International Journal of
EXERCISE SCIENCE

Original Research

Effects of Three Modest Levels of Proximal Loading on Marathon Pace Running Economy

JACKSON W. GADDIE†1, EMILY P. KENNEDY†1, MATT GREEN‡1, LAUREN G. KILLEN‡1, BRAXTON A. LINDER*1, ANGEL A. HEINKEL*1, and ERIC K. O'NEAL‡1

1Department of Kinesiology, University of North Alabama, Florence, GA, USA

*Denotes undergraduate student author, †Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(7): 1120-1131, 2020. This study examined the effect of modest increases in proximal body mass on running economy expressed as metabolic cost (MC). External loads of 1.6 (L), 2.4 (M), and 3.2 kg (H) were added to the anterior and posterior torso region of male (n = 18) and female (n = 18) runners using a double-layered compression garment with gel inserts. MC was evaluated using stoichiometry equations of data collected via indirect calorimetry. Data was collected during four, 5-min running bouts at marathon pace for the 3 load levels and an unloaded state (CON). When data from both sexes were combined, MC for CON (13.2 ± 2.7) was lower ($p < 0.05$) versus L (13.5 ± 2.6), M (13.6 ± 2.6), and H (13.7 ± 2.6 kcal/min), but L did not differ from CON when data was analyzed for each sex. Male runners exhibited stepped increases in MC across loads and a weak-moderate relationship ($r = 0.37$; $p < 0.01$) between percentage change in absolute MC and increased percent body mass. A prediction model for MC (Δ% kcal/min = 0.98(Δ% body mass) – 0.91; SEE = ± 2.5%) was developed. For female runners, L increased MC by ~3.5% above CON, but no differentiation was found among L, M, and H, limiting the development of a prediction equation for females. Modest increases in body mass can produce detectable and potentially important levels of running economy impairment, but the relationship between changes in body mass and RE are complex, particularly in regards to sex.

KEY WORDS: Racing weight, weighted compression garment, metabolic cost

INTRODUCTION

While certainly not the only factor (2, 19), marathon performance is influenced by body mass and composition in both non-elite male and non-elite female runners (1, 16). Racing weight is a topic regularly discussed in the running community and popular running periodicals (6, 9), but we are aware of only one investigation examining proximal loading and overground running performance. Sharp and colleagues (21) recently reported that 2.4 kg of proximal loading impaired collegiate cross-country runners' 5-km performance by ~4%. Similarly designed performance studies for longer distance event such as the marathon, are unlikely to be attempted, but multiple studies have examined proximal loading effects on running economy. Two often cited investigations (5, 23) have confirmed artificially increasing body mass by 10% or more impairs running economy in laboratory settings. However, these studies may not be particularly useful in regards to ecological relevance. Trained recreationally competitive runners are unlikely to experience such significant changes in day-to-day body or compete at the slower paces required to establish a steady state oxygen consumption in these two studies.

Information concerning the impact of more modest increases in body mass on running economy is limited to two investigations that both used male only cohorts. Beis, Polyviou, Malkova and Pitsiladis (3) used creatine, glycerol, and glucose loading to create a state of hyperhydration that increased body mass by ~1% in trained runners and found no effect on maximal oxygen consumption or running economy. Scheer, Cramer and Heitkamp (20) found wearing backpacks of 1 and 3 kg did not increase oxygen consumption or metabolic cost while running at 70% of lactate threshold speed but did impair running economy at 80 and 90% lactate threshold speed.

A better understanding of the impact of modest proximal body mass shifts on running economy could be of value, particularly for recreationally competitive runners that may not exhibit as low of body fat percentages as that of elite marathoners or for runners that carry hydration backpacks. The primary aim of this study was to determine if differences in running economy could be detected between baseline, unloaded body mass (CON) and three modest and stepped (1.6, 2.4, and 3.2 kg) levels of proximal loading in recreationally competitive long distance runners at individual goal marathon pace. Additionally, we sought to develop regression equations to estimate the effect of simulated body mass gain on running economy. Because of the lack of evidence concerning the effects of external loading on running economy in females, responses were also examined based on runner's sex.

