A kinetic comparison of back-loading and head-loading in Xhosa women

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Abstract

The purpose of this study was to compare the kinetic responses associated with ground reaction force measurements to both head-loading and back-loading in a group of Xhosa women. Sixteen women were divided into two groups based on their experience of head-loading. They walked over a force plate in three conditions: unloaded or carrying 20kg in either a back-pack or on their head. The most striking finding was that there was no difference in kinetic response to head-loading as a consequence of previous experience. Considering the differences between the load carriage methods most changes were consistent with increasing load. Head-loading was, however, associated with a shorter contact time, smaller thrust maximum and greater vertical force minimum than back-loading. Both loading conditions differed from unloaded walking for a number of temporal variables associated with the ground contact phase e.g. vertical impact peak was delayed whilst vertical thrust maximum occurred earlier.

Keywords: Load carriage, kinetics, head-loading, back-loading, African women

50 word statement

Consideration of the kinetics of head and back load carriage in African women is important from a health and safety perspective, providing an understanding of the mechanical adaptations associated with both forms of load carriage for a group of people for who such load carriage is a daily necessity.

1. Introduction

The study of human load carriage remains an important area of investigation, with much recent research relating to the physiology (e.g. Abe *et al*, 2008; Bastien *et al*, 2005), kinematics (e.g. Attwell *et al*, 2006; Sharpe *et al*, 2008;) or subjective perceptions of load carriage (e.g. Lloyd *et al*, 2010a; Mackie and Legg, 2008) . Recent years have also seen an increase in studies that have employed analysis of Ground Reaction Forces (GRF) as a way of characterising load carriage (e.g. Birrell and Haslam, 2010; Singh and Koh, 2009). This approach to the study of load carriage is still, however, under-represented in the literature. This is despite the fact that such analyses have been sensitive enough to differentiate not only between different loads and speeds (Tilbury-Davis *et al*, 1999; Wiese-Bjornstal and Dufek,1991; Harman *et al*, 2000a,b) but also between different load carriage systems and load placements. Lloyd and Cooke (2000), Kinoshita (1985), and Kinoshita and Bates (1981) have all reported differences in kinetic responses associated with double pack systems as compared to backpacks. Birrell and Haslam (2010), and Birrell *et al* (2007) demonstrated differences between military load carriage systems with and without webbing belts whilst both LaFiandra *et al* (2003) and Harman *et al* (1999) reported kinetic differences associated with essentially similar backpack designs.

The carrying of relatively heavy loads remains a necessity for a number of different groups, particularly schoolchildren, hikers and the military and this is reflected in the load carriage literature with a number of studies examining kinetic variables concentrating on schoolchildren (Singh and Koh, 2009; Chow *et* al, 2005; Hong and Li, 2005), the military (e.g. Birrell and Haslam, 2010; Birrell and Haslam, 2008; Birrell *et al*, 2007; Polcyn *et al*, 2002) and recreational hikers (Lloyd and Cooke, 2000; Wiese-Bjornstal and Dufek,1991; Kinoshita, 1985; and Kinoshita and Bates, 1981). There is, however, one extremely large group for whom the carrying of heavy loads is a daily necessity and who are significantly under represented in the literature, rural dwellers in the developing world. For a variety of reasons, historical, political, social and economic, these rural dwellers typically use traditional means for carrying heavy loads such as water and wood. In Africa this work falls mainly to the women and the dominant form of load carriage is head-loading, either directly on the head or via a forehead strap with the load resting on the back. The issue of head load carriage has received little attention in the literature, mainly concentrating on the metabolic cost of the activity. Such data as does exist is somewhat contradictory and confounded by very small sample sizes. On the one hand Maloiy *et al* (1986), Charteris *et al* (1989a,b), and Nag and Sen (1978) have all presented data, based on samples of 4-6 participants, suggesting that head-loading is an extremely efficient method of load carriage whilst on the other hand Datta and Ramanathan (1971) and Das and Saha (1966) have argued, based on samples of 6 and 7 participants, that it is less efficient than back-loading. In the case of Maloiy *et al* (1986) the findings are further confounded by the use of two different methods of head-loading, with two women using the direct method and three women using the indirect, strap method. Malville *et al.* (2001) and Minetti *et al.* (2006) reached contrasting conclusions in relation to the economy of the method based on a consideration of load carriage by Nepalese porters, who use the head strap method. More recently Lloyd *et al* (2010b,c) have suggested that there is no particular advantage for head-loading in terms of physiological response and load carriage economy. Moreover, it has been suggested that head-loading may be inferior to back-loading in respect of pain and discomfort (Lloyd *et al*, 2010a). The purpose of this study was therefore threefold: to provide a comprehensive evaluation of the kinetic responses to load carriage; a comparison of the kinetic responses to typical load carriage tasks, using both head and back-loading; and a comparison of the kinetic responses of experienced and novice head load carriers in a representative group of African women. The primary experimental hypothesis tested in this study is that there will be differences in the kinetics of head and back load carriage in African women. A secondary hypothesis is that there will be kinetic differences between experienced and novice head load carriers, which reflect differences in learning and habituation to head load carriage. Consideration of the kinetics of head and back load carriage in African women is important from a health and safety perspective given such load carriage is a daily necessity and that both forms of load carriage have recently been associated with different patterns of pain and discomfort (Lloyd *et al*, 2010a).

2. Methods

2.1 Participants

The sample for the study was drawn from the Xhosa people who are indigenous to the Eastern Cape region of South Africa. 17.6% of the South African population speak isiXhosa as a first language (South African Census, 2001). Sixteen Xhosa women, eight with at least ten years experience of head load carriage (EXP) and eight with no experience of head load carriage (NOEXP) were recruited to take part in the study. Load carriage experience was determined via questionnaire designed to elicit load carriage history and a subsequent interview to check the accuracy of responses. Mean age, stature and mass of participants were 21.3±2.2 years, 1.57±0.05m and 62.7±9.6 kg respectively. Independent t-Tests indicated no significant differences between the two groups for any of these. Participants were recruited from amongst the student body at Cape Peninsula University of Technology and from the township of Khayelitsha on the outskirts of Cape Town. All participants gave informed consent for their participation in the study which had received ethical approval through standard institutional review procedures at both the University of Abertay Dundee and Cape Peninsula University of Technology.

2.2 Experimental setup

The data collection area was arranged as shown in figure 1. The force plate (Kistler Type 9287CA, Kistler Instrumente, Winterthur, Switzerland) was covered in the same material as the runway and was effectively hidden from view. Small tape markers were placed on the runway to allow the operator to assess the validity of foot contacts during the experimental trials. The area containing the runway was a total of 15m in length and 4m in width and covered in rubberised matting.

