Hudson, S., Cooke, C. and Lloyd, R. (2017) The reliability of the Extra Load Index as a measure of relative load carriage economy. *Ergonomics*, DOI: 10.1080/00140139.2017.1282629

Title: The reliability of the Extra Load Index as a measure of relative load carriage economy

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Disclosure of funding: No funding was received

Conflicts of interest: None

Abstract

The aim of this study was to measure the reliability of the Extra Load Index (ELI) as a method for assessing relative load carriage economy.

Seventeen volunteers (12 males, 5 females) performed walking trials at 3 $km \cdot h^{-1}$, 6 $km \cdot h^{-1}$ and a self-selected speed. Trial conditions were repeated 7 days later to assess test-retest reliability. Trials involved four, four-minute periods of walking, each separated by 5 minutes of rest. The initial stage was performed unloaded followed in a randomised order by a second unloaded period and walking with backpacks of 7kg and 20kg.

Results show ELI values did not differ significantly between trials for any of the speeds (p = 0.46) with either of the additional loads (p = 0.297). The systematic bias, limits of agreement and coefficients of variation were small in all trial conditions.

We conclude the ELI appears to be a reliable measure of relative load carriage economy.

Key Words: load carriage, economy, reliability, physiology, ergonomics tools and methods

Practitioner Summary

This paper demonstrates that the Extra Load Index (ELI) is a reliable measure of load carriage economy at a range of walking speeds with both a light and heavy load. The ELI, therefore, represents a useful tool for comparing the relative economy associated with different load carriage systems.

1. Introduction

Load carriage economy can be defined as the energy demand for a given velocity of walking while carrying an external load and is determined by measuring steady-state oxygen consumption ($\dot{V}O_2$). Accounting for body mass, individuals with good load carriage economy use less oxygen and therefore, less energy than individuals with poor load carriage economy at the same velocity.

The Extra Load Index (ELI) is a measure of load carriage economy, developed by Lloyd *et al.* (2010a) from the seminal work of Taylor *et al.* (1980). The advantage of the ELI (equation 1) over other measures of load carriage economy is that it accounts for individual differences in oxygen consumption when walking unloaded. This enables simple comparisons between individuals and different loading methods.

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

Equation 1. $\text{mlO}_{2\text{L}}$ refers to oxygen consumption when carrying a load per kilogram of the total mass (body mass and external load mass combined), $\text{mlO}_{2\text{U}}$ refers to oxygen consumption for unloaded walking per kilogram of body mass.

An ELI value of 1 indicates that the additional energy expenditure required to transport an external load is proportional to the mass of the load. An ELI value < 1 indicates a relatively better economy, while an ELI value > 1 indicates a relatively worse economy. As such, if the aim when designing a load carriage system is to improve load carriage economy, then developers should aim to reduce the ELI value as much as possible. The ELI is sensitive enough to differentiate between load placements and can accommodate for variations in body composition, the magnitude of external load and walking speed (Lloyd *et al.* 2010a). The measure has previously been used to compare the relative economy of different load carriage systems (Lloyd *et al.* 2010a; Lloyd *et al.* 2010c; Lloyd and Cooke, 2011). However, the reliability of the ELI has yet to be reported. Knowledge of reliability is important if the measure is to be used with confidence.

While the reproducibility of $\dot{V}O_2$ during treadmill running has been frequently reported (e.g. Brisswalter and Legros, 1994; Periera and Freedson, 1997; Pereira *et al.* 1994), few studies have determined the day-day variation in walking economy in healthy populations and to our knowledge, no studies have assessed the reliability of load carriage economy. Of those that have reported the reproducibility of walking economy in healthy adult populations (Wergel-Kolmert and Wohlfart, 1999; de Mendonça and Pereira, 2008; Darter, Rodriquez, and Wilken, 2013; Davidson, Gardinier, and Gates, 2016), the day to day variation appears to be less reliable compared to running economy, with coefficients of variation (CV) between ~ 8 - 9% and ~ 1.5 - 5% for walking and running economy, respectively. Furthermore, the reliability of $\dot{V}O_2$ appears to decrease at lower intensities of both running (Pereira *et al.* 1994) and walking (de Mendonça and Pereira; 2008). A number of different exercise intensities have been employed in the load carriage literature with walking speeds ranging from ~ 3 $km{\cdot}h^{-1}$ (Maloiy *et al.* 1986; Lloyd *et al.* 2010b) to ~ 6 $km{\cdot}h^{-1}$ (Quesada *et al.* 2000) and loads ranging from 10% body mass (Abe *et al.* 2004; Singh and Koh, 2009) to in excess of 50% body mass (Lloyd *et al.* 2010b). For this reason, knowledge of the reproducibility of load carriage economy across a range of exercise intensities would be beneficial, particularly at lower intensities were the reliability of $\dot{V}O_2$ appears to be lessened.