METHODS

Participants

Due to vast differences in running economy variables between sexes, power analysis were performed with consideration for a single sex pool in a post hoc paired samples comparison scenario. Using an expected standard deviation for absolute VO_2 of ~0.3 L/min and a difference of 0.2 L/min as a practical difference of significance, single sex participant sample sizes of 20 runners were required to exceed a power of 0.80 with an α of 0.05 (15). Non-elite but trained male (n = 18) and female (n = 18) runners between the ages of 18 to 55 years of age completed all study requirements. The heterogeneous group of runners varied on race performance level, but inclusion criteria included running ≥ 4 times per week and regular participation in organized road races of half-marathon distance or longer. Anthropometric description of participants is displayed in Table 1. All participants were informed of the experimental protocol and associated risks. Written informed consent was obtained prior to any data collection procedures. This study was approved by the University of North Alabama Institutional Review Board. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (18).

Table 1. Training history and descriptive data.

	All (*n* = 36)	Female (*n* = 18)	Male (*n* = 18)
km per week	62 ± 32	53 ± 21	72 ± 38
Personal best 5-km run (min)	21.9 ± 3.9	23.7 ± 3.9	20.1 ± 3.1
Age (years)	32.8 ± 13.1	32.2 ± 12.9	33.3 ± 13.6
Height (cm)	171 ± 10	165 ± 8	177 ± 7
Waist circumference (cm)	73 ± 13	65 ± 11	81 ± 8
Skin fold body fat (%)	18 ± 5	20 ± 3	15 ± 5
Weight (kg)	65.7 ± 12.5	57.2 ± 6.6	74.3 ± 11.3
BMI (kg/m^2)	22.3 ± 2.7	21.1 ± 1.7	23.6 ± 2.9
$\dot{V}O_{2peak}$ (L/min)	3.39 ± 0.69	2.69 ± 0.30	3.88 ± 0.36
$\dot{V}O_{2peak}$ (ml/kg/min)	49.9 ± 6.7	46.9 ± 5.5	52.7 ± 6.5
Estimated marathon pace (km/h)	11.9 ± 1.4	11.4 ± 1.2	12.3 ± 1.5

Note: Mean ± SD

Protocol

Participants reported for a single data collection session after 24-h of limited physical activity and restriction from excessive caffeine or any alcohol consumption. Morning sessions (fasted) were completed before 0900. Afternoon testing began after 1600 at least 4 h following the participant's self-selected light lunch. Following health screening procedures, participants completed a training and racing history questionnaire to confirm study eligibility. Body composition was assessed via 3 site skinfold thickness test (males = chest, abdomen, and thigh; females = triceps, suprailliac, and thigh) (12). The participant's body mass was then determined using a digital scale (BWB-800, Tanita Inc. Tokyo, Japan) measured to the nearest 0.1 kg. Height was assessed to the nearest cm using a stadiometer (Invicta Plastics Limited, Leicester, England) and body mass index was calculated (kg/m^2).

Participants were then fitted with a soft silicone facemask (V2 facemask, Cosmed, Rome, Italy) and prepared for aerobic capacity testing. Peak oxygen consumption was determined during a graded motorized treadmill test (TrackMaster TMX425C, Fullvision Inc., Newton, KS). In brief, after a self-selected warmup, participants began running at 2.4 km/h slower than their estimated 5-km personal best rounded to the nearest 0.8 km/h. Treadmill speed was then increased by 0.8 km/h every 2 minutes until volitional fatigue. Oxygen consumption was measured via indirect calorimetry (TrueOne2400, Parvo Medics Inc. Provo, Utah). The metabolic cart was calibrated in accordance with manufacturer guidelines and included gas volume (3-L syringe) and two-point gas concentration calibration confirmation.

Following a 15 min recovery period after the $\dot{V}O_2$ peak test, participants were reweighed in minimal running attire plus shoes, socks, and heart rate monitor. This apparel configuration was defined as baseline body mass (CON). Participants were then fitted for the experimental weighted compression garment attire (TITIN Force™ Weighted Shirt System, Titin Tech, USA). The outer shirt (~0.2 kg) was short sleeve (87% Sorbtek, 13% Lycra). The inner shirt (Pocket Suiri 52% A.M.Y. 48% Polyester) weighed (~0.3 kg), and had multiple pockets in which flat, dense gel inserts could be placed. There were 2 pockets in the upper chest and upper back, 2 pockets in the lower abdomen area and lower back, and 2 pockets located above the shoulders. Inserts for both the chest/upper back pockets weighed ~0.3 kg each. The inserts for pockets above the shoulder, abdomen, and lower back weighed 0.2 kg each. Once the inner weighted compression shirt was on the outer short sleeve compression shirt was donned to minimize weight shifting of the gel inserts while running.

