STATURE AND LOAD AFFECT THE WALK TO RUN TRANSITION SPEED

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Military personnel are often required to march "in-step" while carrying heavy loads. For example, the two speeds required to complete the role fitness test for the British Army are close to the preferred walking speed and preferred walk-to-run transition speed (PTS) for healthy adults when unloaded. PTS depends on anthropometry, including stature. Walking at speeds markedly different to PTS has been associated with increased metabolic cost and increased joint loading. There is also limited research into how this PTS is affected by load carriage. To minimise the risk of injury, there is a need to understand how load carriage affects PTS. This study found PTS for male and female personnel decreased with increased load carried, and that female personnel tended to transition from walking to running earlier than male personnel. The relationship between PTS and stature became more positive as load increased, irrespective of sex. Due to the association between deviating from preferred walking gait and increases in joint loading, these findings may have implications for the risk of injury in military personnel who are required to march "in-step".

KEYWORDS: Load Carriage, Walk to Run Transition.

INTRODUCTION: Military personnel are often required to march "in-step" whilst carrying heavy loads (20kg to 68kg). The British Army's Role Fitness Test – Soldier (RFT-S) requires personnel to cover 4 km in 50 min, carrying 40 kg, followed by 2 km in 15 min, carrying 25 kg. These required speeds (1.3 $m\cdot s^{-1}$ and 2.2 $m\cdot s^{-1}$, respectively) are close to the average preferred walking (1.4 $m\cdot s^{-1}$) (Browning et al. 2006) and walk-to-run transition (PTS; 1.6 – 2.1 $m\cdot s^{-1}$) (Hreljac 1995, Sentija et al. 2012, Gill et al. *under review*) speeds for healthy adults when unloaded. Furthermore, when an individual was required to carry a load equivalent to 15% of their body mass, the transition speed decreased by 0.1 $m\cdot s^{-1}$ (Raynor et al. 2002). However, these relative loads were much lighter than those carried by military personnel, which can equal their body mass (Andersen et al. 2016).
Walking at step lengths greater than the preferred step length, or at speeds markedly different to PTS, may be energetically less efficient and increase joint loading, which could increase the risk of lower limb and lower back injuries. Therefore, marching at a fixed pace and, consequently, a fixed step length may potentially lead to injury. This is particularly important for female personnel marching alongside male personnel as female personnel are generally shorter in stature; mean (SD) stature for male: 1.77 (0.07) m and female: 1.65 (0.06) m personnel (Wilson and Usher 2017). Preferred walking speed, step length, and step frequency have also been associated with stature. Furthermore, during load carriage, stature is said to be positively correlated with PTS in a mixed group of male and female civilians (Raynor et al. 2002). However, whether these relationships are the same for male and female personnel individually is unknown. Therefore, this study aimed to evaluate PTS during loaded walking for both male and female personnel of different statures.

METHODS: Thirty-two (12 female) military personnel volunteered to participate. Stature and body mass were recorded before completing a transition protocol. Participants were asked to wear their military boots for testing. Using the C-Mill (Motek Medical, The

Netherlands) instrumented treadmill, the starting speed was set to 1.2 $m \cdot s^{-1}$ and the speed increased every 2 mins in increments of 0.2 $m \cdot s^{-1}$, up to a final speed of 2.6 $m \cdot s^{-1}$. Participants were asked to walk on the treadmill until they felt it would be more comfortable to run and then transition into a run. This protocol was completed three times, under three conditions of load (unloaded and loaded with 25 kg and 40 kg). For the load conditions, participants wore Patrol and Marching order dress states (Ministry of Defence 2019); including a scalable tactical vest (without plates), webbing (9.5 kg), weapon (4.5 kg), and daysack (11 kg or 26 kg, respectively). Independent samples t-tests were used to compare the participant demographics. Two-way repeated-measures ANOVA was used to compare PTS between male and female participants and across different load conditions. Effect sizes were defined as weak: ηp2=0.01, moderate: ηp2=0.06, or strong: ηp2=0.14 (Richardson 2011, Lakens 2013). A linear mixed model was used to determine the association between PTS and load, sex, and stature. Load and sex were defined as factors, and stature was defined as a covariate. Baseline models were defined using load, sex, and stature as fixed effects with random intercepts for participants. Then more complex models were defined where interactions between sex and stature or load and stature were added to the baseline model, respectively. Baseline and complex models were compared using log-likelihood ratio tests. Significance was adjusted for multiple comparisons using a Holm-Bonferroni correction.