The purpose of this study, therefore, was to establish the reliability of the ELI as a measure of load carriage economy across a range of walking speeds with both light and heavy loads.

2. Methods

Participants:

Seventeen apparently healthy volunteers (12 males, 5 females) took part in the study (age 29 ± 10.7 years, mass 77.5 ± 13.9 kg, stature 177 ± 8.7 cm). All volunteers had no history of back pain and gave written informed consent to participate. The study received approval from the institutional ethics committee at Leeds Trinity University.

Experimental Design:

All trials were conducted at Leeds Trinity University. Participants attended the laboratory on six occasions in order to complete test-retest reliability of three different trial conditions. Trial conditions differed in walking speed, with a slow speed (3 $\text{km}\cdot\text{h}^{-1}$), fast speed (6 $\text{km}\cdot\text{h}^{-1}$) and a self-selected speed (4.4 ± 0.7 $\text{km}\cdot\text{h}^{-1}$). Trial conditions were completed in a randomised order, separated by a minimum of 48 hours and repeated identically seven days later. The order in which trial conditions were undertaken was randomised via a Latin square design with participants randomly assigned (by drawing lots) to one of three speeds. Trials involved four, four-minute periods of walking, each separated by 5 minutes of rest. The initial stage was performed unloaded followed in a randomised order by a second unloaded period and walking with backpacks of 7kg and 20kg. The order of loading was identical for each of the initial trial and repeat trials. In an attempt to control for possible circadian variations in walking economy, test-retest trails were performed at approximately the same time of day for each individual Participants were also asked to maintain a similar diet and refrain from moderate-vigorous exercise and alcohol consumption in the 24 hours prior to each test.

Experimental Procedures:

Loading Methods:

For each loading condition, participants were fitted with a traditional back-loading rucksack, with a hip belt for support (AARN, New Zealand). The mass of the load was made up of the rucksack itself plus sandbags and water bottles, stored in plastic containers to help evenly distribute the load and improve stability within the rucksack. Participants were asked to wear a t-shirt, shorts and the same footwear during each test, in order to minimise the influence of clothing.

Initial Screening and Habituation:

The first laboratory visit included an initial screening of participants for any contraindications to exercise. Body mass (Seca scales, UK) and stature (Seca, UK) were measured, followed by a habituation period lasting ~ 20 minutes, which involved walking on the motorised treadmill (Mercury, HP Cosmos, Germany) at each of the walking speed conditions, with and without the 7 kg and 20 kg backpacks. The facemask for the online gas analysis system (Metalyzer 3B, Cortex, Germany) was also fitted, in order for participants to become accustomed to it. The self-selected walking speed established during the habituation period, recorded as the speed at which participants felt most comfortable while walking unloaded, was used as the self-selected walking speed in subsequent trials.

Experimental Trials:

Each trial began by recording the participant's body mass in order to calculate the ELI for that trial. Resting heart rate (Polar, H7, Finland) and oxygen uptake were then measured for two minutes prior to exercise. Exercise began with participants walking unloaded at 0% gradient for four minutes at a speed determined by the trial condition. After four minutes, there was a five-minute rest period, during which, participants stepped off the treadmill and removed the facemask. Heart rate was monitored during the rest period to ensure that participants returned to the baseline resting level established before exercise began. The final minute of each rest period was used to refit the facemask and rucksack. The procedure of four minutes walking followed by five minutes of rest was then repeated with the light load, heavy load and unloaded walking for a second time, in a randomised order if it was the first trial or in an identical order to the first test if it was a repeat trial.

Expired Gas Analysis:

Expired gas measurements were made continuously throughout each period of exercise using a computerised online breath-by-breath system (Metalyzer 3B, Cortex, Germany). On the completion of each test, 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).