The weight of all these materials were considered in calculations to determine external load mass with final mass being rounded to the nearest 0.1 kg. A low (L), medium (M), and high (H) loading scheme were incorporated. L included inserts in the chest and upper back (1.6 kg). M included inserts in the chest, upper back, abdomen, lower back (2.4 kg). H included inserts in the chest, upper back, abdomen, lower back, and above the clavicles and upper arm sleeves (3.2 kg). Uniform loads representing an exact percent of body mass was not possible, because of the limited combinations of inserts that could be used. However, the external loading goal was intended to represent increases of approximately 2-3, 3-4, and 4-5% of baseline body mass for the majority of participants.

Participants completed 4 running bouts of 5 min with 5 min recovery periods between each bout (11, 20) at the target pace the individual would attempt for a marathon distance race based on current training status and a racing pace history questionnaire. Treadmill grade was maintained at 1% incline to simulate road running (13). A counter-balanced crossover design was used to limit the potential ordering effects of fatigue and with one of the bouts being performed without the weighted compression garment to represent CON metabolic conditions. Fans were placed in front of the treadmill and comfortable ambient room temperature was maintained by a central heating and cooling source. Body mass was assessed with the new trial load before each running bout. If the desired body mass was not met due to sweat losses from the previous running bout, participants consumed a measured volume of water of no more than 200 mL to reach goal body mass. Participants could obviously not be blinded to the CON bout, but no information was given concerning whether the loaded conditions were L, M, or H to mitigate influence on RPE ratings.

Running economy has traditionally (4, 5, 8) been represented simply using oxygen consumption units. However, expression in rates of kcal per unit time or distance is now promoted (7), as oxygen cost is less sensitive to changes in running speed than energy costs (22). With this in consideration, the authors have chosen to report both oxygen cost (units) and metabolic cost (units). Metabolic variable data was collected continuously during each running bout and reported in 60-s averages. Confirmation of a steady state $\dot{V}O_2$ was determined by an increase of less than 0.1 L O_2/min for $\dot{V}O_2$ collected from minutes 3:00-4:00 and 4:00-5:00 (7). All metabolic data and respiratory exchange ratio (RER) was averaged from the two, 1-min steady state periods for data analysis. The metabolic cost (MC) of each running stage was determined using a stoichiometry equation table (17) to calculate MC. At 4:30, participants were asked to provide rate of perceived exertion (RPE) for breathing, legs, and overall using a 1-10, running pictorial RPE scale (24) in a counterbalanced order. Heart rate (H-10, Polar Electro Oy) was visually observed and recorded for the last 10 s of each running bout.

Statistical Analysis

Metabolic data was averaged between minutes 3-4 and 4-5. To determine reliability of this data, intraclass correlation (ICC) and coefficient of variation (CV) were determined for absolute $\dot{V}O_2$ and RER. Repeated measures ANOVA was used to determine if differences in physiological measures were detected between external load levels. Mauchly's Test of Sphericity was incorporated and Greenhouse-Geisser adjustments were made if needed when examining main effects. Bonferroni post hoc tests were incorporated if overall main effects were found for treatment. Additionally, Cohen's *d* effect sizes were calculated using CON standard deviations for CON versus each external load level. Pearson *r* was used to determine relationship strength between increases in percentage of body mass with external loading and percentage change in MC. A regression model was generated from this relationship to predict change in % MC with increase in simulated % body mass. Standard error of the estimate (SEE) for the model was determined with these data. Due to expected differences in perceptual data, Friedman's 2-way ANOVA by Ranks was used to determine if main effects were exhibited between treatment levels. If a main effect was found, post hoc testing was compared between CON and each external load level but not among external load levels. Because such vast differences existed between sexes for anthropometric and running performance variables, all statistical procedures were repeated with data from male and female runners separately. Data analysis was completed using SPSS Ver. 23.0 (IBM Inc., Chicago, IL) and Microsoft Excel 2016. All data are presented as mean ± SD unless otherwise noted.

RESULTS

Strong relationships for data collected for minutes 3-4 and 4-5 were found for absolute $\dot{V}O_2$ (ICC = 0.998; CV = 0.96 ± 0.80%) and RER (ICC = 0.915; CV of 1.37 ± 1.01%). When all data was combined MC for CON was less than L, M, and H ($p < 0.05$), but when separated by sex only M and H differed from CON (Table 2). Figures 1A-1C represent the relationship between percentage changes in body mass and MC. While an increase in body mass resulted in positive relationships with change in MC for all comparisons, these correlations were only significant when all data was combined or with male only data. All data in Figure 1 are relative to change from CON. Two female runners displayed (top 6 markers at the top of Figure 1 A & B) up to triple the percentage change from CON versus the next highest percentage changes. Trends were consistent within these 2 individual runners versus CON, but resulted in 2.7 times greater SEE versus men (Figure 1C). Differences exhibited in MC were replicated for absolute $\dot{V}O_2$ and percentage of $\dot{V}O_{2peak}$ (Table 2). RER was not altered for men regardless of load, but increased enough for women that multiple load levels differed in post hoc testing and influenced combined sex data to result in a main effect for load on RER (Table 2).

