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Minimalist style boot improves running but not walking economy in trained men

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ABSTRACT
This study examined movement economy under load with 1000 g minimalist (MIN) vs. 1600 g traditional (TRD) style boots. Fourteen trained, male participants completed a VO_{2peak} test (46.6 ± 7.3 ml/kg/min) while wearing a 16 kg external load. Treadmill speeds for the running economy (RE) trials were determined by the slowest pace in which participants completed a full stage with a running gait pattern during the VO_{2peak} test. Walking economy (WE) pace was 1.6 km/h slower than RE pace. During the second session, participants completed 5-min exercise bouts at WE and RE pace under load wearing MIN and TRD. There were no differences for any measured variables during WE trials. In contrast, RE (MIN $= 2.95 \pm 0.28$ vs. TRD $= 3.04 \pm 0.30$ L/min; $p = .003$: Cohen's $d = 0.32$), respiratory exchange ratio ($p < .001$), and perceptual measures ($p < .05$) were all improved while wearing MIN.

Practitioner summary: In trained men, 1000 g/pair minimalist style boots (MIN) resulted in improvements of approximately 3% and 5% for running economy and respiratory exchange ratio versus 1600 g/pair traditional boots while wearing a 16 kg kit. Perceptual responses, including comfort, also favoured MIN. These effects were not found at walking pace.

Abbreviations: MIN: minimalist style boots; TRD: traditional style boots; RE: running economy; WE: walking economy; ES: effect size; RER: respiratory exchange ratio; HR: heart rate

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Military footwear; tactical athlete; oxygen uptake; energy cost; military workload

Introduction

Minimalist style shoes are lighter, feature short stack height, minimal drop height from heel to forefoot (typically <5 mm), and lack motion control characteristics. All these features may potentially impact gait and movement economy (Dobson et al. 2017). Grier et al. (2016) reported minimalist athletic shoes were used by 17% of United States Army soldiers during training and appear to be more preferential to younger and more physically fit soldiers with no increase in injury risk compared to traditional running shoes. Recently, minimalist style AR670-1 compliant boots (MIN) with similar characteristics to the upper and lower shaft of traditional military boots (TRD) have become commercially available. However, differences in human performance outcomes when wearing MIN vs. TRD have only recently been explored (Simpson et al. 2018; DeBusk et al. 2018; Hill et al. 2017) with no documentation concerning difference in movement economy between boot types under load.

With a lack of data comparing MIN and TRD, expected movement economy outcomes can only be hypothesised from studies examining traditional style athletic shoes and minimalist running shoes or from boot studies in which boot mass was manipulated without other features of minimalist shoes being considered. A recent meta-analysis by Cheung and Ngai (Cheung and Ngai 2016) reported of the six studies (Squadrone and Gallozzi 2009; Perl, Daoud, and Lieberman 2012; Lussiana et al. 2013; Paulson and Braun 2014; Sobhani et al. 2014; Warne and Warrington 2014) comparing running economy of minimalist vs. traditional running shoes, a consistent but modest effect size (overall mean effect size = 0.49) with considerable variance (ES range 0.16–0.78) was found suggesting minimalist footwear (<230 g) improves running economy in comparison to traditional athletic footwear (>300 g). However occupational boot design and increased footwear mass make extrapolation of findings in light running shoes to tactical boots difficult. For example, in a recent study

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Table 1. Description of participants ($n = 14$; mean ± SD).

Height (cm)	Mass (kg)	Body fat (%)	Load VO_2 max (ml/kg/min)	No Load VO_2 max (ml/kg/min)
177 ± 6	86.2 ± 10.4	8.1 ± 3.2	46.6 ± 7.3	47.1 ± 5.7

Load: VO_2 max test performed while wearing ∼16 kg external load. No Load: VO_2 max test performed without rucksack.

comparing running economy between non-minimalist style popular road racing shoes, the three shoes used displayed masses of only 200–250 g per shoe (Hoogkamer et al. 2018). Conversely, even lightweight, traditional style military boots are likely to have masses three to four-fold that of non-minimalist style running shoes.