Statistical Analysis:

Bland-Altman plots were generated to assess the systematic bias and 95% limits of agreement (LoA: mean of the differences ± 1.96 SD of the differences; Bland and Altman, 1986) for each trial condition. Prior to creating the Bland-Altman plots, Heteroscedasticity was formally assessed by plotting the absolute differences between the two trials against the individual means and calculating the correlation coefficient. Coefficient of variation (CV) and standard error of measurement (SEM) were also assessed following the guidelines of Atkinson and Nevill (1998).

3. Results

ELI values did not differ significantly between test-retest trials in any of the walking speed conditions ($p = 0.464$) with either of the additional loads ($p = 0.297$). Following confirmation that heteroscedasticity was not present in any of the trial conditions, the systematic bias and 95% LoA were determined and are presented in table 1. The CV and SEM (table 1) were small in all conditions with the highest CV (4.17%) and SEM (0.04) recorded when walking at $3 \text{km}\cdot\text{h}^{-1}$ with 7 kg. ELI values did increase significantly with walking speed ($p = 0.018$).

[Table 1 near here]

[Table 2 near hear]

There was no significant difference between the two unloaded periods of walking performed in each of the trial conditions ($p = 0.235$). The variations in $\dot{V}O_2$ between the unloaded periods of walking in each trial are presented in table 2. There was no significant difference in $\dot{V}O_2$ between test-retest trials ($p = 0.851$). Walking at $6 \text{ km}\cdot\text{h}^{-1}$ with a load of 20 kg produced the largest LoA and SEM of ± $0.19 \text{ l}\cdot\text{min}^{-1}$ and $0.06 \text{ l}\cdot\text{min}^{-1}$, respectively. The largest CV (4.50%) was measured for the self-selected speed when carrying 20 kg. $\dot{V}O_2$ did significantly increase with an increase in walking speed ($p = 0.001$) and when the mass of the load carried increased ($p = 0.001$).

[Table 3 near here]

4. Discussion

The ELI demonstrated good reliability at different walking speeds with both a relatively light and heavy load. The systematic bias was small in all conditions, with the largest LoA within ± 0.11, the largest SEM was 0.04 and the highest magnitude of CV was 4.17%. The ELI was found to be most reliable at the self-selected speed with the light load (95% LoA = 0.05; CV = 1.75%; SEM = 0.02). The self-selected speed was also the only condition in which the CV appeared larger when carrying the heavy load than when carrying the light load. This is, perhaps, because the speed-load combination of the self-selected speed with a light load was closest to representing the participant's natural walking pattern, and therefore, the between day variation was smallest in this condition. Additionally, the self-selected speed was chosen unloaded, which might have led to greater variability with the heavier load.

The ELI was assessed across a range of walking speeds with both relatively light and heavy loads because a range of speed-load combinations are employed in a variety of applied scenarios. Individuals in the military services are regularly required to carry heavy loads in excess of 30 kg at walking speeds of between 5-6 $km{\cdot}h^{-1}$ (Harman *et al.* 2001), while school children and individuals in rural areas of developing countries often adopt a slower walking pace of around $3km{\cdot}h^{-1}$ with both light and heavy loads (Singh and Koh, 2009; Lloyd *et al.* 2010b). Although previous research, particularly those on military personnel, have used loads in excess 40 kg (Harman *et al.* 2000), 20 kg was chosen in this study due to the untrained nature of some participants and because similar loads have been frequently used to represent a heavy load in the literature (e.g. Lloyd *et al.* 2011; Birrell and Haslam, 2009). As much of the literature on unloaded exercise suggests that the reliability of energy expenditure increases as the exercise intensity increases, and as there was no difference in the reliability of ELI across a range of exercise intensities in the present study, we would expect ELI values to demonstrate good reliability with loads in excess of 20 kg.

As expected given the ELI results, the results of $\dot{V}O_2$ also showed good test-retest reliability with the largest LoA within ± 0.19 $l{\cdot}min^{-1}$, a highest SEM of 0.06 $l{\cdot}min^{-1}$ and a highest CV of 4.50%. Furthermore, there appears to be little difference in test-retest reliability between unloaded and loaded $\dot{V}O_2$. This demonstrates a better level of reliability than previously reported for walking economy at speeds of 4-5 $km{\cdot}h^{-1}$ (Wergell-Kolmert and Wohlfart, 1999;