Different trends in perceptual data were noted between male and female runners (Table 3). No main effect was found for overall RPE in men and only H (legs) M and H (breathing) differed from CON for men. In contrast, women reported higher RPE versus CON for every load level and RPE type except versus breathing RPE for M (Table 3).

Table 2. Comparison of metabolic and physiological responses when running at normal body mass (CON) and with additional external loads of 1.6 kg (L), 2.4 kg (M), and 3.2 kg (H).

	Metabolic Cost (kcal/min) (effect size vs. CON)	VO$_2$ (L/min)	VO$_2$ (% of max)	RER	Heart Rate (beats/min)
All participants (n = 36)					
CON	13.18 ± 2.71^{BCD}	2.66 ± 0.54^{BCD}	81.9 ± 6.0^{BCD}	0.92 ± 0.03^{CD}	167 ± 13^{D}
L	13.49 ± 2.58^{AD} (0.14)	2.71 ± 0.52^{AD}	83.3 ± 6.0^{AD}	0.93 ± 0.03	168 ± 12
M	13.62 ± 2.63^{A} (0.16)	2.73 ± 0.53^{A}	83.9 ± 5.6^{A}	0.94 ± 0.03^{A}	169 ± 13
H	13.69 ± 2.61^{AB} (0.19)	2.75 ± 0.52^{AB}	84.4 ± 5.5^{AB}	0.94 ± 0.04^{A}	170 ± 13^{A}
Male runners (n = 18)					
CON	15.40 ± 1.52^{CD}	3.11 ± 0.30^{CD}	80.1 ± 4.4^{CD}	0.92 ± 0.03	164 ± 13^{D}
L	15.58 ± 1.47^{D} (0.12)	3.14 ± 0.29^{D}	80.9 ± 4.6^{D}	0.93 ± 0.03	166 ± 13
M	15.75 ± 1.57^{A} (0.23)	3.17 ± 0.32^{A}	81.7 ± 4.7^{A}	0.93 ± 0.04	166 ± 13
H	15.89 ± 1.40^{AB} (0.32)	3.19 ± 0.29^{AB}	82.4 ± 4.7^{AB}	0.94 ± 0.04	167 ± 13^{A}
Female runners (n = 18)					
CON	10.97 ± 1.56^{CD}	2.22 ± 0.31^{CD}	83.7 ± 7.1^{CD}	0.92 ± 0.03^{CD}	172 ± 13
L	11.40 ± 1.49 (0.28)	2.29 ± 0.29	85.9 ± 6.4	0.93 ± 0.03^{C}	171 ± 11
M	11.48 ± 1.45^{A} (0.33)	2.30 ± 0.27^{A}	86.3 ± 5.6^{A}	0.94 ± 0.03^{AB}	172 ± 12
H	11.49 ± 1.34^{A} (0.33)	2.31 ± 0.26^{A}	86.5 ± 5.7^{A}	0.95 ± 0.03^{A}	173 ± 12

Note: Mean ± SD; ^{A} = Significantly different from CON ($p < 0.05$); ^{B} = Significantly different from L ($p < 0.05$); ^{C} = Significantly different from M ($p < 0.05$); ^{D} = Significantly different from H ($p < 0.05$).

Table 3. Comparison of perceptual data when running at baseline body mass (CON) and with additional external loads of 1.6 kg (L), 2.4 kg (M), and 3.2 kg (H).

	RPE Legs	RPE Breathing	RPE Overall
All participants (n = 36)			
CON	3.9 ± 1.8	4.1 ± 1.5	4.1 ± 1.6
L	4.3 ± 1.7^{A}	4.6 ± 1.6^{A}	4.4 ± 1.6^{A}
M	4.5 ± 1.7^{A}	4.7 ± 1.5^{A}	4.6 ± 1.4^{A}
H	4.9 ± 1.8^{A}	5.0 ± 1.6^{A}	5.0 ± 1.7^{A}
Male runners (n = 18)			
CON	4.1 ± 1.7	3.8 ± 1.4	4.2 ± 1.5
L	4.3 ± 1.8	4.2 ± 1.6	4.3 ± 1.6
M	4.3 ± 1.6	4.4 ± 1.6^{A}	4.6 ± 1.5
H	4.9 ± 1.9^{A}	4.6 ± 1.6^{A}	4.8 ± 1.8
Female runners (n = 18)			
CON	3.7 ± 1.8	4.2 ± 1.7	4.0 ± 1.8
L	4.2 ± 1.7^{A}	5.0 ± 1.6^{A}	4.5 ± 1.6^{A}
M	4.7 ± 1.9^{A}	4.9 ± 1.5	4.7 ± 1.3^{A}
H	4.9 ± 1.6^{A}	5.4 ± 1.6^{A}	5.2 ± 1.6^{A}

