A comparison of economy and sagittal plane trunk movements among back-, back/front- and head-loading.

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Abstract

It has been suggested that freedom of movement in the trunk could influence load carriage economy. This study aimed to compare the economy and sagittal plane trunk movements associated with three load carriage methods that constrain posture differently.

Eighteen females walked at 3 km·h^{-1} with loads of 0, 3, 6, 9, 12, 15 and 20 kg carried on the back, back/front and head. Load carriage economy was assessed using the Extra Load Index (ELI). Change in sagittal plane trunk forward lean and trunk angle excursion from unloaded to loaded walking were assessed.

Results show no difference in economy between methods (p = 0.483), despite differences in the change in trunk forward lean (p = 0.001) and trunk angle excursion (p = 0.021) from unloaded to loaded walking.

We conclude that economy is not different among the three methods of load carriage, despite significant differences in sagittal plane trunk movements.

Key words load carriage, economy, forward lean, trunk movement

Practitioner Summary

This paper shows, based on mean data, that there is no difference in economy among back, back/front and head-loading, despite differences in trunk movement. It is possible a combination of factors align to influence individual economy, rather than a single set of factors, applicable to all individuals for each method.

1. Introduction

Manual load carriage remains a prevalent task for many individuals, particularly those in the military and emergency services, school children, and individuals living in rural areas of developing countries where transport infrastructure is poor. There has been a substantial amount of research on the physiology of load carriage, particularly the effect of load position on energy expenditure, and it is generally accepted that carrying a load more distally (e.g. in the hands or on the feet) results in an increased energy expenditure (Soule and Goldman, 1969; Kamon and Belding, 1971; Abe *et al.*, 2004) compared to carrying a load closer to the body's centre of mass (COM) (Myo Thien *et al.,* 1985; Legg and Mahanty, 1985; Datta and Ramanathan, 1971; Abe *et al.*, 2004). Methods that place the load close to the bodies COM include variations of trunk loading (e.g. back-loading and evenly distributing load around trunk) and head-loading, which places the load directly above the bodies COM.

Much work has been done to identify mechanisms that may contribute to greater economy when carrying a load (e.g. Jones *et al.,* 1987; Heglund *et al.*, 1995; Abe *et al.*, 2004; Lloyd and Cooke, 2011). In particular, Abe *et al.* (2004) and Lloyd and Cooke (2000b) identified a potential energy saving mechanism in back-loading and back/front-loading, respectively. In the case of Abe *et al.* (2004), they proposed a potential energy saving mechanism when carrying light loads on the back at low speeds (2.4 – 3.6 $km \cdot h^{-1}$), which they characterised as the contribution of rotative torque about the lower limb. Lloyd and Cooke (2000b) proposed a potential energy saving mechanism for combined back/front loading at heavier loads, which they characterised as the contribution of trunk momentum to the energy required for walking. Although characterised slightly differently these proposed mechanisms appear similar and suggest that an increased sagittal plane trunk movement during load carriage might act as an energy saving mechanism. It is possible that an increased trunk movement through the step cycle, when carrying a load at slow speeds, could contribute to a forward momentum, thus reducing the amount of force required to propel the body forward with each step (Lloyd and Cooke 2000a, 2011).

Unlike back and back/front-loading, head-loading is likely to require a constrained, upright posture to maintain equilibrium of the load, regardless of the mass. If constraining the trunk increases the energy cost of load carriage, then head-loading, in theory, would be less economical than methods that load the trunk. Yet, research on head-loading economy is equivocal. Some studies have reported that the energy cost of head-loading rises in proportion to the mass supported by the muscles (Soule and Goldman, 1969; Datta and Ramanathan, 1971; Datta *et al.,* 1973; Lloyd *et al*., 2010a; Lloyd *et al,*. 2010b), while others have reported that head-loading could represent a remarkably economical method for certain individuals, with African women able to carry loads of up to 20% body mass on their head with no additional energy cost above that required for unloaded walking (Maloiy *et al*., 1986; Charteris *et al.,* 1989; Bastien *et al.*, 2005). More recently, Lloyd *et al*. (2010b) demonstrated a large level of individual variation in economy in both head- and back-loading with some individuals being remarkably economical at head-loading, while others were very economical at back-loading. Furthermore, Lloyd *et al*. (2010b) showed that load carriage economy with head-loading was independent of experience. As the mechanisms underpinning the variations in energy cost of head-loading and back loading are yet to be established, examining the role of postural adjustments associated with transporting a load seems warranted, particularly given the potential energy saving role of sagittal plane trunk movements in methods that load the trunk.

Load carriage economy is frequently measured as the rate of oxygen consumption ($\dot{V}O_2$) when carrying a load, usually expressed relative to body mass (Legg and Mahanty, 1985; Quesada *et al.*, 2000; Hinde *et al.*, 2017; Pigman *et al.*, 2017). However, this approach makes it difficult to compare studies using different loading methods and walking speeds. The Extra Load Index (ELI) is a measure of load carriage economy that factors out the energy cost of unloaded walking (Lloyd *et al*., 2010a). This produces a single, dimensionless index that allows for simple comparisons between different loading methods. It could be argued that all investigations into load carriage should be referenced to unloaded movement, whether they are assessing the physiological cost, kinematics, kinetics, subjective perceptions or muscle activations.