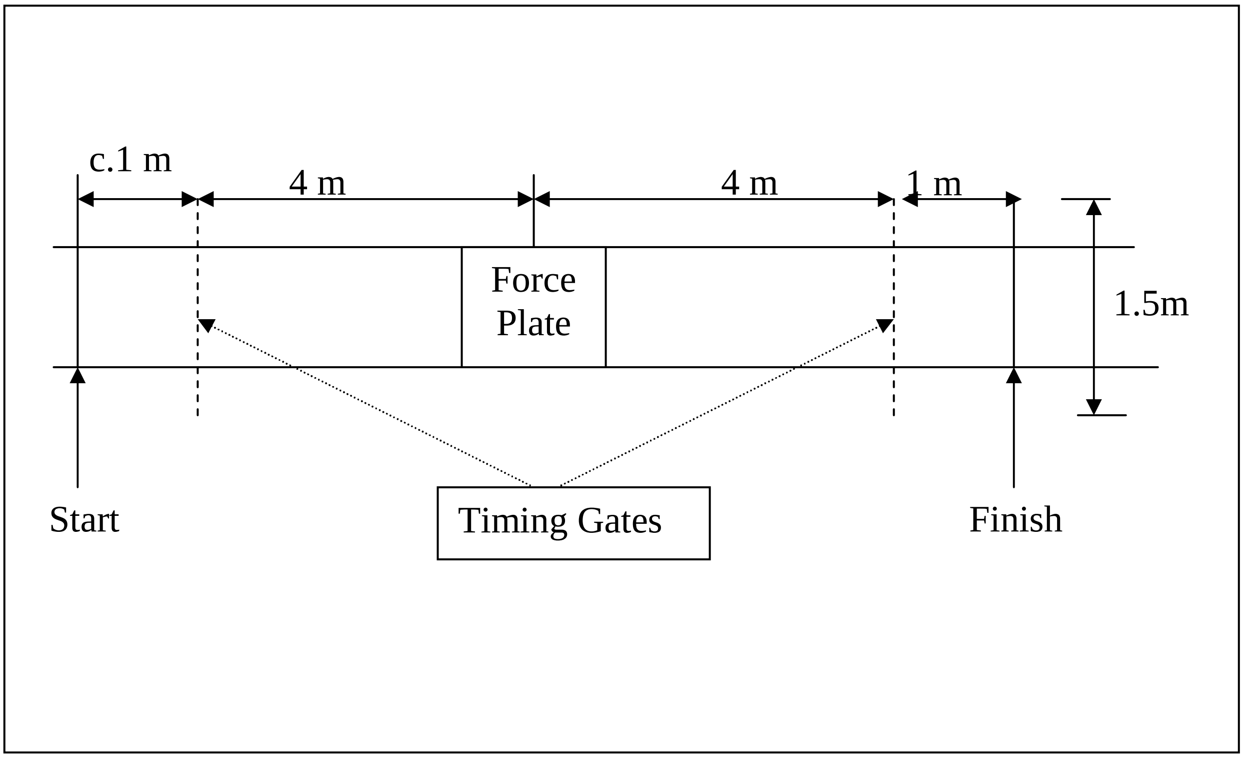


Figure 1. Experimental set up

2.3 Experimental procedures

All the women came to the Human Performance Laboratory at Cape Peninsula University of Technology on two separate occasions. On the first occasion participants were screened for any potential contraindications to exercise, stature and mass were assessed, and questionnaires were completed relating to load carriage history. The women were then habituated to the experimental protocol. A typical habituation session lasted thirty minutes and involved the women walking along the runway, between two sets of timing gates, at a speed of 3 $km \cdot h^{-1}$ (figure 1). The speed was chosen based on previous studies of head-loading (Maloiy *et al.* 1986, Charteris *et al.* 1989a) and was similar to self selected walking speeds in recent studies involving a similar sample (Lloyd *et al*, 2010a,b,c). In addition the women tried out the two load carrying devices, a standard 45 litre backpack with hip belt (Karrimor, SA) for back-loading and a plastic bucket for head-loading (the bucket placed either directly on the head or on a small piece of rolled cloth to provide some cushioning), with and without loads.

On arrival at the laboratory at the next visit each participant chose at random, via the picking of a suitably marked piece of paper from a hat, the loading method that would be employed first for each of the experimental loads. They then stood on the force plate whilst body mass was assessed. Once this was completed the participant took up a position one metre before the first pair of timing gates and walked, unloaded, a total of 10m to the finish point. Participants were instructed to look straight ahead whilst walking and to maintain a natural gait. For head-load trials participants used one hand to steady the load, in line with habitual practices. Participants performed all trials either barefoot or wearing light plimsolls. A trial was only deemed acceptable if three conditions were met: the participant's right foot must have landed wholly within the boundaries of the force plate; there must have been no alteration to normal walking gait; and the recorded time for the trial must have been within ±2.5% of the target time. If the first of these conditions was not met the starting point of the participant was adjusted accordingly before the next attempt. If the second or third conditions were not met the participant was given suitable advice and asked to repeat the trial. The participant continued to walk unloaded along the runway until three acceptable trials (e.g. Chow *et al*, 2005; Harman *et al*, 1999) had been achieved. The participant was then either fitted with a backpack, which was adjusted to ensure appropriate seating of the hip belt and shoulder straps, or given the plastic bucket to place on their head. The total load, loading device plus added load, was equal to 20kg, which is a typical load carried on the head, usually in the form of 20l of water. The participant then completed three successful trials, as described above, in this condition before repeating the process for the remaining loading method.

2.4 Data analysis

Verical (Fz), antero-posterior (Fy) and medio-lateral (Fx) force data was recorded at 1000Hz for each successful trial. The data was subsequently resampled at 500Hz via Bioware software (v4.0, Kistler Instrumente, Winterthur, Switzerland) and normalised in respect of contact time before being exported to Excel spreadsheets (Microsoft, Redmond, WAS, USA). Key variables were identified as follows (see also figures 2-4):

Fz1	Maximum Vertical Impact force

Fz2	Minimum Vertical force
Fz3	Maximum Vertical Thrust force
Tz1	Time to Fz1 (% contact time)
Tz2	Time to Fz2 (% contact time)
Tz3	Time to Fz3 (% contact time)
Iz	Vertical impulse
Fy1	Peak Braking force
Fy3	Peak Propulsive force
Ty1	Time to Fy1 (% contact time)
Ty2	Time to zero anterior-posterior force (% contact time)
Ty3	Time to Fy3 (% contact time)
Iy1	Braking Impulse
Iy2	Propulsive Impulse
IyT	Total magnitude of │Iy1 │+ │Iy2│
IyN	Net antero-posterior impulse
Fx1	1st Lateral Peak
Fx3	1st Medial Peak
Fx4	2nd Medial Peak
Fx6	2nd Lateral Peak
Tx1	Time to Fx1
Tx2	Time to 1st medio-lateral zero force
Tx3	Time to Fx3
Tx4	Time to Fx4
Tz5	Time to 2nd medio-lateral zero force
Tx6	Time to Fx6
Ix1	1st Lateral Impulse
Ix2	Medial Impulse
Ix3	2nd lateral Impulse
IxT	Total magnitude of │Ix1 │+ │Ix2│ + │Ix3│
IxN	Net medio-loateral impulse
CT	Contact Time

Impulses were calculated as area under the force-time curves which was calculated using the trapezium rule. Calculation was based on the absolute contact times with increments of 2ms on the x-axis. All force data was then normalised to both body mass (N$\cdot$kg^{-1}body mass) and total mass (N$\cdot$kg^{-1}total mass) i.e. body mass plus external load (e.g. Birrell and Haslam, 2010). Contact time was recorded in seconds and all other temporal parameters were expressed as percentage of contact time. Coefficient of Variation (CV) was calculated for each individual for all measured parameters in the unloaded and 20kg conditions.