Mean ± SD; ^{A} = Significantly different from CON ($p < 0.05$); If significant main effects were found during Friedman's 2-way ANOVA, post hoc Wilcoxon Signed Rank Test were only run for L, M, and H versus CON.

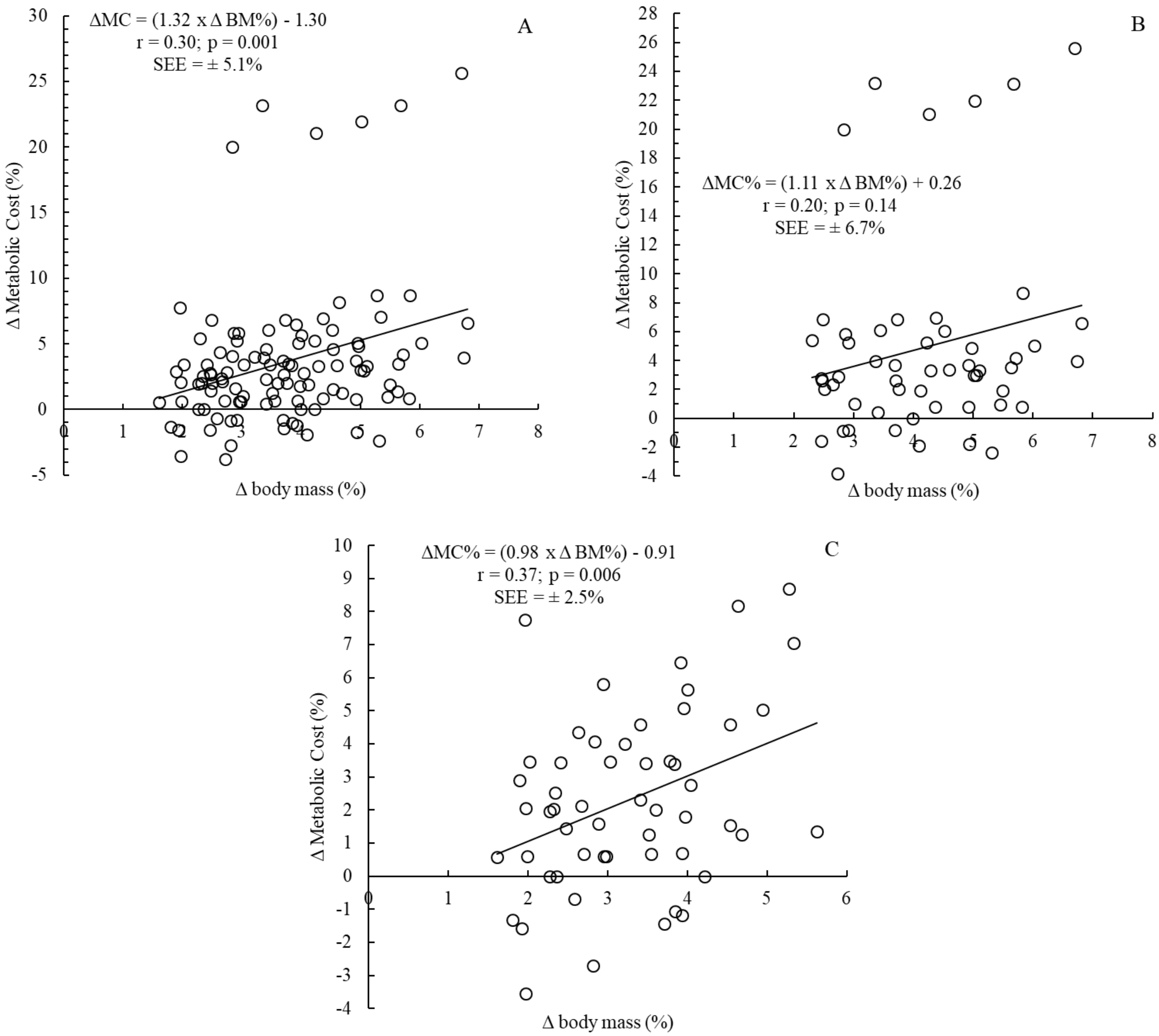

Figure 1. Relationship between change in body mass % and change in metabolic cost % (kcal/min) for all (A), female (B), and male (C) runners. SEE = standard error of estimate of developed prediction equation.

