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Loaded and Unloaded Marching: Implications for Fluid Replacement

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Abstract: Marching with essential survival equipment is a fundamental military exercise. A consequence of this increased load is an increased risk of dehydration. Dehydration may have fatal consequences in a combat situation where performance must be optimal. This risk can be minimized with an understanding of the additional fluid needs of soldiers marching when loaded compared to unloaded. The aim of this study was to quantify fluid loss caused by marching with a loaded Bergen rucksack and webbing of 33.5 kg for 45 minutes when compared to unloaded carriage in eight healthy male officer cadets (age, 20.5 ± 0.9 years; body mass 80.2 ± 9.2 kg). The findings demonstrate an increased rate of sweat loss (0.6 ± 0.2 $L \cdot h^{-1}$ to 1.2 ± 0.4 $L \cdot h^{-1}$; $p<0.001$) and increased average heart rate (105.5 ± 17.7 $beats \cdot min^{-1}$ to 136.6 ± 28.3 $beats \cdot min^{-1}$; $p<0.001$) for unloaded and loaded trial respectively. Urine osmolality significantly increased pre- to post-march ($p<0.05$), however there was no difference in this increase between the loaded and unloaded trial. The present study demonstrated that marching with a loaded rucksack and webbing increased sweat rate by 100% compared to the same march with no additional load. For soldiers to prevent dehydration and the potential detrimental effects on performance, fluid replacement should also be doubled when marching with loading in a temperate environment, however individual differences in sweat rate should be taken into account.

Keywords: Backpack, dehydration, hydration, sweat, thermoregulation, military march, urine osmolality.

INTRODUCTION

Load carriage is a fundamental part of the military personnel's occupation in order to transport essential weapons and equipment for protection, communication and lethal necessities. The standard weight of load carriage has recently been reported to vary between 22-29 kg for a fighting load, 33-44 kg for an approach march load and 58 kg for an emergency approach march [1, 2]. However, soldiers' loads frequently exceed these values, with over 60 kg being reportedly carried [1-3].

The increase in workload results in an increased metabolic demand. Quesada *et al*. [4] reported a proportional increase in metabolic cost of approximately 5-6% for each 15% body weight load increment. A consequence of this increase in metabolic demand is an increase in metabolic heat production. The rise in core body temperature stimulates an increase in sweat production for evaporative cooling from the skin [5]. An increase in exercise-induced sweating can lead to body fluid deficit from both the intracellular and extracellular fluid compartments of the body [6]. If adequate rehydration does not occur to match fluid loss, progressive dehydration can develop [5].

As individuals become dehydrated this puts further strain on the cardiovascular system due to an increase in heart rate, diminished plasma volume, stroke volume and cardiac output, reducing venous return and cardiac filling during both exercise and rest [7-9]. Furthermore, dehydration inhibits thermoregulatory control due to alterations in sweat rate and blood flow. As both are critical to heat dissipation, a consequential rise in core body temperature occurs. With every 1% body mass loss an increase in core body temperature by an additional 0.15 to 0.20 ºC has been observed [5]. This exacerbation in core body temperature can reach dangerous levels evoking the risk of heat related illness [10].

The current consensus is that a 2% body mass loss negatively affects a wide range of physiological [6] and metabolic functions [11] with further levels of dehydration exacerbating their effects [12, 13]. Additionally, substantial evidence exists in the observation of decreased cognitive function when dehydrated by ≥ 2% body mass loss, with decreases in self-rated alertness and perceived tiredness being reported [14, 15]. More specifically, within military personnel, dehydration of ≥ 2% has a negative effect on morale, willingness to work and overall mental performance [16]. In a military environment whereby optimal physiological and cognitive functioning are vital, impairments can not only reduce performance but may also ultimately cost lives. Through adequate hydration, these casualties could be minimized and even prevented, avoiding performance degradation and therefore optimizing the mission's capability, safety and success [17]. Yet individuals seldom replace fluid loss due to inadequate voluntary *ad libitum* intake [13]. It is therefore important to quantify the additional fluid loss caused by marching with loaded rucksack and webbing when compared to unloaded carriage to ensure suitable fluid replacement strategies be adopted.

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METHODS

Participants

Eight healthy male officer cadets (age 20.5 ± 0.9 years; height 179.3 ± 4.4 cm; mean ± SD) participated in this study which was granted institutional ethical approval (approval number: SPA/SD/31102011). All participants met the required fitness entry requirement of the regular armed forces (i.e. achieving a minimum estimated $VO2_{max}$ of 43.7 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$). Both written and oral informed consents were obtained and participants were instructed to avoid alcohol and caffeine prior to participation. Participants were also requested to arrive having consumed 500 ml of water, 2 hours prior to testing and their hydration status was assessed through urine osmolality, with a value of <700 $mmol{\cdot}kg^{-1}$ considered as euhydrated [6].