The aim of this study was to assess the economy and sagittal plane trunk movements associated with three methods of load carriage that constrain posture differently. We hypothesised that the method allowing for the greatest freedom of movement in the trunk, for a given load mass, would have the best associated economy. We suspected that head-loading would constrain the trunk in an upright position, and, as such, be the least economical method. We also suspected that combined back/front-loading would allow for greater trunk movement with heavier loads compared to back-loading, and therefore, be more economical at heavier loads.

2. Methods

2.1 Participants:

Eighteen apparently healthy female volunteers with a minimum of 5 years' experience of head load carriage were recruited (age 23 ± 3.8 years, mass 61.1 ± 10.7 kg, stature 158.9 ± 8.1 cm). All participants were accustomed to carrying 20kg loads on the head (typical load for water carrying; Porter *et al.*, 2013). All volunteers gave written informed consent to participate. The study received ethical approval from the institutional ethics committee at the Cape Peninsula University of Technology and University of Abertay Dundee.

2.2 Experimental Design:

All trials were conducted at the Human Performance Laboratory at Cape Peninsula University of Technology. Participants attended the laboratory on four separate occasions in order to complete an habituation session and three different trial conditions. Trial conditions differed in load carriage method, with load carried on the head, on the back and evenly distributed between the front and back. Each participant chose, at random, the loading method for each experimental trial (via the picking of a marked piece of paper from a hat). Trials involved seven, four-minute periods of walking at $3km{\cdot}h^{-1}$, with each period separated by two minutes of rest. The initial stage was performed unloaded, followed by loads of 3, 6, 9, 12, 15 and 20kg. Participants were asked to maintain a similar diet and refrain from moderate-vigorous exercise and alcohol consumption in the 24 hours prior to each test.

2.3 Experimental Procedures:

2.3.1 Loading Methods:

A traditional 45 litre rucksack (Karrimor, UK) was used for back-loading, a 20 litre plastic bucket was used for head-loading and a load carriage system with front balance pockets was used for front/back loading (AARN design, New Zealand) (Figure 1). A piece of rolled up material was allowed to provide a cushion between the head and the bucket when head-loading. The mass of the load was made up of the load carriage device itself plus sandbags to the nearest 50g.

[Figure 1 near here]

2.3.2 Initial Screening and Habituation:

Prior to completing the first trial, all participants were screened for any potential contraindications to exercise and completed questionnaires relating to load carriage history. The participants were then habituated to the experimental protocol and equipment. A typical habituation session lasted ~ 20 minutes. Body mass (Seca scales, UK) and stature (Seca, UK) were measured, followed by walking on the motorised treadmill (Genesis, South Africa) at $3km{\cdot}h^{-1}$ with each of the loading conditions. The facemask for the online gas analysis system (K4b2, COSMED, Rome) was also fitted, in order for participants to become accustomed to it.

2.3.3 Experimental Trials:

Each trial began by measuring the participant's body mass in order to calculate the ELI for that trial (see equation 1). Participants were then fitted with a face mask and a heart rate monitor (Polar, Finland) and asked to walk unloaded on the treadmill at $3km{\cdot}h^{-1}$ for four minutes at 0% gradient. After four minutes, there was a two-minute rest period during which the participants were fitted with the appropriate loading device for the trial. The initial load was set at 3kg. At the end of the rest period, participants recommenced walking at the same speed for a further four minutes. This pattern of work and rest continued with loads of 6, 9, 12, 15 and 20kg being carried in subsequent stages. A speed of $3km{\cdot}h^{-1}$ was selected because the previous studies that have reported an energy saving phenomenon with load carriage have done so at similarly slow walking speeds (Maloiy *et al*., 1986; Lloyd and Cooke, 2000; Abe *et al*., 2004). Each period of walking lasted for 4 minutes in order to ensure that participants achieved a steady state of oxygen consumption (Poole and Richardson, 1997; Lloyd et al., 2010c).

2.3.4 Expired Gas Analysis:

Expired gas measurements were made continuously throughout each period of exercise using a computerised online gas analysis system (K4b2, COSMED, Rome), which was calibrated prior to the beginning of each trial. Following the completion of each trial, the data were averaged for 60-second intervals. Means and standard deviations were calculated for $\dot{V}O_2$ ($l{\cdot}min^{-1}$). The $\dot{V}O_2$ in the final minute of each walking period was used to calculate the Extra Load Index (ELI; equation 1), (Lloyd *et al*. 2010a) which has been shown to be a reliable measure of load carriage economy (Hudson *et al*. 2017).

$$\text{ELI} = \frac{\text{mlO}_{2L} \cdot \text{kg total mass}^{-1} \cdot \text{min}^{-1}}{\text{mlO}_{2U} \cdot \text{kg body mass}^{-1} \cdot \text{min}^{-1}}$$

where mlO_{2L} and mlO_{2U} refer to loaded and unloaded oxygen consumption, respectively. An ELI value of 1 indicates that oxygen consumption increased in direct proportion to the mass supported by the muscles. Values <1 or >1 indicate a relatively lower or higher energy cost, respectively.