DISCUSSION

The current study examined the influence of modest increases in proximal loading on marathon pace running economy. The weighted compression garment which incorporated thin but dense gel pads positioned throughout the torso region allowed for a unique simulation of running with an extra layer of subcutaneous adipose tissue in a more ergonomically valid manner than past studies using vests with lead strips. Recreationally competitive runners display less favorable body composition than their more elite peers, but intentional nutritional interventions could produce losses of body mass similar to the loading schemes incorporated in the current study (10, 14, 25). With these considerations, three key findings were established. The first is that the M load of 2.4 kg or greater can be expected to increase MC in a meaningful way for both male and female runners (Table 2). The second discovery of importance is that while male runners exhibited a stepped MC response to increases in modest absolute load levels (Table 2 & Figure 1C), female runners' MC was only different between CON and M and H with no differences among L, M, and H (Table 2 & Figure 1B). These differences resulted in the authors only having confidence to endorse the prediction equations developed for male runners.

We are aware of only two investigations that have examined the influence of modest additional body mass loading on running performance without prolonged training interventions (3, 20). Both Beis, Polyviou, Malkova and Pitsiladis (3) (hyper hydration) and Scheer, Cramer and Heitkamp (20) (backpack loading) used external loading of ~1 kg. The former found no difference in oxygen cost and the latter only found a difference in MC at the highest of 3 running intensities. In the present study a slightly greater load (L: 1.6 kg) only differed between CON for MC when the n was doubled to 36 by combining male and female data (Table 2). With this in mind, it is plausible the statistical significance may suffer from a Type I hypothesis testing error as a trivial effect size ($d = 0.14$) was manifested. Although loading methods were different in all three studies, considered in conjunction with (3, 20) the current authors contend that body mass alterations of ≤ 1.6 kg do not consistently and meaningfully alter MC. This may be a consideration when acute changes in body mass are incurred due to glycogen supercompensation strategies or if large volumes of fluid are carried via hydration bladder style packs.

Using a 3 kg backpack, Scheer et al. (20) reported that metabolic cost increased at 80 and 90% of lactate threshold for 10 men capable of running 10-km in less than 42 minutes. The current study supports (20) and potentially lowers this running economy impairment threshold to 2.4 kg in a more diverse running population. When data from all three studies are evaluated in combination there appears to be a distinctive dichotomy between loads of ~1-1.6 kg versus loads of 3.0-3.2 kg. More evidence is needed, but current data from the M load of 2.4 kg, suggest altered MC is likely with increases in body mass between the ~1 and 3-kg range are also to be expected, but with less certainty of impairment for male runners (Table 2).

The current investigation included nearly as many participants as the four comparable running economy under proximal loading studies combined. Only 6 of the 46 particpants in these past studies were female (3, 5, 20, 23). The discrepancies in anthropometric attributes of male and female runners are evident in Table 1 and warrant evaluation by sex. The first trend exhibited is that male and female runners did not respond in a uniform manner physiologically (Table 2, Figure 1) or perceptually (Table 3) to modest absolute increases in body mass. L, M, and H produced an elevated but nearly flat response in MC for women (Figure 1B) similar to that seen between loads of 5 and 10% body mass in Cureton, Sparling, Evans, Johnson, Kong and Purvis (5). Almost any additional load compromised MC for female runners with 40 of 54 observations resulting in an increase of ~1.5% elevation in absolute MC compared to CON without a clear delineation between L, M, and H. It is notable, that 5 women were responsible for 12 of the 14 cases in which an increase of >1.5% was not found when any additional mass load was incorporated (i.e. certain women runners' running economy was unaffected by L, M, and H). Further highlighting the importance of individual responses, two female runners were distinctly more adversely affected by increased artificial body mass (top 6 markers in Figure 1B). One runner was a 27 year old (sub 3:20 marathon). The other was 53 years old and had recently completed a respectable sub 22 min 5-km race. Both runners had estimated body fat percentages below 20%. Despite reporting no more than a 1 unit increase for any RPE type versus CON, compromises in MC were noted versus all external load levels for these two female runners. In contrast, a more uniform but still highly variable response was displayed in male runners (Table 2; Figure 1C).