Protocol

Participants completed two marches, an unloaded and a loaded trial (counterbalanced). Trials were completed one week apart at the same time of day in a temperature of 20 °C and relative humidity of 40%. The unloaded trial consisted of subjects wearing their military clothing (combat trouser, short sleeve T- shirt and boots) along with the British Army issued Bergen rucksack and waist webbing (also referred to as Personal Load Carriage Equipment). The weight of the unloaded rucksack and webbing totaled 4.5 kg. For the loaded trial the subjects wore the same clothing with the rucksack and webbing loaded with 29 kg of extra weight meaning the total rucksack and webbing weight was 33.5 kg, replicating the U.S. Army doctrine recommendations for an approach march load [18]. The extra weight was distributed with 24 kg in the rucksack and 5 kg across the webbing. Weight was added using 0.5 and 1 kg metal disks and cloth to allow even distribution of weight across the rucksack and webbing.

Exercise protocol

In both the unloaded and loaded trials, participants initially stood for 2 minutes (rest) before marching for 5 minutes (warm up) on a treadmill set at $3.5km{\cdot}h^{-1}$. The treadmill speed was then increased to $6.5km{\cdot}h^{-1}$ and this marching speed was maintained for 35 minutes (exercise). Treadmill speed was then reduced to $3.5km{\cdot}h^{-1}$ for 5 minutes (cool down).

Measurements

Nude body mass was measured immediately pre- and post-march, with participants being asked to towel off their sweat. Fluid loss was assumed to be equivalent to the change in body mass (1 mL of fluid loss represents a 1 g loss in body mass). Participants provided a urine sample pre- and post-march to allow urine osmolality to be measured (Pocket Osmocheck, PAL-OSMO). Rate of fluid loss ($L{\cdot}h^{-1}$) was calculated from the total fluid loss and the total exercise duration (warm up + exercise + cool down). No fluid was consumed at any point between pre- and post-march measurements. Heart rate (Polar T31 transmitter, Polar, Kempele, Finland) was recorded at 5 minute intervals throughout the march. Rate of perceived exertion (RPE) [19] was measured at the final minute of the exercise stage (minute 39).

Data Analysis

Normality of the data was tested using Shapiro-Wilk test and subsequently confirmed. Fluid loss, rate of fluid loss, urine osmolality, heart rate at each stage (rest, warm up , exercise, cool down) and RPE were all compared between the unloaded and loaded conditions using a paired sample student's T- Test. Values are presented as mean ± SD. Significance was accepted at the level $p<0.05$. For all statistical analyses, IBM SPSS Statistics v19 was used.

RESULTS

Pre-march body mass was the same in the unloaded and loaded trial (80.2 ± 9.3 kg and 80.5 ±9.1 kg, respectively). Body mass significantly decreased from pre- to post-march in both the unloaded and loaded trial (-0.6 ± 0.15% and -1.1 ± 0.3%, respectively; $p<0.001$). The difference in body mass between pre-march and post-march was significantly higher in the loaded trial compared to the unloaded trial ($p<0.001$; Fig. **1a**). Similarly, when converted to rate of fluid loss ($L{\cdot}h^{-1}$), this was significantly greater in the loaded as compared to the unloaded trial ($p<0.001$; Fig. **1b**).

Urine osmolality significantly increased from pre-march to post-march for both the unloaded and loaded trials (unloaded trial: pre-march 409 ± 186 $mmol{\cdot}kg^{-1}$, post exercise 600 ± 168 $mmol{\cdot}kg^{-1}$; $p<0.05$; loaded trial: pre exercise 390 ± 230 $mmol{\cdot}kg^{-1}$ post exercise 565 ± 178 $mmol{\cdot}kg^{-1}$; $p<0.01$). This increase was not different between the unloaded and loaded trial (Fig. **2**).

Average heart rate was significantly higher for the loaded trial compared to the unloaded trial for all stages of the march (rest: $p<0.05$; warm up: $p< 0.05$; exercise: $p<0.001$; cool down $p<0.001$; Fig. **3**). Similarly RPE was significantly higher for the loaded compared to unloaded trial ($p< 0.001$; Fig. **4**).