It is likely the decreased mass of minimalist shoes accounts for a considerable percentage of the improved running economy vs. traditional running shoes. Franz, Wierzbinski, and Kram (2012) reported that running barefoot (expected to mimic that while wearing minimalist shoes) offers no advantage in running economy vs. traditional running shoes when equal weighting was artificially applied to the feet under barefoot and shod conditions. While the upper and shaft of MIN do not greatly differ from TRD, the soles of each boot type create the opportunity for a significant reduction of mass for MIN. A seminal study (Frederick 1984; Frederick and Hayes 1984) in the early 1980s suggested that for every 100 g of additional load placed on each foot, an ∼1% decrease in unloaded running economy would be exhibited. However, additional investigations have both supported (Divert et al. 2008) and contested (Franz, Wierzbinski, and Kram 2012) the strength of this relationship.

In military time trial tasks performed under load conditions, it is common for soldiers to alternate between running and walking gaits depending on terrain demands. A recent investigation (Simpson et al., 2017) determined that improved movement economy (i.e. decreased oxygen consumption at the same movement velocity) was a strong indicator of performance during a standard 8-mile (20-kg load) time trial in elite soldiers. Relative VO_2 exhibited significant relationships between time trial performance for multiple walking and running paces under load (Simpson et al., 2017). Improvement in movement economy potentially enhances time trial performance capacity under load. MIN are lighter and offer potential movement economy advantages to soldiers vs. TRD. However, we are unaware of any investigations that have examined differences in walking and running economy under load with these different styles of tactical boots. Therefore, the purpose of this study was to examine the impact of military boot type with load carriage on walking and running economy of individuals with experience in walking and running under load. The authors hypothesised that movement economy under load will be improved in the lighter MIN boot versus the TRD for both walking and running conditions.

Methods

Participants

Participants were recruited from the university Reserve Officer Training Corp and Military Science Department, local fire and police stations, and commercial strength training facilities. Male ($n = 14$) participants 20–30 years of age completed all trials. Seven participants had career experience in military or law enforcement, and all participants reported in engaging in strength training four or more days per week. All participants also reported experience participating in traditional exercise training while wearing a weight vest or working/training under load during law enforcement officer or military careers. Descriptive data for participants are presented in Table 1. Written informed consent was obtained from all participants prior to data collection. This project was approved by the Institutional Review Board of the University of North Alabama.

Procedures

Session 1 anthropometric assessments and VO_{2peak} tests

All data collection sessions took place during a weekday at approximately the same time of day for the individual, but time of day testing differed among individuals based on participants' schedule of availability. Participants were instructed to refrain from alcohol use, heavy exercise, and limit caffeine usage in the 24 h prior to each testing session. Participants were asked to eat a light meal/snack and consume a minimum of 500 mL of water 1–3 h prior to reporting to the laboratory and to repeat that dietary intake across all experimental sessions. Following paperwork, participants were assessed for anthropometric data. Height was measured using a stadiometer (Invicta Plastics Limited, Leicester, England) and body mass was assessed to the nearest 0.1 kg using a digital scale (BWB-800, Tanita Inc., Tokyo, Japan). Body fat percentage was estimated (Jackson and Pollock 1985; Brozek et al. 1963) using

3 site skinfold thickness data (Lange Callipers, Cambridge, MD). The sites assessed included the chest, abdomen, and mid-thigh.

VO_{2peak} testing procedures

Traditional VO_{2peak} test. Next, the participants completed two graded exercise tests (VO_{2peak}) on a treadmill (TrackMaster TMX 425 C, Fullvision, Inc., Newton, KS). The first test was a traditional treadmill running protocol and was completed in the participants' own running shoes, shorts, and a t-shirt (i.e. not under load carriage conditions). Briefly, after a self-selected warm-up, participants began running at 4.8 km/h slower than participants' estimated 5 km pace at 1% treadmill grade. Treadmill speed was increased by 1.6 km/h every 2 min for the next 3 min (i.e. until individual 5 km pace was reached). At this point the treadmill speed was increased by 0.8 km/h every minute until volitional exhaustion.