The energy cost of walking per unit distance (*C*w; Equation 2; Abe *et al.* 2004) was also calculated from the $\dot{V}O_2$ data in the final minute of each walking period.

$$C\text{w} = \text{ml} / [\text{BM} + L] / \text{m} \qquad \text{(Equation 2)}$$

where BM refers to the body mass of the participant and *L* is the additional load mass.

2.3.5 Kinematics

Sagittal plane trunk kinematics were filmed using a standard video camera (Panasonic, Japan) set at 50 Hz and placed perpendicular to the treadmill. The treadmill was marked on the vertical (0.5m) and horizontal (1m) axis and recorded prior to each trial for calibration. Superficial joint markers were placed on landmarks for the hip and shoulder on the side of the body ipsilateral to the camera. Six steps from the final minute of each stage were digitised using SIMI motion software (SIMI 8.5.6, Germany). Raw data were filtered using a 2nd order Butterworth filter with a cut-off frequency of 6Hz. Once the reconstruction was complete, trunk angle was calculated by the software for each step at two events of the step cycle (heel-strike and toe-off). Step events were visually identified from the video footage. Heel-strike was identified as the frame where the foot appeared to make contact with the treadmill and toe-off was identified as the frame where the foot appeared to no longer be in contact with the treadmill. Trunk forward lean was measured as the angle of the trunk from horizontal. Therefore, 90º represents a vertical trunk position and angles less than 90º indicate forward lean. A single value for trunk forward lean for each step was calculated as the average from the three events of each step cycle. Trunk angle excursion was measured as the change in trunk angle from heel-strike to toe-off in each step.

2.4 Data and Statistical Analysis:

Means and standard deviations for each of the variables ($\dot{V}O_2$, ELI, Cw, trunk forward lean and trunk angle excursion) from each load method and load mass combination were calculated. Trunk forward lean and trunk angle excursion were analysed as the change from unloaded to loaded walking (Δ trunk forward lean and Δ trunk angle excursion, respectively). Data were analysed using IBM SPSS 22, with significance set at $p \leq 0.05$. To assess for differences between conditions, a two-way repeated measures analysis of variance (ANOVA) (load method x load mass) was conducted to establish any significant main effects and interactions. Post-hoc tests for significant main effects were conducted using a Bonferroni correction. Pearson's Product Moment Correlation Coefficients were calculated to explore the relationships between ELI values and both Δ trunk forward lean and Δ trunk angle excursion for each of the load method and load mass combinations.

3. Results

There were no significant differences between trial conditions for oxygen consumption (p = 0.761), trunk forward lean (p = 0.570) or trunk angle excursion (p = 0.767) when walking unloaded (table 1).

[Table 1 near here]

3.2 $\dot{V}O_2$

There were no significant differences in the $\dot{V}O_2$ between the three loading methods (main effect load method p = 0.814) but $\dot{V}O_2$ did increase significantly as the mass of the load increased (main effect load mass p = 0.001). Post-hoc analysis indicated that $\dot{V}O_2$ significantly increased from unloaded walking with the 9, 12, 15 and 20kg loads ($p \leq 0.05$). Figure 2 shows the interactions between load mass and the three loading methods. The pattern of response was similar between the three load methods and this was confirmed by a lack of interaction effect between load method and load mass (p = 0.151).

[Figure 2 near here]

3.2 Load carriage economy

ELI values were not significantly different between loading methods (main effect method; p = 0.483). With all load masses combined, ELI values were 0.95 ± 0.11, 0.93 ± 0.08 and 0.94 ± 0.06 for head, back and back/front, respectively. There was a significant difference in ELI between the load masses (main effect load mass, p = 0.001). However, there was no significant load method x load mass interaction (p = 0.094). Figure 3 shows that in back-loading, economy decreased from 3kg (ELI = 0.95) to 9kg (ELI = 0.90) and then increased again as the load mass increased. In back/front loading, the ELI values decreased from 3kg (ELI = 0.99) as the load mass increased up to 15kg (ELI = 0.91). In the head-loading, ELI was highest with 3kg (ELI = 1.03) and lowest with 12kg (0.92).

Figure 4 shows the results for load carriage economy presented as the energy cost of walking per unit distance (Cw). There was no significant difference in Cw between loading methods (main effect method $p = 0.802$). The *C*w was significantly different between the load masses, with post-hoc analysis revealing a significant decrease in *C*w from unloaded to loaded walking ($p \leq 0.05$). The largest decrease from unloaded walking in *C*w was in the back-loading method with 9kg (-0.021 ml/kg/min). For head-loading and combined back/front-loading, the largest decrease from unloaded was with 12kg (-0.017 ml/kg/min) and 15kg (-0.018 ml/kg/min), respectively. There was no significant interaction effect between load method and load mass ($p = 0.113$).

