THE EFFECT OF STEP WIDTH CONTROL ON LOAD CARRIAGE ECONOMY

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The purpose of this study was to assess the influence of step width on load carriage economy. Fifteen healthy volunteers (age = 25 ± 3 years; stature = 1.78 ± 0.07 m; body mass = 73.6 ± 10.1 kg) completed three trials in a randomised order. Each trial differed by load carriage method and involved walking on a force-instrumented at 3km·h^{-1} with 0, 3, 12 and 20 kg. This protocol was then repeated with step width controlled to each participant's preferred unloaded width. Relative load carriage economy was measured using the Extra Load Index (ELI). Load carriage economy was significantly worse in the head loading method compared to the other two method with step width uncontrolled (p = 0.02) and controlled (p = 0.02). For the trials where step width was uncontrolled, there was a significant difference in step width from unloaded walking between the different loading methods (p = 0.01) but no significant difference between load mass (p = 0.39). There was no difference in ELI between preferred and controlled step widths. Based on the data presented here, moderate alterations in step width caused by load carriage do not appear to influence load carriage economy.

KEYWORDS: Load carriage, Economy, Step width

INTRODUCTION: Energy saving phenomena have been reported with loads carried on the head (Maloiy *et al.*, 1986), back (Abe *et al.*, 2004) and evenly distributed between the front and back of the torso (Lloyd & Cooke, 2000). Previous work has attempted to identify mechanisms that may contribute to these phenomena (e.g. Jones *et al.,* 1987; Heglund *et al.*, 1995; Abe *et al.*, 2004; Lloyd & Cooke, 2011), yet the determinants remain unclear. Understanding the determinants of energy saving phenomena with different load carriage methods could lead to improved load carriage performance. This would benefit a number of populations including individuals that take part in recreational activities such as hiking and mountaineering, individuals living living in rural areas of developing countries where transport infrastructure is poor, and individuals that regularly carry load as part of their occupation (e.g. military and emergency service personnel).

Individuals prefer to walk at an energetically optimal step width when walking unloaded (Abram *et al.*, 2019). Wide step widths appear to increase the energy cost of unloaded walking by increasing the mechanical work required to redirect the centre of mass from step-to-step (Donelan *et al*., 2002). Narrower step widths (narrower than the width of the foot) appear to increase the energy cost of walking because of the mechanical work required laterally to move the swing leg to avoid the stance leg (Shorter *et al.*, 2017). As such, alterations in step width as a consequence of load carriage could lead to alterations in economy, particularly if load carriage causes an individual to take much wider or narrower steps than their preferred unloaded walking step width. Previous research on the effect of load carriage on step width has found no difference in step width as a percentage of stature with weighted vests between 10-30% body mass (Sidler *et al.,* 2013). However, to our knowledge, no studies have assessed the association between step width and economy in head-loading or back-loading, which might require an increased requirement for lateral stabilisation compared to methods that evenly distribute load around the torso.

The aim of this research was to evaluate changes in step width and economy when carrying loads on the head, back and back/front to assess the extent to which step width contributes to load carriage economy.

METHODS: Fifteen healthy volunteers (10 males, 5 females; age = 25 ± 3 years; stature = 1.78 ± 0.07 m; body mass = 73.6 ± 10.1 kg) completed three trials in a randomised order. Trials differed by load carriage method (head, back and back/front) and involved walking at $3 km \cdot h^{-1}$ on a force-instrumented treadmill carrying loads of 0, 3, 12 and 20kg. Walking periods lasted four-minutes, in order to achieve a steady state of oxygen consumption, and were separated by two minutes rest. This protocol was then repeated after a 10-minute rest period, with step width controlled to each participants preferred unloaded step width. Ethical approval was received from the institutional ethics committee at Leeds Trinity University and KU Leuven. All participants had recreational experience of back-loading and no experience of head- or back/front-loading. Figure 1 shows the method used to control step width. Markers for the preferred unloaded step width where placed on the rear of the treadmill and filmed with a digital camera (JVC Everio, Japan) positioned 1.5 m behind the treadmill. The camera was linked to a monitor placed in front of the treadmill, positioned at the height of each participant's eye-line. Participants were asked to align their heel markers to the taped lines on the rear of the treadmill**Error! Reference source not found.**. As such, step width was controlled using constant visual feedback. A familiarisation period was included to ensure participants were able to accurately align their steps to the marked width.