Load carriage VO_{2peak} test. The second VO_{2peak} test was novel in design, completed with load carriage, and used to determine walking and running velocity for boot experimental trials. Participants performed this test wearing their own running shoes, t-shirt, and shorts plus ∼16 kg of external load. The load included a weighted compression garment (TITIN Force™, New York, NY) (∼7.5 kg) that consisted of an inner compression shirt containing multiple pockets on the upper and lower back and chest/abdomen regions that were filled with dense but pliable gel pads inserts. A second compression overshirt was worn to help minimise insert movement. This configuration allowed anterior/posterior mass distribution to be more similar to that of personnel wearing a ballistic vest without impeding movement or interfering with instrumentation. The remaining 8.5 kg mass was added using a ruck sack filled with additional gel insert pads from the weighted compression garment manufacturer. Treadmill speed began at 2.4 km/h at a + 1% grade. Every 90 s, treadmill speed was increased by 0.8 km/h until volitional exhaustion was achieved. Metabolic data were measured using indirect calorimetry (TrueOne2400, Parvo Medicks Inc. Provo, Utah) reported in 30-s averages. Heart rate (T31 Transmitter, Polar Electro, Kempele, Finland) and rate of perceived exertion (Utter et al. 2004) data were collected at the end of each stage. VO_{2peak} tests were conducted in a counter-balanced, crossover order design. Tests were separated by a 20 min rest period. Both tests were terminated at the point participants could no longer continue. Participants met or exceeded a respiratory exchange ratio (RER; ratio of CO2 produced versus oxygen consumed during cellular metabolism) of 1.00 or greater for 25 of the 28 VO_{2peak} tests. All 3 trials that failed to reach an RER of 1.00 were loaded trials.

During the recovery period, participants were allowed to try on both styles of MIN and STD boot and determine which size (sizes 9.5–11.5 were available) they wanted to wear for the following experimental session. The median size TRD's (Belleville 310 T Hot Weather Standard Tactical Boot, Belleville, IL, USA) mass (801 g per shoe) exceeded the MIN (Tactical Research MiniMil Ultra-Light Minimalist Tactical Military Boot TR101) (500 g per shoe) by approximately 300 g per shoe. Both boots had shaft heights of 20.3 cm and 3–4 mm sole tread depth. The outsole surface area, heel-to-toe drop height, midsole hardness, and midsole thickness were 288.6 cm^2/18 mm/Shore A 66/8 cm for TRD and 235.4 cm^2/2 mm/Shore A83/1 cm for MIN, respectively.

Session 2 experimental boot sessions

Forty-eight to seventy-two hours after the first session, participants reported for the second session which consisted of four, 5-min treadmill exercise bouts with the same ∼16 kg load used during VO_{2peak} testing. The first two bouts were conducted at a brisk walking intensity. Studies examining external loading on movement economy have used walking paces ranging from 4 to 6.5 km/h (Grenier et al. 2012; Holewijn, Heus, and Wammes 1992). For the current study, walking pace (5.75 ± 0.29 km/h) was set at 1.6 km/h lower (i.e. 2 stages) than the treadmill speed that resulted in transitioning to a full running gait during the load carriage VO_{2peak} test. Ten minutes of passive recovery took place between all walking and running bouts to allow participants to rest and switch footwear. Participants then completed two more 5 min bouts of exercise at running intensity. Running intensity (7.40 ± 0.34 km/h) took place at the slowest pace in which participants completed a full stage with a running gait pattern during the load carriage VO_{2peak} test. A previous running economy study (O'Neal et al., In review) from our laboratory have confirmed high reliability in steady state metabolic data (VO_2 intraclass correlation = 0.998, coefficient of variation = $0.96 \pm 0.80\%$; RER intraclass correlation = 0.915, coefficient of variation = $1.37 \pm 1.01\%$) when 1 min averages from minutes 3–4 and 4–5 are used. As such, absolute and relative VO_2, RER and respiratory rate were collected and averaged in 60 s increment for the last 2 min of each exercise bout. VO_2 data from one participant during running trials and four participants during walking