[Figure 3 near here]

[Figure 4 near here]

3.3 Trunk movement

Figure 5 shows Δ trunk forward lean with each of the three loading methods and each load mass. There was a significant interaction effect between load method and load mass ($p = 0.001$). The Δ trunk forward lean was significantly different between loading methods (main effect load method $p = 0.001$) and load mass (main effect load mass $p = 0.001$). In both the back- and back/front-loading methods, Δ trunk forward lean increased each time the external mass increased. This increase was much greater in the back-loading method, (10.7˚ increase from 3kg to 20kg) compared to the back/front method (2.4˚ increase from 3kg to 20kg). In the head-loading method, Δ trunk forward lean decreased as the load mass increased (-2.2˚ decrease from 3kg to 20kg).

[Figure 5 near here]

The Δ trunk angle excursion during the stance phase (heel-strike to toe-off) (Figure 6) was significantly different between loading methods (main effect loading method $p = 0.021$) and load mass (main effect load mass $p = 0.004$). There was also a significant interaction effect between load method and load mass ($p = 0.001$). In the back-loading method, Δ trunk angle excursion decreased as the mass of the load increased. The Δ trunk angle excursion decreased with both the back/front and head methods, although there was not a consistent pattern of response for these two methods across the different load masses.

[Figure 6 near here]

3.4 Relationships between ELI and trunk movement

There were no strong relationships ($r > 0.7$) between Δ trunk forward lean and ELI values, or between Δ trunk angle excursion and ELI values. Considering the back-loading method, there was a moderate relationship between ELI and Δ trunk angle excursion with the 20kg load ($r = -0.507$, $p = 0.032$). In the back/front method, there was a moderate relationship between ELI and Δ trunk forward lean with 9kg ($r = -0.491$, $p = 0.039$). In the head-loading method, there were no moderate-strong relationships between any of the trunk movement variables and ELI (the strongest relationship between ELI and Δ trunk ankle excursion was with 3kg; $r = -0.322$; $p = 0.193$).

4. Discussion

The ELI data presented here show no significant difference in load carriage economy among back-, back/front- and head-loading with loads ranging from 3 – 20kg (figure 3), despite there being significant differences in the change in sagittal plane trunk forward lean (figure 5) and trunk angle excursion (figure 6) from unloaded to loaded walking between the methods.

As expected, the pattern of response for load carriage economy is similar between ELI (figure 3) and *C*w (figure 4). *C*w was included in this study to compare the findings with those of Abe *et al.* (2004), who reported improved economy with 9kg and 12kg carried on the back when walking at speeds of 2.4 – 3.6 $km \cdot h^{-1}$. The *C*w results for back-loading from this study are similar to those of Abe *et al*. (2004), with a decrease of -0.02 ml/kg/meter from unloaded to loaded walking when 9kg was carried on the back, suggesting that there is a trend for back-loading to be more economical with this load mass than either lighter or heavier loads. In line with the findings of Lloyd and Cooke (2000b), the lowest values for both *C*w and ELI in the combined back/front method occurred at a heavier load than in the back-loading only method. Interestingly, the economy data in this study also show that head-loading was as economical as both back-loading and combined back/front-loading. The head-loading data reported here are consistent with the ELI values reported by Lloyd *et al.* (2010b) and previous studies that have investigated the metabolic cost of head-loading (Lloyd *et al.* 2010a; Soule and Goldman, 1969; Nag and Sen, 1978).

Female volunteers with head-loading experience were recruited so that direct comparisons could be made with the research of Maloiy *et al.* (1986) and Charteris *et al*. (1989), both of which reported that African women with several years of head-loading experience were able to carry loads of up to 20% body mass with no additional energy expenditure above that required for unloaded walking. However, it is unlikely that experience influenced economy in the present study, as load carriage economy has been shown to be independent of experience in both head- and back-loading (Lloyd *et al.*, 2010b; 2010c). Increasing the mass of the load resulted in significantly increased $\dot{V}O_2$ with all methods (Figure 2). Therefore, the mean $\dot{V}O_2$ data presented here do not support the existence of an energy-saving phenomenon for experienced head-loaders. The difference in findings between the present study and those of Maloiy *et al.* (1986) and Charteris *et al.* (1989) might be explained by differences in sample size. This findings of Maloiy *et al.* (1986) and Charteris *et al*. (1989) were based on samples of five women and six women, respectively. Lloyd *et al.* (2010b) showed that, with a larger sample of participants (n = 24), it is possible to select a subset of women who can achieve remarkable levels of head-loading economy, similar to those reported in earlier studies (Maloiy *et al.* 1986; Charteris *et al.,* 1989), despite mean group data showing that the energy cost of head-loading rises in proportion to the mass supported by the muscles. Our findings support those of Lloyd *et al.* (2010b) with some women demonstrating better economy when head-loading, while others were more economical at back-loading or back/front-loading, despite there being no difference in economy between methods when comparing the mean data.