Mean values of the force and impulse variables (normalised to both body mass and total mass) as well as associated temporal variables and coefficients of variation in each of the three force directions were analysed via separate MANOVA’s (condition x load x variable) with repeated measures (SPSS, v17.0), whilst absolute contact times and recorded walking speed were analysed via ANOVA (condition x load) with repeated measures. In all cases significant main effects were followed up via paired comparisons with Bonferroni adjustment whilst significant interactions were explored via 95% Confidence Intervals of cell means. Degrees of freedom, F values and P values for the force variables where as indicated in table 1.

Table 1. Degrees of freedom (hypothesis/error), F value and P value for multivariate tests on force variables (C= loading condition, FV = force variable, G = Group, * indicates interaction)

Direction		C	FV	G	C*FV	C*G	FV*G	C*FV*G
Vertical	df	2/13	2/13	1/14	4/11	2/13	2/13	4/11
	F	127.38	163.42	1.26	5.35	0.63	1.62	1.43
	P	**<0.0005**	**<0.0005**	0.281	**0.012**	0.547	0.236	0.289
Antero-posterior	df	2/13	1/14	1/14	2/13	2/13	1/14	2/13
	F	6.41	3.65	0.55	0.95	0.85	0.76	0.30
	P	**0.012**	0.077	0.470	0.414	0.449	0.398	0.749
Medio-lateral	df	2/13	3/12	1/14	6/9	2/13	3/12	6/9
	F	8.91	41.49	0.10	2.12	3.18	0.06	0.79
	P	**0.004**	**<0.0005**	0.755	0.150	0.075	0.981	0.601

Independent t-Tests were used to assess differences in physical characteristics and between the two groups. Representative force-time graphs (figures 2-4) were recreated for each load and condition by interpolation based on the mean maxima and minima for each force variable and their associated temporal characteristics (Lloyd and Cooke, 2000; Hsiang and Chang, 2002; Parvataneni, 2009).

3. Results

3.1 Group effects

Statistical analysis revealed that of the fifty force and time variables, and the thirty eight possible main effects and interactions for the coefficients of variation, that included the between subjects factor of group (experienced and inexperienced head load carriers), none were significant. For example the magnitudes of forces ($N\cdot kg^{-1}$body mass) in the vertical direction for back loading were: Fz1 13.4±0.8 vs 13.6±1.0; Fz2 11.5±0.6 vs 11.7±0.6; Fz3 14.2±0.9 vs 14.3±1.2 for the experienced and inexperienced head-loaders respectively whilst for the head-loading condition the values were: Fz1 13.3±0.7 vs 13.4±0.9; Fz2 11.6±0.6 vs 11.7±0.6; Fz3 14.0±0.9 vs 14.0±1.2. As shown by these typical examples comparing values for the experienced and inexperienced head load carriers, the consistency in response of the two groups to the experimental conditions was quite remarkable. Consequently all subsequent graphs and tables present data for the whole group (n=16).

3.2 Absolute contact time

Mean ± SD absolute contact times for each condition are shown in table 2. There was a significant main effect for loading condition (P=0.027). Paired comparison revealed that only the contact time for back-loading was significantly longer than that for the unloaded condition (mean difference 0.031s, P=0.02).

Considering the variability between loading conditions, the CV’s were not significantly different (P=0.198) between the unloaded condition (2.27 ± 2.27%) and either head-loading (2.02 ± 1.28%) or back-loading (1.86 ± 1.23%) with a 20kg load.

3.3 Vertical Variables

Table 2. Summary of mean ± SD values for force variables ($N\cdot kg^{-1}$body mass), Contact Times (seconds), Temporal variables (% contact time) and Impulse ($N\cdot kg^{-1}$body mass$\cdot$s) in the vertical direction.

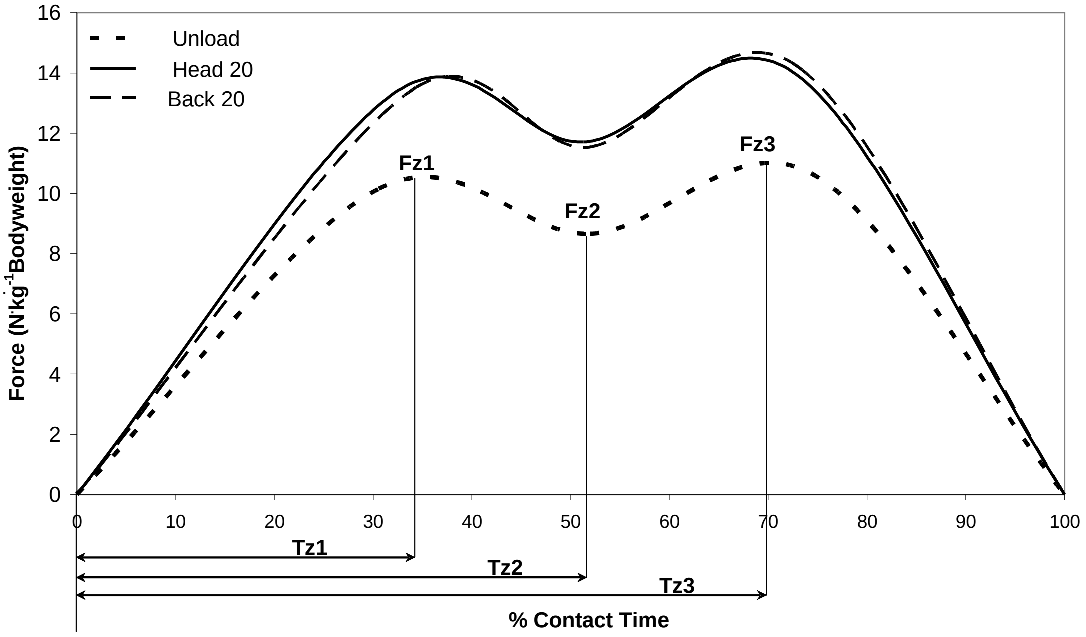
	Unloaded	Back	Head
FORCE			
Fz1	10.16 ± 0.38	13.44 ± 0.94	13.33 ± 0.78

Fz2	8.66 ± 0.26	11.53 ± 0.59	11.70 ± 0.57
Fz3	10.66 ± 0.43	14.20 ± 1.08	13.97 ± 1.05
TIME			
CT	0.85 ± 0.06	0.87 ± 0.03	0.88 ± 0.04
Tz1	30.58 ± 1.86	32.16 ± 3.29	33.99 ± 3.96
Tz2	51.98 ± 3.31	51.29 ± 4.64	51.55 ± 3.19
Tz3	74.39 ± 1.75	72.78 ± 2.41	73.07 ± 2.25
IMPULSE			
Iz	6.32 ± 0.69	8.77 ± 0.54	8.86 ± 0.57

3.3.1 Force variables

Figure 2 provides a representation of the vertical force-time curve for each condition based on mean values for the various force maxima and minima and associated temporal characteristics (Table 2). Considering force data normalised to body mass there was a significant main effect for loading condition ($P<0.0005$) with the overall force associated with the unloaded condition being significantly lower than both of the loaded conditions (mean differences 3.233 and 3.178 N.kg^{-1}body mass for back- and head-loading respectively. This difference was removed after data were normalised against total mass ($P=0.377$). Regardless of normalisation method there was a significant difference between the three force variables ($P<0.0005$) with Fz2 being significantly smaller than either Fz1 or Fz3 and Fz3 being significantly greater than Fz1. There was also a significant interaction between loading condition and force event ($P=0.012$). Fz2 was lower for the back condition than the head condition (11.53 vs 11.70 N.kg^{-1}body mass) whilst Fz3 was greater for the back-loading than for head-loading (14.20 vs 13.97 N.kg^{-1}body mass)

Figure 2. Representative vertical force-time curve in each condition



There was no significant difference in CV between the three force variables (Fz1 = 1.95 ± 1.31%, Fz2 = 1.99 ± 1.24%, Fz3 = 1.53 ± 1.16%, P=0.507), nor between the three conditions (Unloaded = 2.01 ± 1.6%, Back = 1.73 ± 0.81%, Head = 1.73 ± 0.79%, P= 0.783).