Table 2. Metabolic and perceptual data from walking and running sessions ($n = 14$; mean ± SD).

					Rating of Perceived Exertion		
	VO_2 (ml/kg/min)	VO_2 (L/min)	RER	HR (bpm)	*Overall*	*Breathing*	*Leg*
				Walk			
MIN	20.1 ± 2.1	1.76 ± 0.21	0.85 ± 0.04	165 ± 13	2.1 ± 1.0	2.0 ± 0.9	2.6 ± 1.2
TRD	20.4 ± 2.5	1.79 ± 0.21	0.85 ± 0.04	163 ± 13	2.2 ± 1.1	2.4 ± 1.2**	2.5 ± 1.4
ES	0.13	0.14	0.00	0.11	0.03	0.33	0.08
				Run			
MIN	34.4 ± 3.3	2.95 ± 0.28	0.94 ± 0.06	165 ± 13	3.9 ± 1.5	4.0 ± 1.8	4.4
TRD	35.5 ± 3.5*	3.04 ± 0.30*	1.00 ± 0.07*	163 ± 13	4.9 ± 1.5*	4.8 ± 1.5**	5.7 ± 1.7*
ES	0.31	0.32	0.90	0.18	0.83	0.43	0.69

MIN: minimalist style boot; TRD: traditional style boot; ES: Cohen's d effect size; RER: respiratory exchange ratio; HR: heart rate. * $p < .01$; ** $p < .05$.

trials displayed VO_2 values that differed by more than 0.1 L/min. During these trials, participants completed 1 extra minute of exercise to reach steady state. Two participants were unable to reach steady state criteria during a walking trial. Their data were excluded from walking trial economy and RER data analysis.

The order of boot implementation was counterbalanced to limit ordering effects. Whichever boot style was worn first during walking trials was worn last during running trials for each participant. After exercising in both boot types, each participant was asked to subjectively rate shoe comfort on a 100 mm scale with 0 marking 'not comfortable at all' and 100 marking 'extremely comfortable'.

Statistical analysis

Parametric dependent variables (VO_2, RER, HR, and boot comfort rating) were assessed using paired t-test for each boot type. RPE data were analysed using Wilcoxon Signed Rank Tests. All data are reported as the mean ± SD. Results were considered significant at $p \leq .05$.

Results

There were no significant differences for any physiological or perceptual variables during walking trials (Table 2). In contrasts, all variables excluding HR during running trials were significantly different at a level of $p < .01$, except breathing RPE ($p = .02$) (Table 2). Individual response data for RE and WE are presented in Figures 1 and 2. RE when wearing MIN decreased or was improved by less than 1% for 3 participants; improved by 1–3% for 5 participants, and improved by greater than 3% for 6 participants (Figure 1). Only 1 participant exhibited a less efficient RE with MIN, in contrast to 4 participants during WE (Figures 1 & 2). Boot comfort was improved ($p = .003$) while wearing MIN during the running trials (71.2 ± 19.1) versus TRD (47.9 ± 24.7). Comfort ratings neared but did not reach