Trunk forward lean increased from unloaded walking in the back and back/front methods (Figure 5), with a considerably larger increase for back-loading compared to back/front-loading (8.6 ± 2.5° and 3.5 ± 2.7° when all load masses are combined for back-loading and back/front-loading, respectively). Figure 5 shows a load dependent increase in forward lean in the back-loading condition with forward lean increasing each time the external mass increased. An increase in Δ trunk forward lean with back-loading compared to evenly distributing the load around the trunk is consistent with previous research comparing backpacks and back/front packs (Kinoshita, 1985; Lloyd and Cooke, 2011). The addition of external mass to the back will have resulted in a greater posterior displacement of the COM of the whole system compared to the back/front condition. Therefore, the increased trunk forward lean when back-loading is likely to have occurred to counter this posterior shift in an attempt to restore the COM of the combined system to the original COM of the body when walking unloaded to improve postural stability (Kinoshita, 1985; Martin & Nelson, 1986; Goh *et al.*, 1998; Harman *et al.*, 2002).

There is a paucity of research examining the postural adjustments associated with transporting a load on the head. Our findings show that head-loading causes a decrease in trunk forward lean from unloaded walking. This is likely to be a consequence of the need to balance the load on top of the head requiring individuals to adopt a more upright posture. It was expected that smaller perturbations from the unloaded condition would be associated with an improved economy. However, larger increases in Δ trunk forward lean with the back-loading method were not accompanied by a higher energy expenditure compared to the other conditions. Given the lack of association between trunk forward lean and load carriage economy in this study, it would seem unlikely that forward lean alone is not directly responsible for any differences in load carriage economy. This is supported by research that has shown relatively low absolute levels of activity in postural muscles associated with forward lean (Motmans *et al.*, 2006; Al-Khabbaz *et al.*, 2008) and suggests that leaning forward to counteract the posterior shift in the position of the COM when back-loading is not a sole determinant for economy with this method of load carriage.

The Δ trunk angle excursion from unloaded walking during single foot contact (heel-strike to toe-off) decreased in all conditions (Figure 6). A decreased trunk angle excursion in the back-loading condition was associated with a concomitant increase in trunk flexion angle each time mass was added, which has been a consistent finding in the literature (Harman *et al.*, 2000; Harman *et al.*, 2002; Attwells *et al.*, 2006; Yen *et al.*, 2011; Liew *et al.,* 2016). With back/front-loading, the range of motion appeared to be greater than back-loading with 12, 15 and 20kg loads. Lloyd and Cooke (2000a) demonstrated a requirement for lower peak propulsive force with a back/front load compared to back-loading, which they suggested could represent an energy saving mechanism with back/front-loading, caused by increased momentum associated with a greater joint angle excursion in the trunk. However, in our study, the relationships between Δ trunk angle excursion and ELI for the back/front method with heavier load masses (12, 15 and 20kg) were weak. In the head-loading condition, trunk angle excursions were largest for most of the loads. This is a surprising finding given that head-loading requires the load to be balanced on top of the head, and it was expected that this would constrain posture in an upright position. Arm movement was not controlled in the present study, with some participants using one or both arms to support the load on the head, while others walked without supporting the load with arms. At first, it was thought that supporting the load with the hands might allow for a greater trunk angle excursion when head-loading. However, there was only a moderate relationship between how the load was supported on the head (no hands, one had or both hands) and trunk angle excursion (r = -0.465, p = 0.052), and a weak relationship between how the load was supported on the head and ELI (r = 0.316, p = 0.202).

Despite there being no difference in load carriage economy between methods when comparing the mean data, the standard deviations in figure 3 and figure 4 indicate that there was considerable individual variation. The standard deviations in figure 4 and figure 5 also indicate that there was large individual variation present in the change from unloaded walking in trunk forward lean and trunk angle excursion, respectively. Yet, the lack of strong relationships between ELI and either Δ trunk forward lean and ELI and Δ trunk angle excursion indicates that neither of these variables alone were associated with individual load carriage economy. Given the variability in trunk movement, it is possible that a number of factors might align in individuals to influence economy rather than there be a single set of generalizable factors, such as sagittal plane trunk movement, applicable to all individuals for each method. To gain a better understanding of the interactive effects of factors relating to different forms of load carriage, future research would benefit from assessing the individual variation in load carriage economy and the factors that relate to load carriage economy.

The results obtained from controlled laboratory conditions are valuable, but it is important to note that real life load carriage tasks are often performed on uneven terrain at non-constant, self-selected speeds. This may cause additional metabolic costs and biomechanical challenges compared to the laboratory environment and, as such, is a limitation of this research and all laboratory-based load carriage research. A slow speed of $3km{\cdot}h^{-1}$ 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 Cooke, 2000; Abe *et al.*, 2004). However, not permitting participants to walk at a self-selected speed is likely to have perturbed the individuals normal gait pattern (Martin and Morgan, 1992) and could have contributed to the unexpected findings.

