants exceeded their RTE during VEST over CON by 6 and 10% (denoted by short dashed lines in Figure 3). The runners had two of the four lowest body masses (i.e. the VEST was higher relative percentage of body mass) while also displaying some of the higher RSI scores. Contrasting these two runners, the participant that experienced the greatest decrease in RTE performance (34%, denoted by long dashes in Figure 3) had post-walk RSI fall by 8% following VEST. Upon completion of the study, investigators reached out to the runner to determine if there was a reason for the steep performance decrement. The participant reported no injuries or acute issues but stated that he had been (a) training specifically for ultra-marathon distance races for the previous few years, (b) stopped participating in resistance training as part of his strategy for ultra-distance running events, and (c) was surprised at the both mental and physical toll the VEST intervention had played in his ability to push through in the RTE. Eight runners improved RTE by ≥ 1.5% during VEST; one runner finished 1 s slower during VEST. If the negative outlier runner's performance during VEST's data was removed, the statistical significance of the RTE dropped from $p = 0.69$ to $p = 0.12$. In regards specifically to RSI, a positive PAP_E response confirmed by RSI scores was implausible statistically due to the unexpected, marked variance of our sample (Figures 2 & 4). Even with these statistical limitations, a main effect was found for time with post-warm-up (i.e. when PAP would be most likely to be elicited) versus running bouts trend favoring VEST. When individual post-warm-up RSI scores are displayed in Figure 4, six runners improved RSI by > 4% during VEST and are identified with dashed lines. Five of these runners improved their RTE by 6% or greater. The sixth was unable to complete RTE because of a technical error concerning the treadmill grade during testing. Furthermore, 3 of the 4 runners whose RSI decreased with VEST also displayed negative RTE performance with VEST.

Conclusions

The pre-run external loading protocol was ineffective at improving cohort RSI at any timepoint and likely explains the lack of differences between RE or RTE performance between VEST and CON. However, the current investigators caution the complete dismissal of pre-run external loading or PAP_E style interventions to improve running performance as recently suggested by meta-analytical review. A simple individualized approach incorporating PRS or confirmation of RSI changes with an external loading intervention might help coaches target individual runners that could benefit from pre-run loading strategies. We suggest runners conduct their own time trials with and without loading in a similar nature to that of the current study (i.e. 15 min of walking with weight vest of ~25% body mass) and evaluate the perceived readiness outcomes efficacy on their own accord. Multiple runners anecdotally expressed comments about feeling "more springy" or "lighter" after removing the vest. There is a possibility VEST produces a placebo effect with little to no downside unless VEST is perceived negatively by the runner or produces impairment of RSI. For coaches or runners with access to RSI testing instruments, we suggest trying different loading schemes and possibly duration to optimize load and duration for a more objective and individualized approach.

There are limitations in regards to the current findings. While exceeding the n of all previous similar investigations, the unexpected vast decrease in one participant's RTE and between subject variance in RSI reduced the power of this study beyond a priori expectations and reduced the likelihood of statistical significance being exhibited. We specifically targeted a population of runners (non-elite and older) that we felt would be less likely to consider the higher intensity striding under load protocol incorporated by past weight vests warm-up intervention studies[3 4 7] in younger cohorts. Our cohort did not include female runners. These factors should be considered in limiting the generalizability of the current study.

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