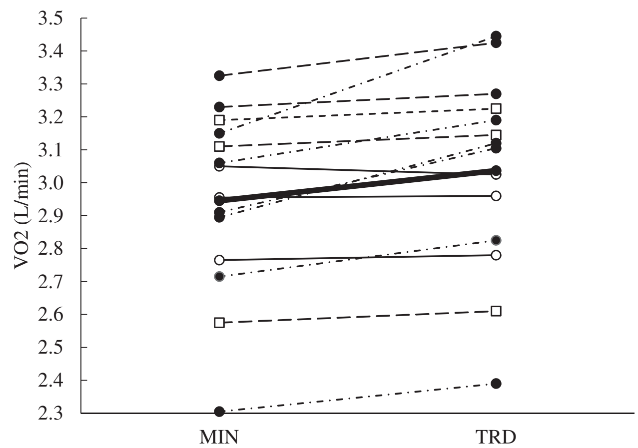

Figure 1. Individual responses in absolute VO_2 during running trial. Solid, thick line represents group means. Broken dashed lines with solid markers represents ≥ 3% improvement with MIN ($n = 6$). Long dash lines with open markers represents 1–3% improvement with MIN ($n = 5$). Thin, solid lines with open fill markers represents no or less than 1% improvement with MIN ($n = 3$).

significance during the walking trials ($p = .06$) while wearing MIN (70.5 ± 20.1) vs. TRD (57.4 ± 21.4).

Discussion

Improving movement economy has become an increasing priority for modern tactical personnel. One potential external factor that could improve movement economy is manipulating the mechanical and design characteristics of the tactical footwear these individuals are required to wear. Results from the present study provide two important findings with regard to boot selection for military personnel. The first is that movement economy, RER, and perceived exertion displayed consistent and worthwhile improvement when wearing MIN versus TRD at minimal running pace under load, and boot comfort exhibited favourable ratings with MIN. The second major finding, in contrast to our hypothesis, is that similar trends of improvement were not exhibited at walking pace under load (Table 2).

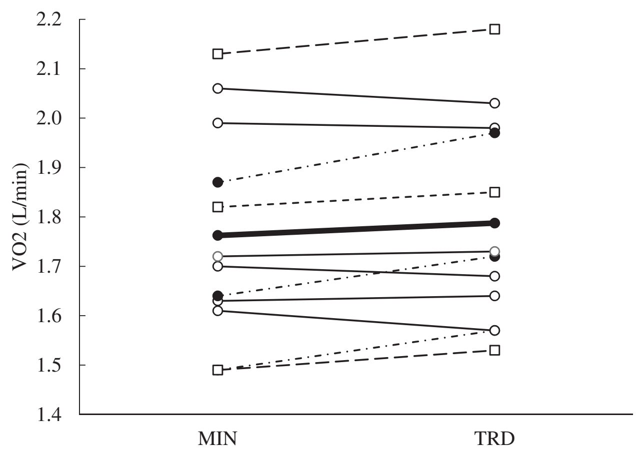

Figure 2. Individual responses in absolute VO_2 during walking trial. Solid, thick line represents group means. Broken dashed lines with solid markers represents $\geq$ 3% improvement with MIN ($n = 3$). Long dash lines with open markers represents 1–3% improvement with MIN ($n = 3$). Thin, solid lines with open fill markers represents no or less than 1% improvement with MIN ($n = 6$).

The most apparent explanation for the consistent and meaningful differences in between running economy for MIN vs TRD (Figure 1) is the nearly 40% reduction in boot mass found in MIN. Although only published in abstract form, Catlin and Dressendorfer (Catlin and Dressendorfer 1979) were the first to report a 3.3% increase in energy cost when wearing regular training shoes (870 g/pair) versus lighter (520 g/pair) racing flats. The 1% change in oxygen consumption per 100 g increase in total footwear mass (Catlin and Dressendorfer 1979) doubles the more commonly accepted 1% for each 200 g of total additional footwear mass during unloaded running reported by Frederick and colleagues' work in the early 1980s. There are three limitations in comparing the current protocol with Frederick and Hayes (Frederick and Hayes 1984) or Catlin and Dressendorfer (Catlin and Dressendorfer 1979). These factors include; (1) the substantial difference in footwear style and weight (running shoes versus boots), (2) greater treadmill velocity (up to17.6 km/h) used, and (3) the lack of external load was worn by the participants in past studies. Despite these major methodological differences, our data support the model promoted by Frederick and colleagues (Frederick 1984; Frederick and Hayes 1984) that for each 100 g added per foot (200 g in total mass), RE will be compromised by ~1%, with an increase of 600 g in total footwear impairing RE by 3.1% in the current study.