5. Conclusion

Based on the mean data presented here, there appears to be no difference in load carriage economy among back, back/front and head-loading loading, despite significant differences between the methods in the change in trunk forward lean and change in trunk angle excursion from unloaded to loaded walking. There was, however, a considerable amount of individual variation in both load carriage economy and sagittal plane trunk movements. It's likely that a number of kinematic and kinetic movement factors align to influence load carriage economy rather than there be a single set of generalizable factors, applicable to all individuals for each method. Future research would benefit from assessing the individual variation in load carriage economy and the factors that relate to it.

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Captions for figures

Figure 1. Pictures showing the load carriage devises used in each condition. (A) Sagittal plane view of the back-loading condition. (B) Sagittal plane view of the back/front-loading condition. (C) Sagittal plane view of the head-loading condition.

Figure 2. Mean ± SD rate of $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) values for each load method and load mass.

Figure 3. Mean ± SD Extra Load Index values for each load method and load mass.

Figure 4. Mean ± SD the energy cost of walking per unit distance (*C*w) for each load method and load mass.

Figure 5. Mean ± SD change in trunk forward lean (degrees) from the unloaded walking for each load method and load mass.

Figure 6. Mean ± SD Trunk angle excursion (degrees) values during the stance phase from heel-strike to toe-off with each load method and load mass.

Table 1. Mean ± SD differences in $\dot{V}O_2$, trunk forward lean and trunk ROM between trial conditions (Head, Back, Back/Front) when walking unloaded.

	Trial Condition		
	Head	Back	Back/Front
$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	10.20 ± 1.50	10.35 ± 1.42	10.42 ± 1.18
Trunk Forward Lean (˚)	87.9 ± 2.6	87 ± 3.5	87.4 ± 2.9
Trunk ROM (˚)	4.1 ± 1.9	3.9 ± 1.5	4.3 ± 1.8

Figure 1. Pictures showing the load carriage devises used in each condition. (A) Sagittal plane view of the back-loading condition. (B) Sagittal plane view of the back/front-loading condition. (C) Sagittal plane view of the head-loading condition.

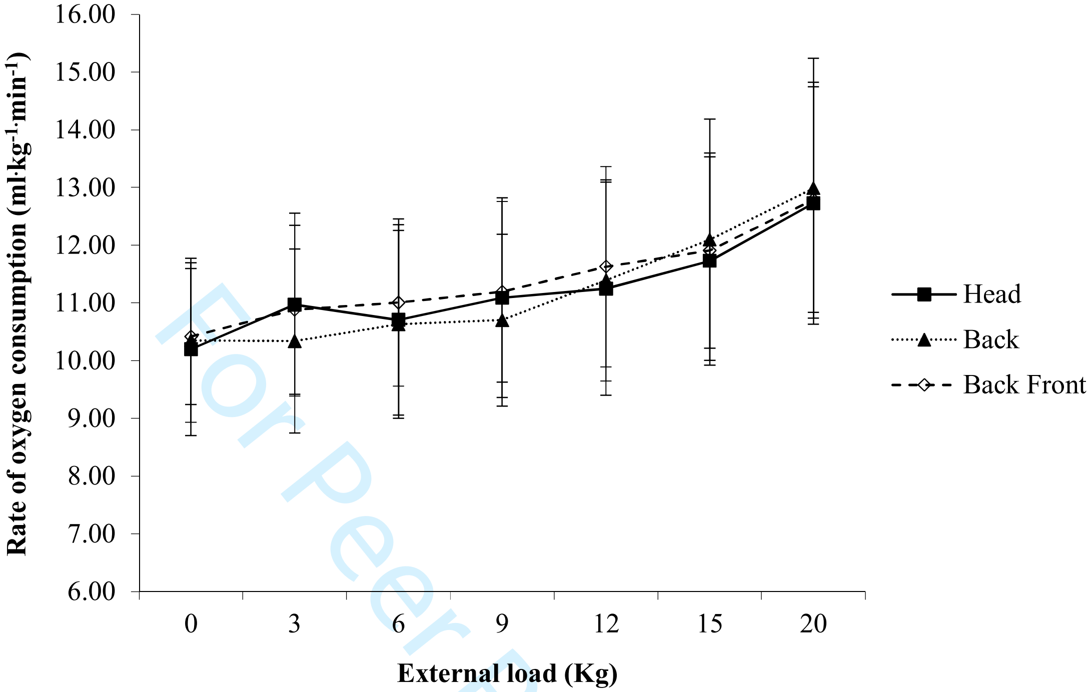

Figure 2. Mean ± SD rate of $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) values for each load method and load mass.