The second aim of this study was to determine if alteration in MC could be predicted when modest increases in body mass are incurred. Two investigations have frequently been cited in popular running periodicals in attempts to suggest the effects of body mass loss or gain on running economy or performance (5, 23) Both investigations used torso harnesses or belts with strips of lead to artificially increase body mass. Increasing baseline body mass by 10, 20, and 30% resulted in increased metabolic rate by 14, 24, and 38% in Teunissen, Grabowski and Kram (23), and loads equal to 5, 10, and 15% body mass increased absolute $\dot{V}O_2$ by 2.5, 3.1, and 9.7% in Cureton, Sparling, Evans, Johnson, Kong and Purvis (5), respectively. While not completely interchangeable, metabolic rate (23) and oxygen consumption (5) produced considerably different outcomes at the load shared by both studies (i.e. 10%). Furthermore, a doubling of percent body mass from external loading (from 5 to 10%) did not produce a linear response in oxygen cost, failing to follow the more direct relationship displayed by the 3 external loads used in(23). When group mean responses are presented for loads of 10, 20, and 30% of body mass, a valid model appears to have been produced for predicting the relationship between increase in body mass and increased metabolic rate.(23) However, the standard deviation for each of these levels of increase in body mass was 8.5, 10.1, and 12.0% and clouds the utility of the equation to accurately predict change in metabolic rate. Likewise, Cureton et al. (5) found a puzzling difference in means of absolute $\dot{V}O_2$ of only 0.013 L/min when increasing external load from 5 to 10% of body mass (average load difference of 3.3 kg). This is unexpected in comparison to the current study where incremental increases of 0.8 kg resulted in approximately double the increase in absolute oxygen costs versus CON (Table 2).

The current authors contend that these levels of variance and numerous running economy confounders make it difficult to extrapolate the data from past studies (5, 23) using considerably greater loading levels into reliable and valid generalized models for predicting running

economy or metabolic cost alteration with changes in regards to more modest changes in body mass without chance of significant error in prediction models. Data from both past studies may have been influenced because small samples sizes of runners of both sexes served as participants. Our data suggests if future models are used to predict the effect of change in body mass on running economy should be sex specific. Concerning our data, we contend the only model that can be promoted is for male runners only (prediction equations presented in Figure 1C). Using this model, an increase in 3, 4, and 5% body mass would result in predicted increases of approximately 2, 3, and 4% increase in MC, respectively. For female runners it can only be confirmed that increases in body mass by 1.6 kg or greater result in compromised RE/MC for most women, but the weak relationship between change in body mass and RE/MC and high SEE does not warrant promotion of the regression equation to be used in practice.
A limitation of this study is that all data was collected in one laboratory visit, but the counter-balanced crossover order by sex should have limited an ordering effect. This design was implemented to decrease variability in metabolic variables due to changes in fitness level, fatigue from previous exercise bouts, dietary replication, body mass stability, and metabolic cart calibration reliability. Completing the $\dot{V}O_{2peak}$ test before MC evaluation bouts may have resulted in novel fatigue and altered natural running gait. The population investigated included trained, but non-elite runners between 18-55 years of age. External validity should be considered when comparing these results to different populations of runners. Finally, no kinematic data was obtained eliminating the ability to account for gait alteration as a mechanistic factor when interpreting data.

In conclusion, a shift in 2.4 kg or more of lean tissue mass to the torso is expected to impair running economy in recreationally competitive runners. Additionally, sex is an important consideration when strategies involving altering body mass are implemented to improve running performance. Approximately three-fourths of data points for women runners exhibited an increase of 1.5% or more of MC with any additional loading level, but no difference was detected among load levels. The weak relationship between modest additions in body mass and MC and robust estimation error does not provide justification for incorporation of the prediction models developed in this study for women or when both sexes' data are combined. Modest increases in body mass displayed a stronger relationship with MC in male runners and suggest approximate decrease in MC will be 1% less than percent increase in body mass when running at marathon pace. Future investigations are needed to determine the mechanisms that explain the sex specific responses to modest increases in torso loading.

ACKNOWLEDGEMENTS

The authors thank our participants for their time and effort in contributing to this project. There was no external funding for this project. The authors declare no conflicts of interest.

REFERENCES

1. Barandun U, Knechtle B, Knechtle P, Klipstein A, Rust CA, Rosemann T, Lepers R. Running speed during training and percent body fat predict race time in recreational male marathoners. J Sports Med 3: 51-58, 2012.