3.3.2 Temporal Variables

There was a significant interaction between loading condition and temporal variable (P<0.0005). Fz2 was consistent across all three conditions, Fz1 occurred later in the loaded conditions than in the unloaded condition whilst Fz3 was earlier (Table 2).

There was a trend for significant difference (P = 0.057) in CV between the three time variables with the CV associated with Tz3 (1.94 ± 1.16%), being smaller than the other two variables (Tz1 = 5.07 ± 4.35%, Tz2 = 4.64 ± 5.13%). There was no significant difference between the three conditions (Unloaded = 3.81 ± 2.52%, Back = 3.81 ± 2.94%, Head = 4.00 ± 3.12%, P= 0.524).

3.3.3 Impulse

When data was normalised against body mass there was a significant main effect for loading condition (P<0.0005) with the unloaded condition being associated with a smaller impulse than either of the loading conditions which were not different (P=1.00). This difference was removed by expressing impulse relative to total mass (P=0.195). Coefficient of variation was not significantly different between the three conditions (Unloaded = 2.66 ± 2.61%, Back = 2.00 ± 1.32%, Head = 2.02 ± 1.21%, P= 0.365)

3.4 Anterior – Posterior Variables

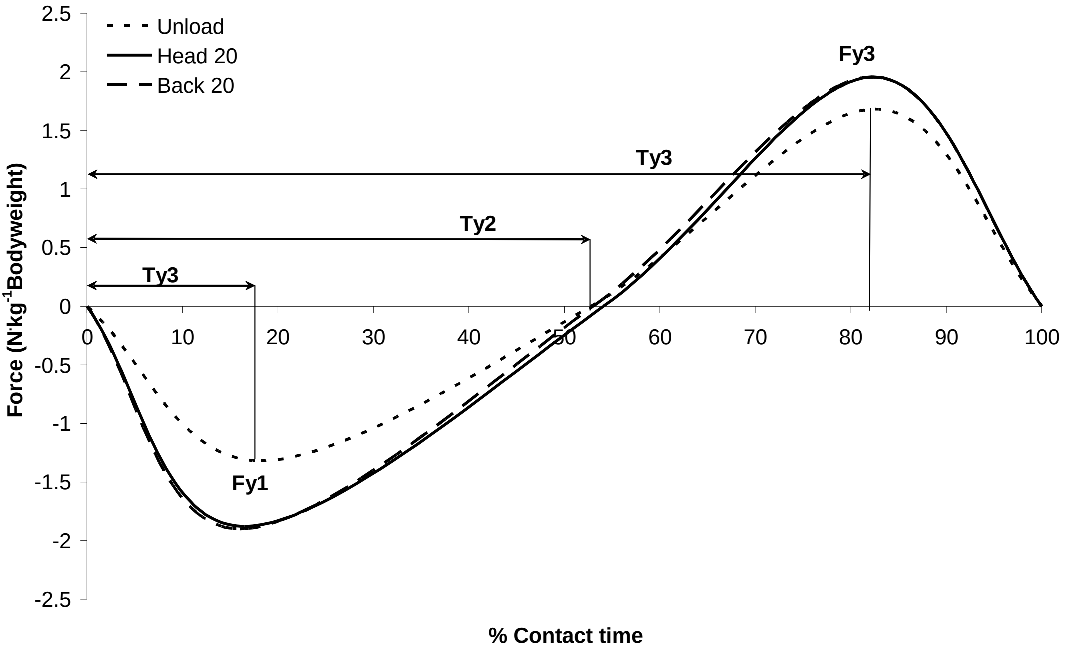
3.4.1 Force variables

Table 3. Summary of mean ± SD values for force variables (N·kg^{-1}body mass), Temporal variables (% contact time) and Impulse (N·kg^{-1}body mass·s) in the antero-posterior direction.

	Unloaded	Back	Head
FORCE			
Fy1	-1.3 ± 0.15	-1.89 ± 0.30	-1.88 ± 0.36
Fy3	1.68 ± 0.88	1.96 ± 0.46	1.95 ± 0.31
TIME			
Ty1	18.17 ± 1.28	16.50 ± 0.53	16.04 ± 1.94
Ty2	52.77 ± 4.18	54.06 ± 2.67	52.99 ± 3.16
Ty3	82.53 ± 2.34	82.36 ± 2.67	82.21 ± 2.40
IMPULSE			
Iy1	-0.30 ± 0.05	-0.44 ± 0.06	-0.45 ± 0.07
Iy2	0.27 ± 0.05	0.38 ± 0.05	0.39 ± 0.08
IyN	-0.03 ± 0.05	-0.07± 0.05	-0.06 ± 0.09

Figure 3 provides a representation of the antero-posterior force-time curve for each condition based on mean values for various force maxima and minima and associated temporal characteristics (Table 3). Overall, when considering forces normalised to body mass there was a significant main effect for loading condition (P=0.012) with the unloaded condition being significantly lower than both the head-load condition (mean difference 0.414 N.kg^{-1}body mass, P=0.007) and the back-load condition (mean difference 0.426.kg^{-1}body mass, P=0.008). When forces were normalised against total mass this effect was removed (P=0.687). There was a tendency for Fy1 to be lower than Fy3 (P=0.077) and this was consistent across loading conditions (Force event x loading condition interaction, P=0.383)

Figure 3. Representative anterior-posterior force-time curve in each condition



There was no significant difference in CV between the two force variables (Fy1 = 8.19 ± 3.36%, Fy3 = 10.23 ± 5.27%, P=0.196), nor between the three conditions (Unloaded = 9.21 ± 5.37%, Back = 9.19 ± 4.56%, Head = 9.28 ± 3.83%, P= 0.935).

3.4.2 Temporal variables

There was a tendency for Fy1 to occur earlier in both of the loaded conditions compared to the unloaded condition (P=0.065) whilst Fy2 occurred slightly later in the back-loading condition than either the unloaded or head-load conditions (P=0.100)

The CV was significantly smaller (P=0.005) for Ty3 (1.98 ± 1.13%), than the other time variables (Ty1 = 9.44 ± 8.06%, Ty2 = 5.88 ± 4.01%). There was no significant difference between the three conditions (Unloaded = 6.64 ± 4.56%, Back = 5.41 ± 3.87%, Head = 5.24 ± 3.52%, P= 0.231).