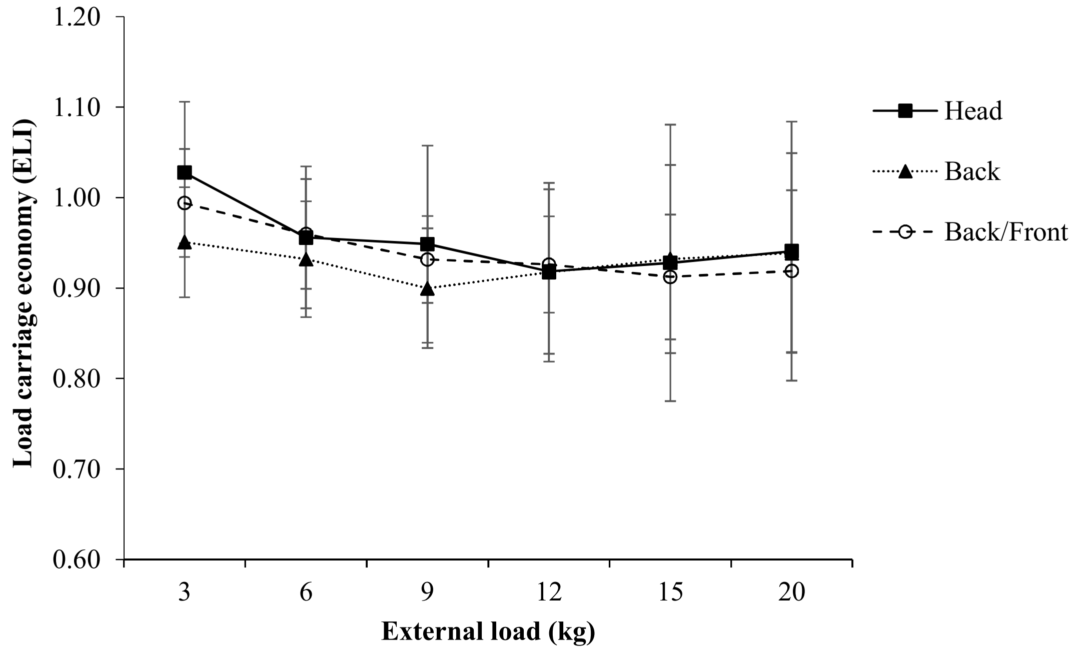

Figure 3. Mean ± SD Extra Load Index values for each load method and load mass.

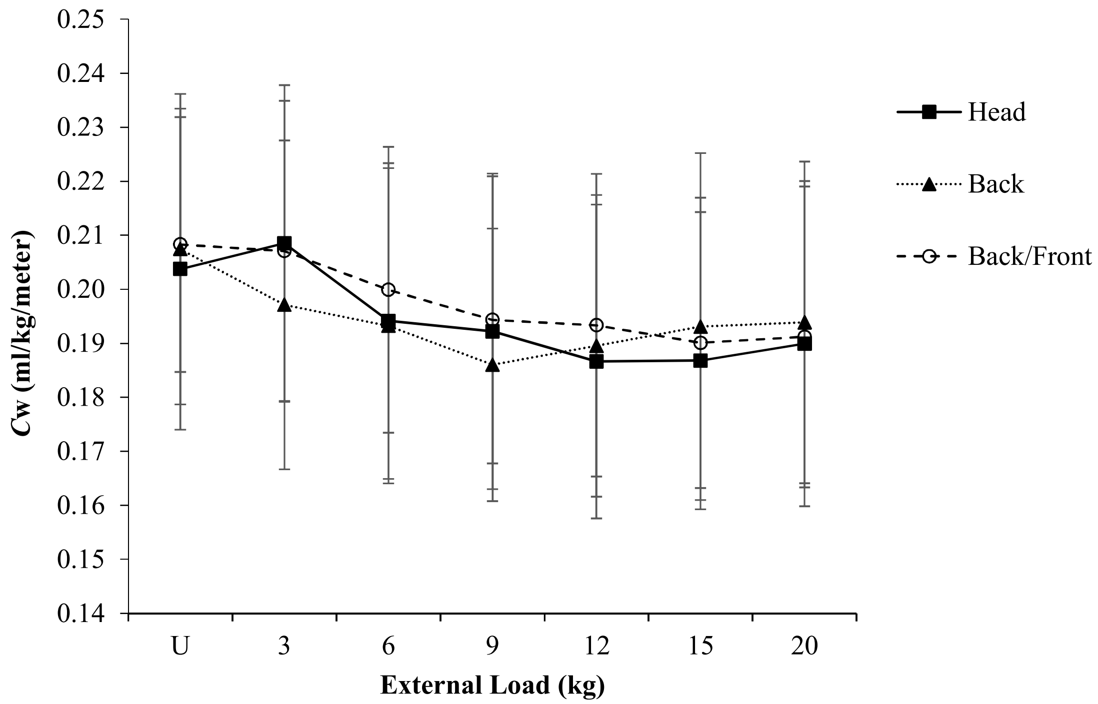

Figure 4. Mean ± SD the energy cost of walking per unit distance (*C*w) for each load method and load mass.