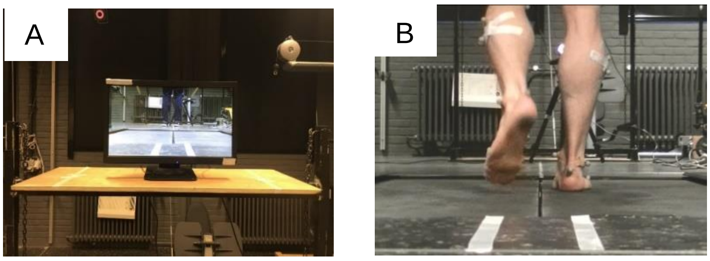

Figure 1. Images of the experimental set-up to control step width. Image A shows the monitor which provided visual feedback of foot placements. Image B shows a participant walking with their heel markers aligned with tape positioned at the rear of the treadmill, used to signify the participants required foot placements.

Expired gas was analysed continuously throughout exercise using a portable online gas analysis system (Oxycon Mobile, Jaeger). Three-dimensional motion capture (Vicon, Oxford Metrics, UK), sampling at 100Hz, was used to capture the heel marker trajectories. Step width was defined as the medio-lateral distance between the right and left heel markers during successive points of initial contact. Relative load carriage economy was calculated using the Extra load Index (ELI). ELI is calculated as $mlO_{2L} \cdot kg \cdot min^{-1}$ / $mlO_{2U} \cdot kg \cdot min^{-1}$), where mlO_{2L} refers to oxygen consumption when carrying an additional load and mlO_{2U} refers to oxygen consumption when walking unloaded.
Two-way repeated measures ANOVAs (IBM SPSS 22) were used to test for significant main effects and interactions in relative load carriage economy and step width between loading methods and load mass. Post-hoc tests for significant main effects were conducted using a Bonferroni correction. Significance was set as $p = \leq 0.05$.

RESULTS: Load carriage economy was significantly worse in the head loading condition compared to the other two conditions (main effect of method of load carriage, $p = 0.01$) for both preferred and controlled step width. The ELI associated with Back/Front-loading decreased as the mass of the load increased in both step width conditions, while the ELI values for back-loading remain fairly constant across each load mass (main effect of load mass $p = 0.41$) (Figure 2).
For the trials where step width was uncontrolled, there was a significant difference in step width from unloaded walking between the different loading methods (main effect of method of load carriage, $p = 0.01$) but no significant difference between load masses (main effect of mass, $p = 0.39$). Table 1 shows the differences in preferred step width with each load carriage condition. When step width was controlled, there was no significant difference between loading

methods (main effect of method of load carriage, p = 0.51) or load mass (main effect of mass, p = 0.21). The difference in step width between the controlled and uncontrolled conditions was significantly different between methods (main effect of method of load carriage, p = 0.05) but no significant difference was found between load mass (main effect of mass, p = 0.53).

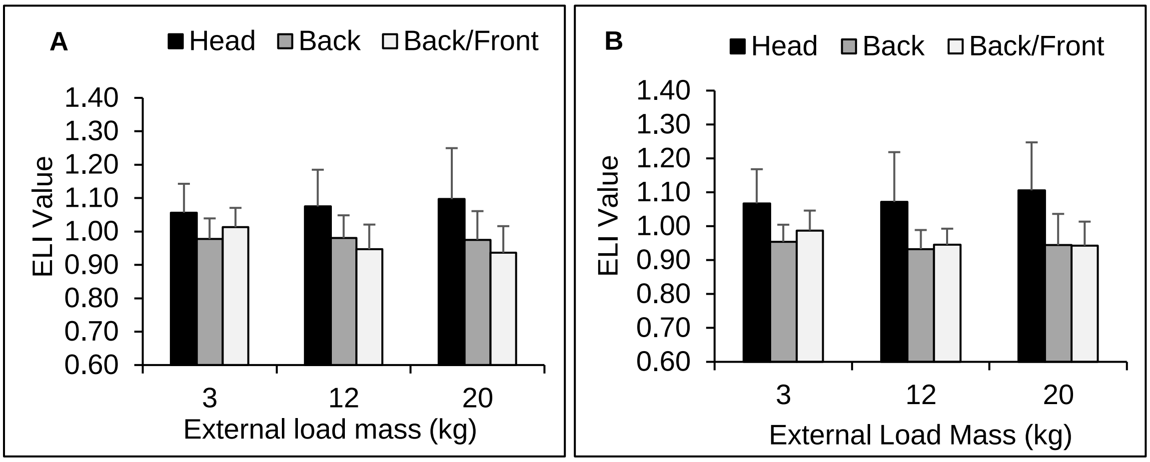

Figure 2. Mean ± SD Extra load index (ELI) values for each load carriage condition with preferred (A) and controlled (B) step width.