3.4.3 Impulses

When normalised against body mass there was a significant difference in net impulse (P=0.019) with the magnitude of the impulse associated with the head-loading condition being significantly greater than the unloaded condition. This difference was removed when impulse was normalised against total mass (P=0.179). Total impulse was significantly lower in the unloaded condition as compared to either head-loading or back-loading (P<0.0005). This difference disappeared when data was normalised against total mass. Considering the magnitude of the two constituent impulses, Iy1 was significantly greater than Iy2 (P=0.002). There was also an interaction between loading condition and magnitude of impulses (P=0.020) with the absolute difference between the two impulses being less in the unloaded condition than either of the loaded conditions (relative difference 13.7%, 14.8% and 8.9% for back-loading, head-loading and unloaded conditions respectively).

There was no significant difference in the CV for the magnitude of the two impulses (Iy1 = 8.91 ± 3.97%, Iy2 = 8.74 ± 4.13%, P = 0.914) nor between the conditions (Unloaded = 10.93 ± 6.67%, Back = 7.72 ± 2.93%, Head = 7.83 ± 2.58%, P = 0.316

3.5 Mediolateral Variables

Table 4. Summary of mean ± SD values for force variables (N·kg^{-1}body mass), Temporal variables (% contact time) and Impulse (N·kg^{-1}body mass·s) in the mediolateral direction.

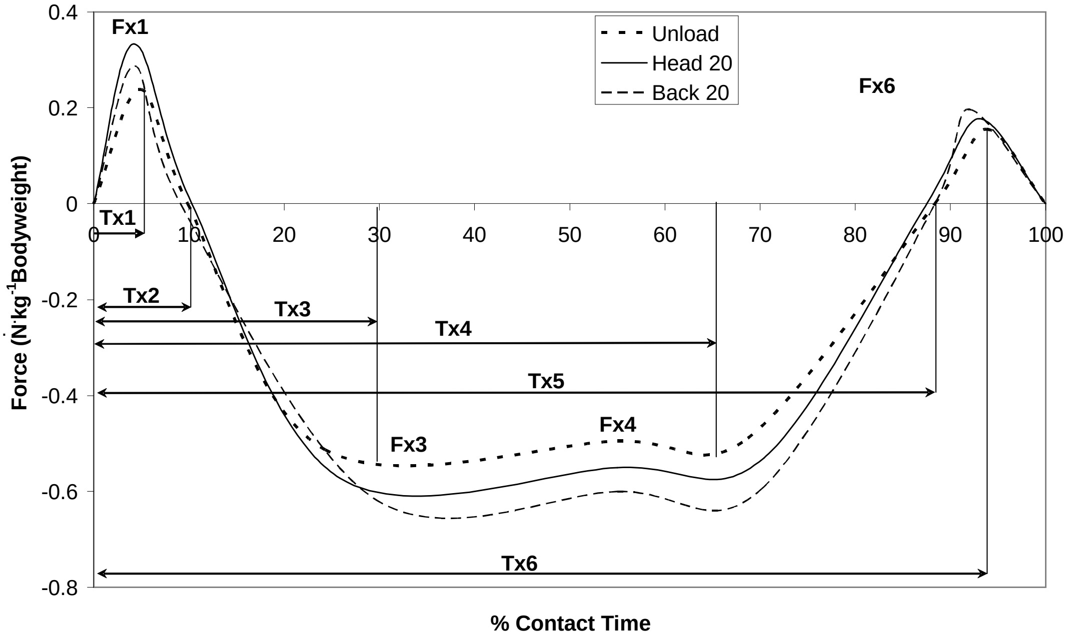
	Unloaded	Back	Head
FORCE			
Fx1	0.24 ± 0.10	0.29 ± 0.13	0.33 ± 0.14
Fx3	-0.51 ± 0.13	-0.61 ± 0.13	-0.57 ± 0.14
Fx4	-0.49 ± 0.23	-0.59 ± 0.22	-0.53 ± 0.17
Fx6	0.16 ± 0.08	0.20 ± 0.13	0.18 ± 0.08
TIME			
Tx1	4.86 ± 1.94	4.23 ± 1.50	4.29 ± 1.38
Tx2	9.87 ± 1.72	10.31 ± 1.74	9.10 ± 2.39
Tx3	24.29 ± 2.95	25.88 ± 2.07	29.42 ± 1.73
Tx4	68.72 ± 1.91	70.41 ± 4.31	70.18 ± 1.31
Tx5	88.38 ± 2.59	87.53 ± 5.12	88.41 ± 1.70
Tx6	93.75 ± 1.54	93.00 ± 2.62	92.85 ± 2.27
IMPULSE			
Ix1	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.01
Ix2	-0.25 ± 0.11	-0.26 ± 0.09	-0.32 ± 0.10
Ix3	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01

IxN	-0.22 ± 0.12	-0.23 ± 0.10	-0.29 ± 0.11

3.5.1 Force Variables

Figure 4 provides a representation of the medio-lateral force-time curve for each load in each condition based on mean values for various force maxima and minima and associated temporal characteristics (Table 4). Across all force variables normalised against body mass there was a significant main effect of loading condition (P=0.004) with the back loading condition being significantly greater than the unloaded condition (P=0.002) whilst there was a tendency for head-loading also to be associated with greater forces than the unloaded condition (P=0.058). Normalising the data against total mass removes this significant difference. There were significant differences in the magnitude of the individual force variables with Fx6 being significantly lower than all other variables, Fx1 being less than both Fx3 and Fx4, whilst Fx3 and Fx4 were not significantly different (P=1.00). These differences remained regardless of normalisation method and were consistent across loading conditions (P=0.562).

Figure 4. Representative mediolateral force-time curve in each condition



Considering the coefficients of variation there was a trend (P=0.097) for greater variability to be associated with Fx6 (46.74 ± 27.35%), than the other three force variables (Fx1 = 21.76 ± 20.32%, Fx3 = 17.49 ± 20.10%, Fx4 = 16.98 ± 17.31%). There was no significant difference between the three conditions (Unloaded = 24.06 ± 11.13%, Back = 25.18 ± 14.16%, Head = 27.99 ± 17.32%, P= 0.495).

3.5.2 Temporal variables

There were no significant main effects for any of the temporal variables. The interaction between loading condition and temporal variables did, however, exhibit a tendency for difference (P=0.064). This was associated with Fx3 being delayed in the back-loading condition (29.4%) compared to both the unloaded (24.3%) and the head-loading (25.9%) conditions.

The CV was significantly greater (P=0.028) for Tx1 (33.40 ± 39.73%), than the other time variables (Tx2 = 14.45 ± 14.52%, Tx3 = 8.66 ± 13.79%, Tx4 = 3.64 ± 4.03%, Tx5 = 2.56 ± 2.96%, Tx6 = 0.91 ± 0.96%). There was no significant difference between the three conditions (Unloaded = 9.98 ± 11.35%, Back = 11.27 ± 10.69%, Head = 10.57 ± 10.24%, P= 0.679).

3.5.3 Impulses

The magnitude of the net mediolateral impulse was significantly greater for the head-loading condition than the unloaded condition (P=0.018) and there was a tendency for head-loading to be also associated with greater impulse than back-loading (P=0.078). When normalised against total mass the significant difference between head-loading and unloaded conditions was removed whereas the tendency for difference between the two loaded conditions remained (P=0.079). Considering the magnitude of the constituent impulses, Ix3 was significantly lower than both Ix1 (P=0.046) and Ix2 (P<0.0005) whilst Ix1 was significantly smaller than Ix2 (P<0.0005). This difference was consistent across loading conditions (P=0.145).