The current authors are aware of two investigations that have measured walking economy under load in boots of different masses. Turner et al. (Turner et al. 2010) reported an increase of ~4% in VO_2 when male firefighters walked (4.8 km/h) in heavier (2900 g) versus lighter (2600 g) leather boots while wearing a 10.5 kg backpack and carrying a 9.5 kg hose. Legg and Mahanty (Legg and Mahanty 1986) compared walking economy (4.5 km/h) with 35% of body mass load carried in a hiker's pack or 30% of body mass in a hiker's pack and 5% of body mass added to boots via lead strips. While not the optimal design for comparison to the current study due to the external loading protocol and considerable differences between the control boot and boot loaded with lead strips, Legg and Mahanty (Legg and Mahanty 1986) reported a relative increase in VO_2 of 0.96% for each 100 g increases in boot mass, similar to that of Catlin and Dressendorfer (Catlin and Dressendorfer 1979) and Turner, Chiou, Zwiener, Weaver and Spahr (Turner et al. 2010). The current authors have no clear mechanistic explanation or evidence for why WE findings failed to manifest the profound differences reported in these two past investigations. It is possible methodological difference in walking speed (current study was ~20% faster), boot mass loads and styles, external load masses, external loading distribution patterns, or items used to produce external load may explain some of the inconsistencies. Regardless, the current study provides no consistent evidence (Table 2 and Figure 2) that WE will be improved with modern MIN versus modern TRD boots. Over 3 decades have passed, but the standard military boot (1540 g per pair) worn in (Legg and Mahanty 1986) study was almost identical in mass to the popular, modern TRD used in the current study (1602 g). Despite considerable shoe design and material advancements, it is unlikely traditional style boots will ever exhibit the reduced mass of minimalist style boots. However, if no running tasks are expected to be experienced by tactical personnel, boot comfort or other footwear qualities should be given greater consideration when selecting boot style.

The most significant limitations to the current study are those found universally to movement economy studies. Although boot order was counter-balanced, it is still possible that fatigue from the previous walking or running bout led to VO_2 drift. However, the crossover design should have minimised this risk. Furthermore, the overwhelming one-sidedness of findings during RE trials suggests these concerns should be minimal. Based on the common incorporation of multiple bout RE trials completed in a single laboratory visit (Hoogkamer et al. 2016; Teunissen, Grabowski, and Kram 2007; Scheer, Cramer, and Heitkamp 2019) and experience in our own laboratory

(O'Neal et al. In review; Sharp et al. In press), the current authors considered the single RE/WE experimental session to be superior to 4 testing sessions as fluctuations in daily body mass and multiple calibrations of the metabolic cart were greater risks to internal validity than previous exercising altering VO_2 with considerations that a counter-balanced crossover design was incorporated. Finally, because of a lack of internal funding resources to supply women's boots and a lack of local well-trained women accustomed to running while wearing a weight vest, there was no data collected on women. This population should be examined with the rise in female tactical personnel.

Conclusion

There are many factors to consider when transitioning to a minimalist style shoe (Warne and Gruber 2017). The main finding of this investigation was that if improved movement economy is a key consideration when selecting footwear for tactical personnel, MIN provides meaningful improvement in metabolic and perceptual responses at running but not walking pace. This should be considered for tactical personnel that expect to complete extended running tasks under load. MIN was also rated more favourably in regard to comfort in 93% and 71% of participants during running and walking trials, respectively. Future studies should examine running tasks under load with MIN and TRD to determine the application effects of improved RE with MIN.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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