DISCUSSION

The main finding of the present study was the 100% increase in rate of fluid loss ($L{\cdot}h^{-1}$) when marching with a loaded military rucksack and webbing (total additional weight 33.5kg) compared to marching with an unloaded rucksack and webbing (total additional weight 4.5 kg). This highlights the need for a specific fluid replacement strategy when marching with and without loading in order to avoid dehydration and the well documented performance decrements which could ultimately compromise the success of a mission.

The present study showed a 1.1 ± 0.3% body mass loss from pre to post exercise in the loaded trial compared to a 0.6 ± 0.2% body mass loss during the unloaded trial. A body mass decrease of ≥ 1% is classified as a marker of dehydration [5, 6] therefore following a march of only 45 minutes the participants were in the process of dehydrating when marching with loading. Military personnel frequently march for over 2 hour's duration over substantial distances. If participants in the present study were to march for such

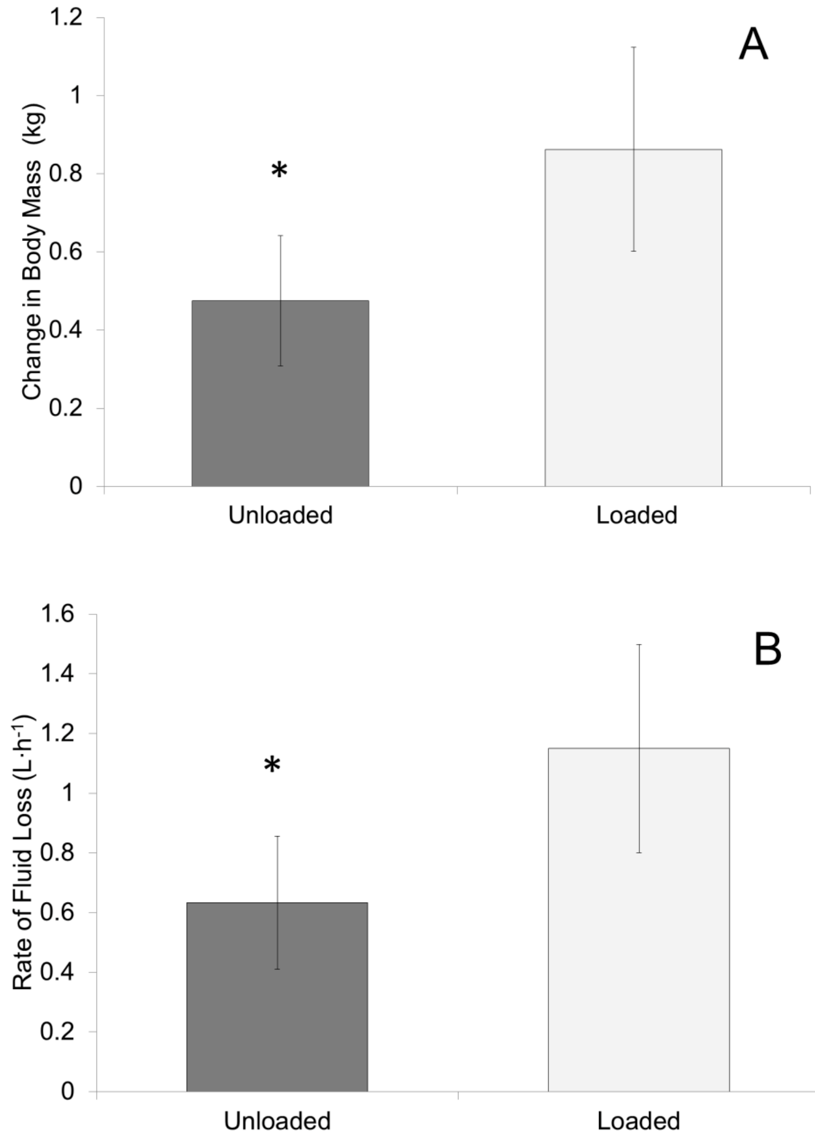

Fig. (1). A. Change in body mass from pre to post exercise and B. rate of fluid loss for the unloaded (dark fill) and loaded trial (light fill). * denotes significant difference between the trials ($p < 0.001$). Data are presented as mean ± SD.