There was no significant difference in medial or lateral forces between methods with preferred and controlled step width (main effect of method of load carriage, $p>0.05$). There was also no significant difference in the change in force from preferred step width to controlled step width between load carriage methods for medial (main effect of method of load carriage, $p>0.05$) or lateral force.

Table 1. Mean ± SD for step width (m) in the preferred step width and controlled step width conditions with each load carriage method and load mass combination.

	Uncontrolled step width				Controlled step width			
	0kg	3kg	12kg	20kg	0kg	3kg	12kg	20kg
Head	0.14 ± 0.02	0.15 ± 0.03	0.16 ± 0.03	0.16 ± 0.02	0.15 ± 0.02	0.15 ± 0.02	0.15 ± 0.02	0.15 ± 0.02
Back	0.15 ± 0.02	0.14± 0.02	0.14± 0.02	0.15± 0.02	0.15± 0.02	0.15± 0.02	0.14 ± 0.02	0.15 ± 0.02
Back/Front	0.14 ± 0.01	0.14 ± 0.01	0.14 ± 0.02	0.14 ± 0.02	0.15 ± 0.02	0.15 ± 0.02	0.15 ± 0.01	0.15 ± 0.02

DISCUSSION:

The lack of significant difference in ELI between the two step width conditions (preferred and controlled) suggests that alterations in step width and medial-lateral stability due to load carriage does not soley explain differences in load carriage economy between head-, back- and back/front-loading. In the uncontrolled condition, step width was wider in the head-loading condition with all load mass compared to the other methods. An increase in step width has been associated with an increased requirement for medio-lateral stability (Young and Dingwell, 2012), which suggests that individuals required wider steps to maintain stability when head-loading. However, the pattern of response for ELI was similar in both step width conditions, which suggests that the alterations in step width when head-loading were not solely responsible for the increased ELI values.

Step width was controlled to each participant's preferred width when walking unloaded because, for unloaded walking, both widening and narrowing step width from an individual's preferred width appears to increase the energy cost of walking (Donelan *et al.*, 2002; Shorter *et al*., 2017). Furthermore, it has been suggested that an individual's normal walking gait may represent an optimal solution for that individual in relation to their economy (Martin and Morgan, 1992). As such, we hypothesised that larger adjustments from the preferred unloaded walking gait, as a consequence of load carriage, could worsen economy. It's possible that the small difference in step width between the controlled and preferred conditions seen in this study were not large enough to influence economy. Donelan *et al.* (2002) showed a substantially greater metabolic cost for unloaded walking when step width was increased from preferred (0.14m) to 0.42m. The largest difference found in this study between controlled and uncontrolled step width was 0.01 metres. As such, it's likely that when walking on even terrain, the alterations in step width induced by load carriage are not large enough to cause an alteration in relative load carriage economy. This is also likely to explain for the lack difference in medial and lateral ground reaction force between the conditions.

A walking speed of $3 km \cdot h^{-1}$ was used in this study to enable comparisons with previous research that have reported an energy saving phenomenon with load carried at slow walking speeds (Maloiy *et al*., 1986; Lloyd and Cook 2000; Abe *et al.,* 2004). However, not permitting participants to walk at a self-selected speed could have perturbed some participants normal gait pattern more than others, depending on their preferred walking speed.

The method used to control step width in this study relied on the successful alignment of heel-markers with markers at the rear of the treadmill. While most participants were able to consistently align their heels with the markers, two participants produced narrower step widths in the back 12kg condition (0.03 metres from the desired width in the controlled condition). As such, the average step width for this load carriage condition was lower than other conditions. Similar real-time visual feedback methods have also reported slightly narrower than target step widths when running (Arellano and Kram, 2011).

CONCLUSION:

Based on the data presented here, there is a significant difference in load carriage economy associated with head-, back- and back/front-loading methods. These differences in economy are not explained by load carriage induced changes to step width from an individual's preferred step width when walking unloaded on even terrain.

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