de Mendonça and Pereira, 2008) and is similar to the CV of 4.4% reported when walking intensity is increased by gradients up to 10% (de Mendonça and Pereira, 2008). In the present study, the CV for $\dot{V}O_2$ did not reduce as a result of increasing walking speed or when carrying an external load. Furthermore, the present study showed that the LoA and SEM were lower at 3 $km{\cdot}h^{-1}$ compared to 6 $km{\cdot}h^{-1}$, which is somewhat unexpected, given that previous research has suggested that an increase in exercise intensity increases reliability of $\dot{V}O_2$ (Pereira *et al.* 1994; de Mendonça and Pereira, 2008). However, the difference in $\dot{V}O_2$ between 3 $km{\cdot}h^{-1}$ and 6 $km{\cdot}h^{-1}$ in LoA and SEM were small, and there was no difference in CV between speeds and no significant difference in $\dot{V}O_2$ between the conditions.

Unloaded $\dot{V}O_2$ was measured twice in each trial to assess its reliability between repeated bouts of walking on the same day because of its important role as the denominator in the calculation of the ELI. Based on previous literature, we predicted that $\dot{V}O_2$ during unloaded walking might be less reliable than $\dot{V}O_2$ during loaded walking, as the exercise intensity is lower. However, there was no difference in $\dot{V}O_2$ between the two unloaded periods in each trial (Table 2) and as such, $\dot{V}O_2$ from the first unloaded period of each trial was used in the calculation of the ELI.

5. Conclusion

Based on the evidence provided here, the ELI appears to be a reliable measure of relative load carriage economy that can be easily interpreted by developers and manufacturers as well as scientific researchers. We conclude the ELI represents a useful and reliable tool for comparing the relative economy of different load carriage systems.

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Tables with captions

Table 1. Reliability measures for the Extra Load Index at different walking speeds with 7 kg and 20 kg loads

	3 km·h^{-1}		Self-Selected Speed		6 km·h^{-1}	
	7 kg	20 kg	7 kg	20 kg	7 kg	20 kg
Trial 1	0.94	0.95	0.98	0.99	0.97	1.00
Trial 2	0.95	0.95	0.96	0.96	0.98	1.00
Systematic Bias	-0.01	0.00	0.01	0.03	-0.02	0.00
95% LoA (±)	0.11	0.10	0.05	0.09	0.09	0.07
CV (%)	4.17	2.74	1.75	3.42	3.51	2.51
SEM	0.04	0.03	0.02	0.03	0.03	0.03

LoA = limits of agreement; CV = coefficient of variation; SEM = standard error of measurement

Table 2. Reliability measures for $\dot{V}O_2$ ($l \cdot min^{-1}$) between repeated bouts of unloaded walking within the same trial.

	$3\ km \cdot h^{-1}$		Self-Selected Speed		$6\ km \cdot h^{-1}$	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Unloaded 1	0.69	0.7	0.87	0.89	1.27	1.24
Unloaded 2	0.67	0.68	0.87	0.88	1.25	1.24
Systematic Bias	-0.02	-0.02	0.00	-0.01	-0.01	0.00
CV	3.62	3.68	2.3	2.63	1.86	2.72
SEM	0.02	0.03	0.02	0.02	0.02	0.03

LoA = limits of agreement; CV = coefficient of variation; SEM = standard error of measurement

Table 3. Reliability measures for $\dot{V}O_2$ ($l \cdot min^{-1}$) at different walking speeds with 7 kg and 20 kg loads.

	3 km·h^{-1}				Self-Selected Speed				6 km·h^{-1}			
	U1	U2	7 kg	20 kg	U1	U2	7 kg	20 kg	U1	U2	7 kg	20 kg
Trial 1	0.69	0.67	0.71	0.83	0.87	0.87	0.93	1.09	1.27	1.25	1.34	1.59
Trial 2	0.70	0.68	0.72	0.84	0.89	0.88	0.94	1.08	1.24	1.24	1.33	1.56
Systematic Bias	-0.01	-0.01	-0.02	-0.01	-0.02	-0.01	-0.01	0.01	0.03	0.01	0.01	0.03
95% LoA (±)	0.06	0.07	0.05	0.09	0.07	0.09	0.08	0.14	0.16	0.15	0.14	0.19
CV (%)	3.78	4.08	3.59	4.32	3.62	4.05	3.62	4.50	3.80	4.01	3.58	3.64
SEM	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.05	0.05	0.05	0.05	0.06

U1 = Unloaded; U2 = Unloaded 2; LoA = limits of agreement; CV = coefficient of variation; SEM = standard error of measurement