When considering the three constituent impulses the CV was significantly greater (P=0.022) for Ix3 (65.82 ± 44.12%), than the other impulse variables (Ix1 = 31.64 ± 20.36%, Ix2 =

23.64 ± 28.03%). There was no significant difference between the three conditions (Unloaded = 35.42 ± 35.24%, Back = 43.73 ± 23.12%, Head = 41.96 ± 30.97%, P= 0.734).

4. Discussion

4.1 Group comparisons

The lack of any significant group interaction between experienced and novice head load carriers for any variable was unexpected. Early studies into head-loading (e.g. Maloiy *et al*, 1986) have suggested that it is only long term habituation to head-loading, and potentially even structural alterations to the skeleton, that make efficient head-loading possible. Although recent data suggests that the latter is unlikely (Lloyd *et al,* 2010d) it would have still been anticipated that the difference in head-loading experience between the two groups would have been evident in at least some of the variables measured. In particular, it would have been expected that stability would have been compromised provoking changes in mediolateral response and variability (Birrell *et al,* 2007). Since the only difference between the groups was in head-loading experience (all the women had back-loading experience as this is the traditional method for carrying small children) we conclude that head-loading, at least in the controlled conditions of this laboratory based experiment, requires minimal habituation.

4.2 Contact Times

The significantly longer stance time for the back-loading condition than the unloaded condition is consistent with previous studies which have shown increasing load to be associated with longer contact times (Kinoshita and Bates, 1981; Kram *et al,* 1987; Birrell *et al*, 2007). On the basis of these findings for back loading it may have been expected that there would also be a significant difference between the head-loading condition and the unloaded condition. Previous studies have demonstrated that double pack systems are associated with shorter contact times than back packs (Birrell and Haslam, 2010; Lloyd and Cooke, 2000, Kinoshita, 1985). This difference has been attributed to the more upright posture associated with this loading method which acts to reduce the time taken for the CoM to pass over the base of support (Lloyd and Cooke, 2000; Kinoshita, 1985). It seems likely that head-loading requires a posture at least as upright as that associated with a double pack and consequently this may explain the difference between the effects of back and head loading observed here. It has also been suggested that greater stability is provided by an even loading of the body and that more stable conditions reduce contact time (Schiffman, 2006). Given the lack of group differences it may be that this explanation contributes to differences in contact times reported here.

4.3 Vertical GRF

Overall the magnitude of the vertical ground reaction forces, normalised for total mass, were consistent with previous studies. Birrell *et al* (2007) suggested that each kg of load provoked an increase of approximately 10N and Polcyn *et al* (2002), based on pooled data from a number of studies, suggested that adding a load of 1N provoked a 1N increase in peak impact (Fz1) and maximum thrust (Fz3) forces. The normalised data, (N·kg^{-1}totalmass) for these variables in the present study were 10.16 ± 0.38 and 10.66 ± 0.43 for the unloaded condition, 10.01 ± 0.25 and 10.48 ± 0.43 for back-loading and 10.10 ± 0.35 and 10.67 ± 0.43 for head-loading. Similarly the data for net impulse suggests that it is load, rather than condition that makes a difference, with the significant increase above unloaded for both back- and head-loading being removed when normalised against total mass.

The finding that Fz3 was greater than Fz1 in all conditions was consistent with the majority of previous studies that have reported these variables (Hong and Li, 2005; Lloyd and Cooke, 2000; Harman *et al*, 2000a, Tilbury-Davis and Hooper, 1999) but in contrast to Kinoshita (1985) and Kinoshita and Bates (1981), although the latter study only used 5 participants. Harman *et al* (2000a) suggested that the differences observed between their study and that of Kinoshita (1985) were a consequence of cultural difference and consequently differences in gait. There is no data available to verify this suggestion for the sample in the present study. The difference observed here may be a consequence of the differences in timing of the two maxima. The impact peak occurred significantly later in the two loaded conditions than in the unloaded condition, whilst the thrust maximum occurred significantly earlier. This is consistent with the findings of Singh and Koh (2009), although their findings are difficult to interpret in this respect as walking speed decreased as loads increased. Harman *et al* (2000b) also reported that Fz1 was achieved later as speed of progression decreased. It has been argued previously that a delay in peak forces is a mechanism to reduce the magnitude of those forces (Tilbury–Davis and Hooper, 1999) and that a reduction in impact forces is a desirable adaptation to gait patterns as it is likely to reduce injury risk and fatigue (Harman *et al*, 1999).

The significant interaction between loading condition and vertical force events is not entirely consistent with data reported in previous studies. In the present study the force minimum was lower for the back-loading than the head-loading whilst the thrust maximum was greater for the back condition than the head condition. Considering force minimum, Kinoshita (1985) suggested that the more vertical application of force associated with an upright posture would explain the greater magnitude of vertical forces associated with a double pack system as compared to a backpack. If this were the case it might have been expected that this trend would have been evident throughout ground contact, although it may be that the effect would be most noticeable at force minimum. This is supported by Birrell and Haslam (2008) who suggest that force minimum occurs at the time when the CoM is at its highest and report that the carrying of a wooden rifle in front of the body, which would further raise the CoM, resulted in a greater force minimum than when a load was carried close to the body. Head-loading will raise the CoM of the system as compared to back-loading, for two reasons, namely the position of the load itself and also the use of an arm to support the load. It is of course possible that the difference between the two conditions may be associated with a reduced force minimum in the back-load condition. Harman *et al* (2001) reported a reduced force minimum for back-packing and ascribed this to a more posterior location of the CoM. The greater force minimum for head-loading observed in this study is likely to be explained by a combination of these factors.

There appears to be less consistency in the literature in relation to differences in thrust maximum. Birrell and Haslam (2010) report a lower thrust maximum for back-loading as opposed to two other conditions that involved some element of spreading the load around the trunk, a finding that echoed Hsiang and Chang (2002). Kinoshita (1985) and Kinoshita and Bates (1981) showed no difference between back-pack and double pack-conditions, whilst Birrell *et al* (2007) show no difference between a back-pack and a combination of back-pack and webbing and LaFiandra *et al* (2003) showed no difference in thrust maximum for three different backpack designs. The present study is the first to show a greater thrust maximum for back-loading as opposed to a more upright loading condition. In contrast to the findings presented here, Kinoshita (1985) argued that a more posterior placement of the load increases forward lean, which aids in the advancement of the body and increases passive momentum, increasing the force minimum but reducing the thrust maximum (Kinoshita,1985). Alternatively, Birrell and Haslam (2010) suggest that the increased force minimum and reduced force maximum when back-loading are a consequence of increased stride length which would increase active momentum early in the gait cycle. It is likely that the pattern of response found here is specific to head-loading and that previous comparisons between back-loading and back/trunk loading are not appropriate to this form of load carriage. There has previously been a suggestion that trunk range of motion through the gait cycle will influence momentum and, consequently, force application (Lloyd and Cooke, 2000). It was reported that a double pack system was associated with greater range of trunk motion than a back pack and that this might be attributed to the forced forward lean associated with back-loading restricting trunk movement. In contrast, for head-loading the requirements of balance may serve to restrict the trunk range of motion and thus inhibit the development of forward momentum to a greater degree than is the case for back loading. Further research is warranted to examine the contribution of changes in trunk angle to momentum during loaded walking and in particular the contribution of 'freedom of movement'.