*Table 1 - Mean (SD) participant demographics and preferred walk-to-run transition speeds (PTS). * indicates a significant sex difference after a Holm-Bonferroni correction.*

SEX (N)	FEMALE PERSONNEL (12)	MALE PERSONNEL (20)	SIG. (2-tail)
AGE [yrs.]	32 (6)	30 (7)	0.567
MASS [kg]	68.67 (11.96)	78.63 (6.98)	0.019*
STATURE [m]	1.68 (0.07)	1.79 (0.07)	≤0.001*

Table 2 - Mean (SD) preferred transition speed [$m \cdot s^{-1}$] for the unloaded and loaded conditions.

PERSONNEL	UNLOADED	LOADED 25 KG	LOADED 40 KG	BETWEEN SIG.	EFFECT SIZE (η_p^2)
ALL	2.17 (0.23)	2.03 (0.18)	1.91 (0.20)		
FEMALE	2.12 (0.18)	1.93 (0.16)	1.77 (0.17)	0.017	0.180
MALE	2.21 (0.25)	2.06 (0.16)	1.99 (0.17)		
WITHIN SIG.		≤0.001		0.139	0.070
EFFECT SIZE (η_p^2)		0.584			

Table 3 - Outputs from the linear mixed model including stature, sex, and load.

	Estimate [95 % Confidence Interval]	Sig.
	Stature	
Δ per 0.1 m	0.07 [-0.01 0.15]	0.102
	Load	
25 – 0 kg	-0.16 [-0.22 -0.10]	≤0.001
40 – 0 kg	-0.27 [-0.33 -0.21]	≤0.001
	Sex	
M – F	0.09 [-0.06 0.23]	0.237
	*Stature * Load*	
25 – 0 kg	0.60 [-0.05 1.24]	0.068
40 – 0 kg	1.06 [0.41 1.70]	0.002
	*Stature * Sex*	
M – F	-0.15 [-1.79 1.48]	0.848

M indicates male participants; F indicates female participants. Estimates are relative to the reference condition (unloaded – 0 kg).

RESULTS: Participant demographics are reported in Table 1. No significant interaction was found between sex and load ($F_{(1.42,\ 41.05)}$=2.19, p=0.139, and η_p^2=0.070). PTS decreased as

load increased (main effect of load, $F_{(1.42,\ 41.05)}$=40.63, $p \leq 0.001$, and η_p^2=0.584), independent of sex (Table 2). Male personnel had significantly higher PTS than female personnel (main effect of sex, $F_{(1,\ 29)}$=6.36, p=0.017, and η_p^2=0.180), irrespective of load (Table 2).
The baseline linear mixed model (Table 3) showed that for each 10 cm increase in stature, PTS increased by 0.07 $m{\cdot}s^{-1}$, but this increase was not statistically significant (p=0.102). PTS for loaded conditions were significantly (p≤0.001) lower than the unloaded condition (0.16 and 0.27 $m{\cdot}s^{-1}$ lower for 25 kg and 40 kg, respectively). Male participants had a PTS that was 0.09 $m{\cdot}s^{-1}$ higher than female participants, but this difference was not statistically significant (p=0.237). Including the interaction between stature and load had a significant effect on PTS (p=0.007). This model showed that the relationship between PTS and stature was more positive for loaded conditions than the unloaded condition (Figure 1; 0.60 (p=0.068) and 1.06 (p=0.002) for 25 kg and 40 kg, respectively). Including the interaction between stature and sex did not significantly affect PTS (p=0.848).