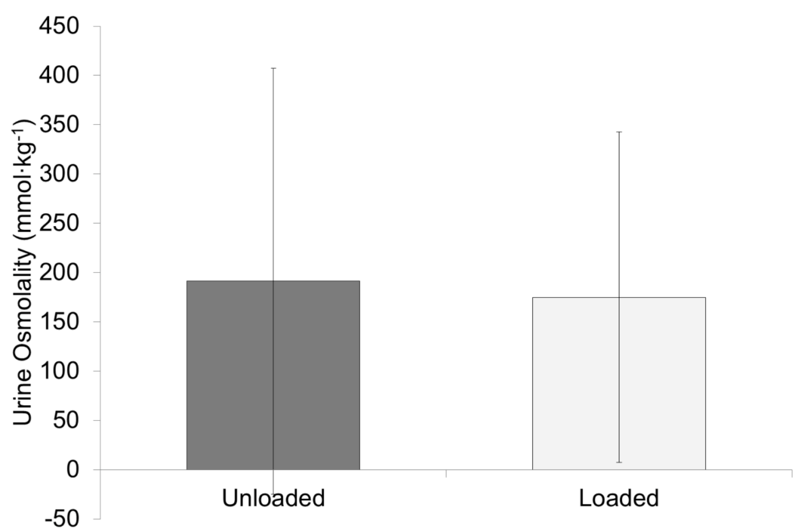

Fig. (2). Change in urine osmolality form pre to post exercise for the unloaded (dark fill) and loaded trial (light fill). Data are presented as mean ± SD.

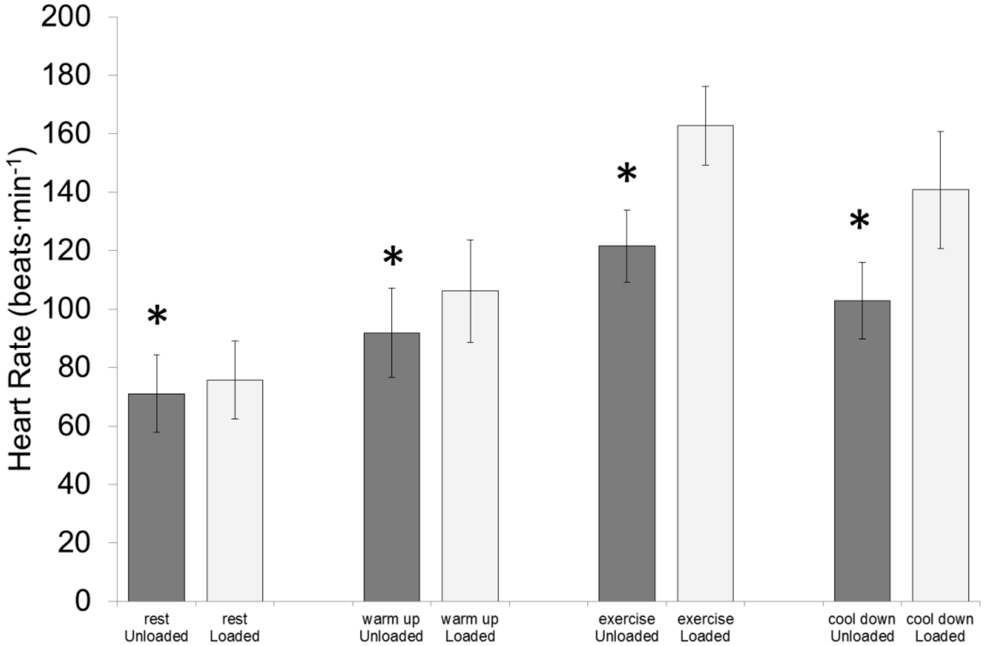

Fig. (3). Average heart rate for the unloaded (dark fill) and loaded trial (light fill) at each stage of the march (rest, warm up, exercise, cool down) . * denotes significant difference between the trials ($p < 0.05$). Data are presented as mean ± SD.

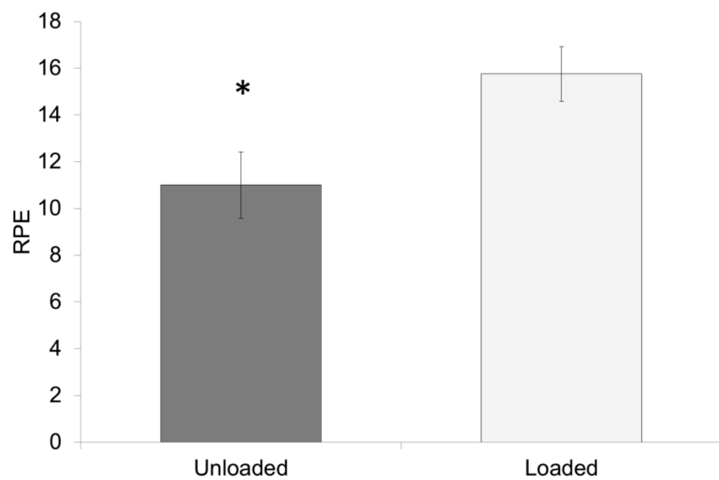

Fig. (4). Rate of perceived exertion for the unloaded (dark fill) and loaded trial (light fill) during the exercise stage of the march. * denotes significant difference between the trials ($p < 0.05$). Data are presented as mean ± SD

durations, it is likely that this would elicit a body mass loss > 2% when unloaded and potentially > 4% when loaded, assuming a constant sweat rate throughout the duration of the march. The current consensus is that a body mass loss ≥ 2% is the critical threshold which can negatively impact on performance and health [13].