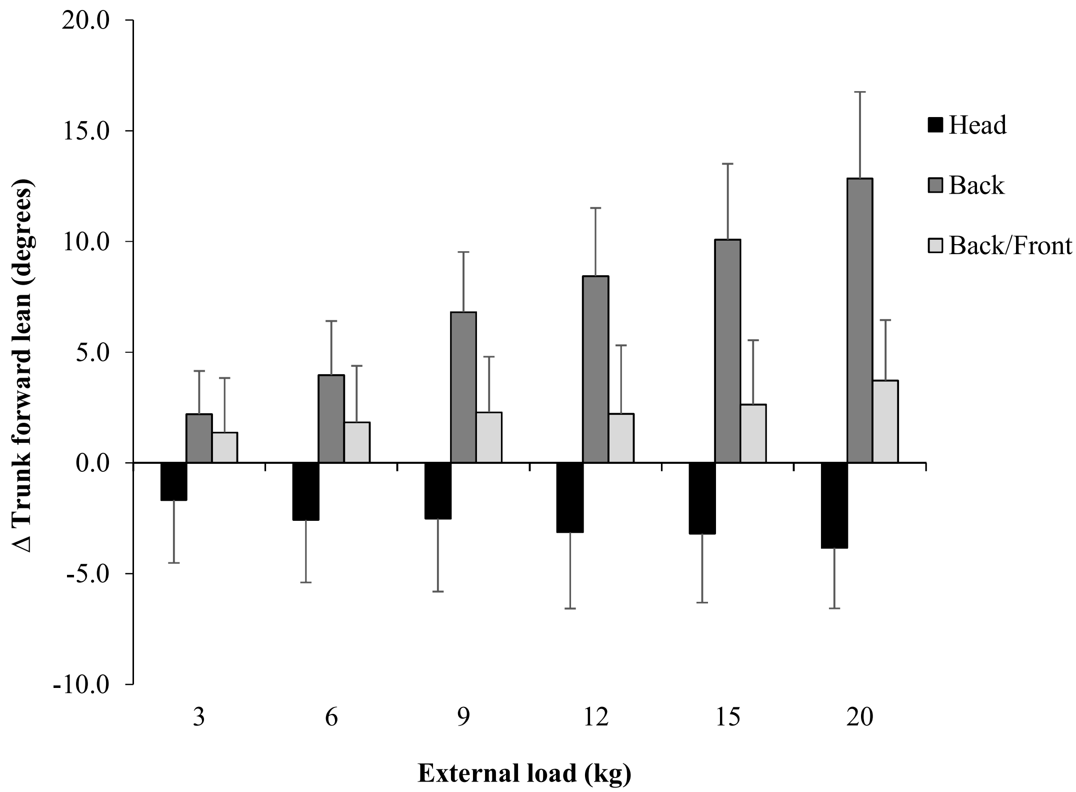

Figure 5. Mean ± SD change in trunk forward lean (degrees) from the unloaded walking for each load method and load mass.

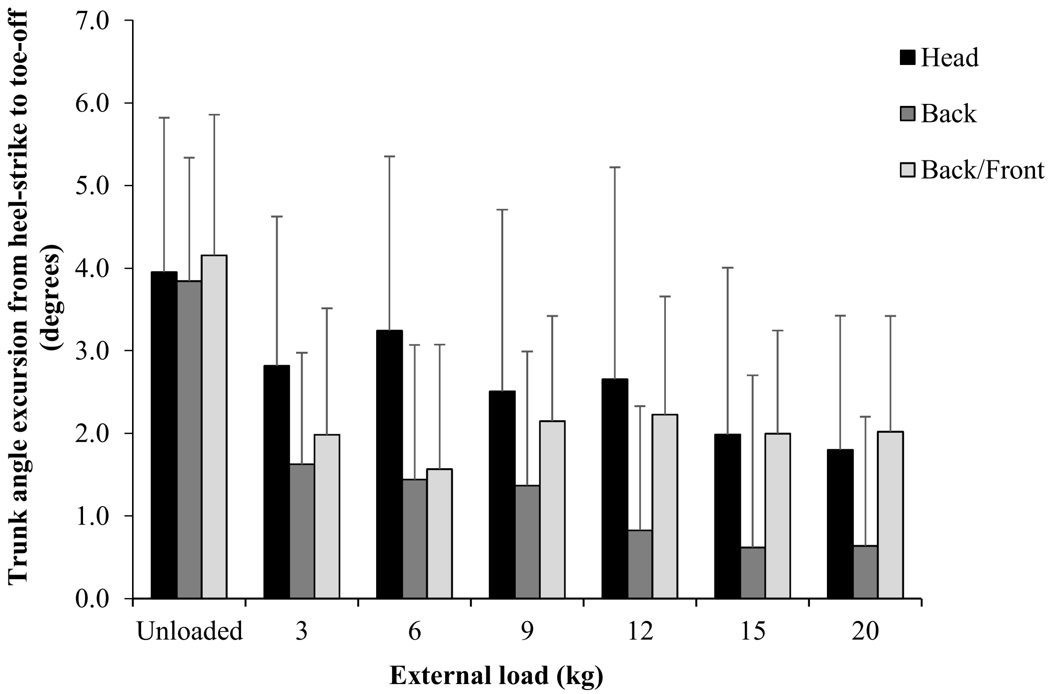

Figure 6. Mean ± SD Trunk angle excursion (degrees) values during the stance phase from heel-strike to toe-off with each load method and load mass.