4.4 Antero-posterior GRF

The tendency for peak braking force to be lower than the peak propulsive force is consistent both with previous findings (Harman *et al*, 2000a, Polcyn *et al*, 2002) and with the pattern of response in the vertical direction for the present study. As previously argued this is likely to be a protective mechanism whereby the tendency for a delayed, and reduced, peak braking force and an earlier, but greater, peak propulsive force for the loaded conditions serves to reduce potentially harmful impact peaks (Kram, 1997; Harman *et al*, 1999).

Considering previous comparative studies, some have reported no difference in magnitude of antero-posterior forces between loading conditions (Birrell *et al*, 2007; LaFiandra *et al* 2003; Harman *et al*, 1999a,b) although these have tended to be in cases where load carriage system design differed subtly between conditions. Most previous studies that have compared substantively different load carriage methods have reported differences in antero-posterior force application. Kinoshita (1985) reported a greater braking force for back-loading as opposed to a double pack when carrying 40% BM and Birrell and Haslam (2010) reported a marked difference (c10%) between a back pack and two other methods which loaded both the trunk and the back. In contrast, Lloyd and Cooke (2000) found no difference in braking forces but instead reported that a reduced propulsive force was associated with a double pack system compared to a backpack. In light of this, and the distinct difference between loading conditions employed, the lack of difference in the magnitude of antero-posterior force peaks in the present study is somewhat surprising. Birrell and Haslam (2008) found that loading conditions that restricted arm movements (e.g. rifle carriage) were associated with elevated peaks for both braking and propulsive forces compared to loading conditions that allowed free arm swings. They suggested that this may be a consequence of a reduced contribution of the arms to forward drive. It may be that the potential advantages for a more upright posture, as previously identified with double pack systems, do not apply to head-loading. So the reduction in braking force associated with more upright postures (Kinoshita, 1985; Birrell and Haslam, 2010) is neutralised by the fixing of an arm to support the head load whilst the potential reduction in propulsive force, associated with the greater range of trunk motion for upright postures (Lloyd and Cooke, 2000), may be neutralised by the requirements to balance the load and restrict trunk angular motion. Of course, given the very limited number of comparative studies that have considered antero-posterior forces, it may also be that the previous findings of difference between load carriage systems may simply be capricious and more research is warranted.

The finding that the braking impulse was greater than the propulsive impulse in all three conditions was somewhat unexpected. It might be concluded that participants were slowing down when they made contact with the force plate. The net impulse, was, however, very small in all conditions (95% CI's: 0.02-0.06, 0.04-0.11 and 0.05-0.09 ($N \cdot kg^{-1}$body mass) for unloaded, back-loading and head-loading respectively) and thus unlikely to have had any significant effect on overall speed of progression, which was more tightly controlled in the present study than any of the previous studies. However, in the only reference to antero-posterior impulse in the load carriage literature, Harman *et al* (2000a,b) have reported that, in common with other GRF variables, antero-posterior impulses are less sensitive to changes in speed than load for load carriage tasks and in particular that they remain relatively unchanged for speeds of 4.2-5.4 km·h^{-1} (28% change in speed provoked, on average, 4% increase in propulsive impulse and 7% increase in braking impulse). In common with the result here, net impulse was not zero for any of the loads or speeds tested.

4.5 Mediolateral GRF

Mediolateral forces are rarely reported in the literature, despite the suggestion that increases in lateral forces may be associated with injury and increased mediolateral impulse may indicate a lack of stability and therefore a greater predisposition to fall (Birrell and Haslam, 2010). The available evidence does, however, suggest that mediolateral forces are more sensitive to speed than load (Harman *et al*, 2000a,b). In particular Polcyn *et al* (2002) concluded, based on an analysis of four separate studies, that lateral, but not medial, forces increased with load. The data here suggest that both lateral and medial forces may be load dependant as differences between loaded and unloaded conditions were removed when data was normalised to total mass. The same was true for total impulse, however a trend remained for head-loading to be associated with a greater net impulse than back-loading. It has been suggested that increases in mediolateral impulse may be associated with conditions requiring greater postural control and this may be exacerbated by the removal of the usual contribution to balance provided by the arms (Birrell and Haslam, 2008). However their data suggests mediolateral impulse only increased when a load was carried in front of the body, increasing the horizontal excursion of the CoM and consequently reducing stability, and not when the arms were fixed in front of the body carrying a dummy rifle i.e. lack of arm assistance is not a sufficient condition to provoke significant change in mediolateral impulse. It is, however, likely that the act of balancing a load on the head would, of itself, act to reduce stability and therefore contribute to increased mediolateral impulse as reported here.

4.6 Variability of response

Analysis of the coefficients of variation in all three force directions revealed no differences in variability between the unloaded condition and either head- or back-loading with a 20kg load. This is consistent with Hsiang and Chang (2002) who concluded that loads that do not significantly shift the CoM from its position during unloaded walking will have either a neutral or potentially positive effect on the variability of gait. Whilst this lack of difference may have been unexpected it does give greater confidence in the differences identified between back- and head-loading kinetics.

5.0 Conclusion

The most striking and original finding of the present study is the consistency in kinetic responses of the experienced and novice head load carriers which leads to the acceptance of the secondary null hypothesis and the conclusion that head loading, at least under controlled laboratory conditions, requires minimum habituation as far as kinetic responses are concerned.

Overall the responses of the vertical ground reaction forces and impulses to the two forms of loading were consistent and related to the magnitude of load rather than any differences between head and back load carriage. However, there are some noteworthy differences in responses to head-loading and back-loading, such as the shorter contact time, the smaller thrust maximum and the greater force minimum associated with head loading. These findings not only support the conclusion that there are some significant kinetic differences between head and back loading as compared directly in the present study, but also that the responses to head load carriage are not necessarily consistent with findings for other forms of load carriage that spread the load more evenly between the back and front of the trunk. There is therefore some evidence to reject the null hypothesis and support the primary experimental hypothesis, given that there were some significant differences in response to head and back load carriage. However, there was also considerable evidence of consistency in the kinetic responses to both forms of load carriage. Further research is required to substantiate the consistency of kinetic responses to head loading reported here and to explain the differences observed between this and other forms of load carriage. In particular the relationship between sagittal plane trunk motion and kinetic response requires more attention as this variable is emerging as a strong candidate in explaining differences in kinetic response to load carriage.