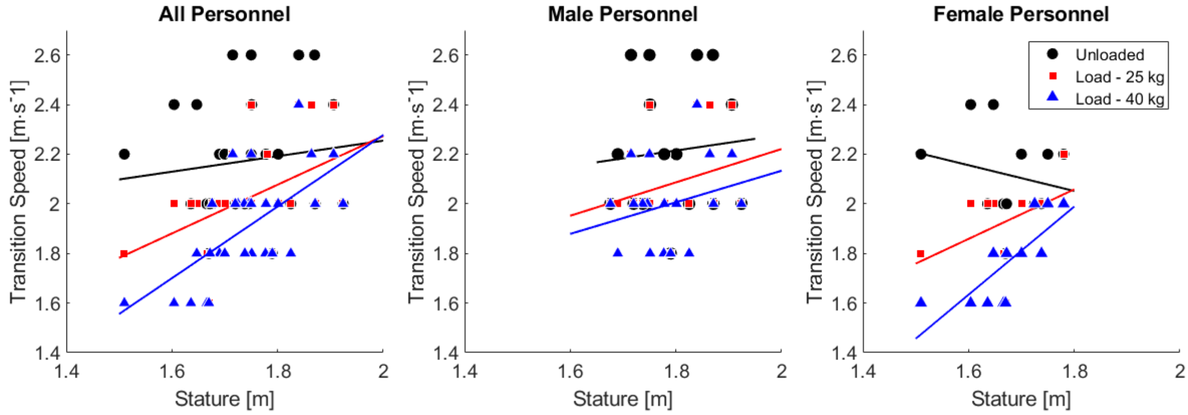

Figure 1 - Relationship between stature and the preferred transition speed.

DISCUSSION: PTS increased by 0.07 $m{\cdot}s^{-1}$ for each 10 cm increase in stature; although, this finding was non-significant. Including the interaction between stature and load significantly affected PTS, suggesting that as load increases the effect of stature becomes more evident. This is evidenced by the relationship between stature and PTS being 1.06 times more positive (p=0.002) when carrying 40 kg compared to when unloaded, i.e. for each increase in stature there would be a 6% greater increase in PTS when carrying 40 kg than when unloaded.
PTS was 0.16 $m{\cdot}s^{-1}$ and 0.29 $m{\cdot}s^{-1}$ lower when carrying 25 kg and 40 kg, respectively, than when unloaded (p≤0.001). This main effect was also seen in the results of the ANOVA, where there was a significant within-subject difference in PTS (p≤0.001).
There was no significant effect of sex (p≥0.078) on PTS. The non-significant interaction between sex and stature suggests the effect of stature on PTS is similar for both male and female personnel (p≥0.773). However, it is worth noting that, when unloaded, it appears as if PTS increases as stature increases for male personnel but decreases for female personnel (Figure 1). This suggests an adaptive mechanism where shorter female personnel have had to develop coping strategies to walk in formation with taller individuals, but that the model might not have been powerful enough to detect it. It is also important to note that the PTS for female personnel carrying 25 kg was lower than that for male personnel carrying 40 kg, which is relevant when considering that female personnel, being lighter, carry relatively heavier loads, as a proportion of body mass, than their male counterparts.
In unloaded conditions, existing literature has reported positive correlation coefficients between PTS and stature (r=0.24 – 0.65) (Hreljac 1995, Sentija et al. 2012, Gill et al. *under review*) for female participants and a wide range of correlation coefficients between PTS and stature (r=-0.53 – 0.50) (Hreljac 1995, Sentija et al. 2012, Ranisavljev et al. 2014) for male participants. These conflicting findings, and the apparent lack of any correlation between PTS and stature for male personnel (Figure 1), could be an adaptive mechanism, where personnel have become accustomed to walking at fast speeds, regardless of stature, and therefore may not experience, or act on, the same triggering mechanisms as untrained civilians.

Boffey et al. (2019) stated there were "*no definitive findings as to how load affects the speed at which the walk-to-run transition occurs*". However, this study showed that when all data were pooled, the PTS decreased by an average of 0.06 $m \cdot s^{-1}$ per 10 kg of additional load, similar to results reported by Raynor et al. (2002). Furthermore, as load increased the relationship between PTS and stature became more positive for both male and female personnel (with the relationship initially appearing negative for female personnel). This finding suggests that the added burden of load may outweigh any adaptive mechanisms for maintaining PTS, especially for shorter personnel. Stature, therefore, appear to become more influential in determining PTS as load increases.

CONCLUSION: These findings could have implications for injury risk when marching at a fixed pace for both male and female personnel. A positive relationship between PTS and stature, as well as sex differences in PTS, suggest that shorter, predominantly female, personnel are likely to spend more time running or walking at speeds close to and/or above PTS, than their taller, predominantly male, counterparts. Furthermore adding load exacerbates these effects. Increases in perceived effort (Hreljac 1993), higher external forces, and larger joint moments (Pires et al. 2014, Lim et al. 2017) have been associated with walking at faster speeds and running. This suggests that female personnel may fatigue quicker than their male counterparts, putting them at an increased risk of developing an injury as muscles may become less capable of resisting joint moments when fatigued.

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