2. Barnes KR, Kilding AE. Strategies to improve running economy. Sports Med 45(1): 37-56, 2015.

3. Beis LY, Polyviou T, Malkova D, Pitsiladis YP. The effects of creatine and glycerol hyperhydration on running economy in well trained endurance runners. J Int Soc Sports Nutr 8(1): 24, 2011.

4. Cochrum RG, Connors RT, Coons JM, Fuller DK, Morgan DW, Caputo JL. Comparison of running economy values while wearing no shoes, minimal shoes, and normal running shoes. J Strength Cond Res 31(3): 595-601, 2017.

5. Cureton KJ, Sparling PB, Evans BW, Johnson SM, Kong UD, Purvis JW. Effect of experimental alterations in excess weight on aerobic capacity and distance running performance. Med Sci Sports 10(3): 194-199, 1978.

6. Dikos J. Fiding your ideal racing weight. Runner's World [Internet]. 2008. Available from: https://www.runnersworld.com/advanced/a20820182/finding-your-ideal-racing-weight/

7. Fletcher JR, Esau SP, Macintosh BR. Economy of running: Beyond the measurement of oxygen uptake. J Applied Physiol 107(6): 1918-1922, 2009.

8. Frederick JR, Hayes JW. The effects of shoe weight on the aerobic demands of running. Current Topics in Sports Medicine: Proceedings of the World Congress of Sports Medicine, Vienna 616-625, 1984.

9. Golub JS. Will losing weight help me run faster? Runner's World [Internet]. 2011. Available from: https://www.runnersworld.com/nutrition-weight-loss/a20803597/quick-bites-will-losing-weight-help-me-run-faster/

10. Heatherly AJ, Killen LG, Smith AF, Waldman HS, Seltmann CL, Hollingsworth A, O'Neal EK. Effects of ad libitum low-carbohydrate high-fat dieting in middle-age male runners. Med Sci Sports Exerc 50(3): 570-579, 2018.

11. Hoogkamer W, Kipp S, Frank JH, Farina EM, Luo G, Kram R. A comparison of the energetic cost of running in marathon racing shoes. Sports Med 48(4): 1009-1019, 2018.

12. Jackson A, Pollock ML. Practical assessment of body composition. Phys Sport Med 13: 76-90, 1985.

13. Jones AM, Doust JH. A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. J Sports Sci 14(4): 321-327, 1996.

14. Klement JR, Frobel T, Albers T, Fikenzer S, Prinzhausen J, Krammerer U. A pilot case study on the impact of self-prescribed ketogenic diet on biochemical parameters and running performance in healthy and physically active individuals. Nutr Med 1(1): 27, 2013.

15. Lenth RV. Java applets for power and sample size [computer software]. 2006.

16. Loftin M, Sothern M, Koss C, Tuuri G, Vanvrancken C, Kontos A, Bonis M. Energy expenditure and influence of physiologic factors during marathon running. J Strength Cond Res 21(4): 1188-1191, 2007.

17. Lusk G. Science of nutrition. Philadelphia, PA: Saunders; 1928.

18. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exercise Sci 12(1): 1-8, 2019.

19. Saunders PU, Pyne DB, Telford RD, Hawley JA. Factors affecting running economy in trained distance runners. Sports Med 34(7): 465-485, 2004.

20. Scheer V, Cramer L, Heitkamp HC. Running economy and energy cost of running with backpacks. J Sports Med Phys Fitness 59(4): 555-560, 2019.

21. Sharp DW, Swain JC, Boy TG, Killen LG, Green JM, O'Neal EK. Modest proximal external loading impairs 5-km running performance. J Strength Cond Res (At press).

22. Shaw AJ, Ingham SA, Folland JP. The valid measurement of running economy in runners. Med Sci Sports Exerc 46(10): 1968-1973, 2014.

23. Teunissen LP, Grabowski A, Kram R. Effects of independently altering body weight and body mass on the metabolic cost of running. J Exp Biol 210(Pt 24): 4418-4427, 2007.

24. Utter AC, Robertson RJ, Green JM, Suminski RR, McAnulty SR, Nieman DC. Validation of the adult OMNI scale of perceived exertion for walking/running exercise. Med Sci Sports Exerc 36(10): 1776-1780, 2004.

25. Zajac A, Poprzecki S, Maszczyk A, Czuba M, Michalczyk M, Zydek G. The effects of a ketogenic diet on exercise metabolism and physical performance in off-road cyclists. Nutrients 6(7): 2493-2508, 2014.