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References

Abe, D., Muraki, S. and Yasukouchi, A. (2008) Ergonomic effects of load carriage on energy cost of gradient walking. *Appl Ergon* **35:** 329-335

Attwell, R.L., Birrell, S.A., Hooper, R.H. and Mansfield, N.J. (2006) Influence of carrying heavy loads on soldiers' posture, movements and gait. *Ergonomics* **49**(14): 1527-1537

Bastien, G.J., Willems, P.A., Schepens, B. and Heglund, N.C. (2005) Effect of load and speed on the energetic cost of walking. *Eur J App Phys* **94:** 76-83

Birrell, S and Haslam, R. (2008). The influence of rifle carriage on the kinetics of human gait. *Ergonomics* **51:** 816-826

Birrell, S and Haslam, R. (2010). The effect of load distribution within military load carriage systems on the kinetics of human gait. *Appl Ergon* **41:** 585-590

Birrell, S, Hooper, R. and Haslam, R. (2007). The effect of military load carriage on ground reaction forces. *Gait Posture* **27:** 611-614

Charteris, J., Nottrodt, J.W. and Scott, P.A. (1989a) The 'free ride' hypothesis: a second look at the efficiency of African women headload carriers. *S Afr J Sci* **85:**68-71

Charteris, J., Scott, P.A. and Nottrodt, J.W. (1989b) Metabolic and kinematic responses of African women headload carriers under controlled conditions of load and speed. *Ergonomics* **32:**1539-1550

Chow, D., Kwok, M., Au-Yang, A., Holmes, A., Cheng, J., Yao, F. and Wong, M. (2005). The effect of backpack load on the gait of normal adolescent girls. *Ergonomics* **48:**642-656

Das, S.K. and Saha, H. (1966) Climbing efficiency with different modes of load carriage. *Ind J Med Res* **54:** 866-871

Datta, S.R. and Ramanathan, N.L. (1971) Ergonomic comparison of seven modes of carrying loads on the horizontal plane. *Ergonomics* **14**(2):269-278

Harman, E., Frykman, P., Pandorf, C., Tharion, W., Mello, R., Obusek, J. and Kirk, J. (1999) Physiological, biomechanical and maximal performance comparisons of soldiers carrying loads using U.S. marine corps Modular Lightweight Load-carrying Equipment (MOLLE), and U.S. army Modular Load System (MLS). U.S. Army Research Institute of Environmental Medicine, Natick, MA. T99-4

Harman, E., Han, K-H., Frykman, P. and Pandorf, C. (2000a) The effects of backpack weight on the biomechanics of load carriage. U.S. Army Research Institute of Environmental Medicine, Natick, MA. T00-17

Harman, E., Han, K-H., Frykman, P. and Pandorf, (2000b) The effects of walking speed on backpack load carriage. U.S. Army Research Institute of Environmental Medicine, Natick, MA. T00-20

Harman, E., Han, K-H. and Frykman, P. (2001) Load Speed interaction effects on the biomechanics of backpack load carriage. In: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, NATO Research and Technology Organisation , RTO meeting proceedings 56

Hong, Y. and Li, J. (2005) Influence of load carrying methods on gait phase and ground reactions in children's stair walking. *Gait Posture* **22:**63-68

Hsiang and Chang (2002). The effect of gait speed and load carrying on the reliability of ground reaction forces. *Safety Science* **40:**639-657

Kinoshita, H. (1985). Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. *Ergonomics.* **28**: 1347-1362.

Kinoshita, H and Bates, B. (1981). Effects of two load carrying systems on ground reaction forces during walking. In: Matsui, H and Kobayashi, K. (Eds) *Biomechanics VIII A&B: Proceedings of the 8th International Congress of Biomechanics,* Nagoya, Japan

Kram, R., McMahon, T. and Taylor, C. (1987) Load carriage with compliant poles – physiological and/or biomechanical advantages. *J.Biomech* **20:**893

LaFiandra, M., Lynch, S., Frykman, P., Harman, E., Ramos, H. and Mello, R. (2003). A comparison of two commercial off the shelf backpacks to the Modular Lightweight Load-carrying Equipment (MOLLE) in biomechanics, metabolic cost and performance. U.S. Army Research Institute of Environmental Medicine, Natick, MA. T03-15

Lloyd, R. and Cooke C.B. (2000) Kinetic changes associated with load carriage using two rucksack designs. *Ergonomics.* **43**(9) pp1331-1341

Lloyd, R., Parr, B., Davies, S. and Cooke, C (2010a), Subjective perceptions of load carriage on the head and back in Xhosa women, Applied Ergonomics **41:**522-529

Lloyd, R., Parr, B., Davies, S. and Cooke, C. (2010b). A comparison of the physiological consequences of head-loading and back-loading for African and European women. *Eur J App Phys* **109**(4): 607-616

Lloyd, R., Parr, B., Davies, S. and Cooke, C (2010c). No 'Free Ride' for African women: a comparison of head-loading versus back-loading amongst Xhosa women. *S. Afr. J. Sci.* **106 (3/4):** 50-54

Lloyd, R., Hind, K., Carroll, S., Truscott, J., Parr, B., Davies, S. and Cooke, C. (2010d). A preliminary investigation of load-carrying on the head and bone mineral density in premenopausal, black African women. Journal of Bone and Mineral Metabolism. **28**(2): 185-190

Mackie, H.W. and Legg, S.J, (2008) Postural and subjective responses to realistic schoolbag carriage. *Ergonomics* **51(2):** 217-231

Maloiy, G.M., Heglund, N.C., Prager, L.M., Cavagna, G.A. and Taylor, C.R. (1986) Energetic costs of carrying loads: have African women discovered an economic way? *Nature* **319** 668-669

Malville, N.J., Burns, W.C., LimHa and Basnyat, R. (2001) Commercial porters of Eastern Nepal: health status, physical work capacity and energy expenditure. *Am J Hum Biol* **13:** 44-56

Minetti, A.E., Formenti, F. and Ardigo, L.P. (2006) Himalayan porter's specialization: metabolic power, economy, efficiency and skill. *Proc Biol Soc* **273:** 2791-2797

Nag, P.K. and Sen, R.N. (1978) Cardiorespiratory performance of porters carrying loads on a treadmill. *Ergonomics* **22:** 897-907

Parvataneni, K., Ploeg, L., Olney, S.J., and Brouwer, B. (2009) Kinematic, kinetic and metabolic parameters of treadmill versus overground walking in healthy older adults, *Clin. Biomech.* **24**:95–100

Polcyn, A., Bensel, K., Harman, A., Obusek, P., Pandorf, C. and Frykman, P. et al (2002) Effects of weight carried by soldiers: combined analysis of four studies on maximal performance, physiology and biomechanics. U.S. Army Research Institute of Environmental Medicine, Natick, MA. TR02-010

Schiffman, J., Bensel, K., Hasselquist, L., Gregorczyk, K. and Piscitelle, L. (2006) Effects of carried weight on random motion and traditional measures of postural sway. *Appl.Ergon.* **37:** 607-614

Schiffman, J., Gregorczyk, K., Bensel, K., Hasselquist, L., and Obusek, J. (2008) The effects of a lower body exoskeleton load carriage assistive device on limits of stability and postural sway. *Ergonomics.* **51:** 1515-1529

Sharpe, SR, Holt, KG, Saltzman, E, and Wagenaar, RC (2008). Effects of hip belt on transverse plane trunk coordination and stability during load carriage. *J Biomech* **41:** 968-976

Singh, T. and Koh, M. (2009) Lower limb dynamics change for children while walking with backpack loads to modulate shock transmission to the head. *J. Biomech.* **42:** 736-742

Tilbury-Davis, D. and Hooper, R. (1999). The kinetic and kinematic effects of increasing load carriage upon the lower limb. *Hum.Mov.Sci.* **18:**693-700

Wiese-Bjornstal, D. and Dufek, J. (1991). The effect of weightload and footwear on kinetic and temporal factors in level grader backpacking. *J.Hum.Mov.St.* **21:**167-181