The use of urine osmolality is a commonly used method to determine hydration status. With a value of < 700 $mmol \cdot kg^{-1}$ being indicative of euhydration [6], all participants in the present study were below this cut off pre-march for both the unloaded and loaded trials. While significant augmentation of urine osmolality was seen for both trials, post-march values remained below < 700 $mmol \cdot kg^{-1}$ for all but one participant in both trials, classifying the participants as being euhydrated despite the loss in body mass suggesting otherwise. Additionally, the augmentation was not different between the loaded or unloaded trial despite the greater body mass loss in the loaded trial. Urine indices have, however, been reported to be less sensitive and demonstrate a delayed response in detecting changes in fluid balance compared to that of other hydration markers, particularly during periods of rapid body fluid turnover as seen in the present study [20, 21].

The assumption that 1g loss in body mass represents a 1 mL fluid loss [6] allows us to calculate the rate of fluid loss for each march. In the present study fluid loss was significantly greater in the loaded when compared to the unloaded trial (1.2 ± 0.4 $L \cdot h^{-1}$ and 0.6 ± 0.2 $L \cdot h^{-1}$, respectively). Average sweat rate during physical activity can vary from 0.5 $L \cdot h^{-1}$ to more than 2.5 $L \cdot h^{-1}$ [5, 6] however these results portray a variety of exercise types, intensities and environmental conditions all of which affect sweat production. It is important to know that there are considerable variations in fluid loss between individuals in different activities and even within the same activity [22-25]. The sweat loss in the participants in the present study ranged from 0.7 $L{\cdot}h^{-1}$ to 1.5 $L{\cdot}h^{-1}$; factors such as genetic predisposition, heat acclimatization state and metabolic efficiency will influence sweat rates for each individual [6].

To prevent fluid deficit from occurring, individuals need to match fluid loss with a sufficient fluid intake [5]. However caution must be taken when using general guidelines for fluid replacement as they do not take into account the considerable variability in sweat losses between individuals nor the additional metabolic and thermal demands of load carriage. In the present study, to offset fluid deficit the participants must intake fluid between 0.4 $L{\cdot}h^{-1}$ to 0.9 $L{\cdot}h^{-1}$ during an unloaded march and 0.7 $L{\cdot}h^{-1}$ to 1.5 $L{\cdot}h^{-1}$ during a loaded march in temperate conditions.

The increase in average heart rate during loaded when compared to unloaded marching seen in the present study is indicative of an increased cardiovascular strain. This is consistent with findings of other laboratory based studies that show exacerbated stress on the cardiovascular system whilst carrying similar load weight. Quesada *et al.* [4] reported a linear increase in heart rate with an increase in load mass from 0, 30, 50% of body mass whilst performing a 40 minute treadmill march at 6 $km{\cdot}h^{-1}$. Similarly, heart rate was also reported to increase by 1.1beat$\cdot$$min^{-1}$ with each kg of weight increase (up to 30 kg) during four walking conditions (rest and treadmill exercise at 25, 50 and 75% of the individual $VO^2{}_{max}$) [26]. In scenarios such as Tactical Advance to Battle, in which soldiers are marching at maximal pace during load carriage with the aim of reaching a destination as quickly as possible, the increase in walking velocity, along with additional factors such as type of terrain, hot environments and walking gradient will further increase the cardiovascular strain of walking, as indicated by heart rate, with a loaded backpack [27].

It is important to highlight that the findings of this study apply to temperate, dry conditions only. Military exercises are done in vast range of environmental conditions with considerable variability in the temperature and humidity, as well as sun, wind and rain exposure, all of which contribute to the rate of sweat loss of the soldiers. Due to considerable number of environmental conditions, it is difficult to provide a standard recommendation for fluid replacement. The purpose of this study was to highlight the additional variable of load carriage when planning a fluid replacement strategy.

CONCLUSION

The present study demonstrated that marching with a loaded rucksack and webbing increases sweat rate from 0.6 ± 0.2 $L{\cdot}h^{-1}$ to 1.2 ± 0.4 $L{\cdot}h^{-1}$ for the unloaded and loaded trials respectively. For soldiers to prevent dehydration and the potential detrimental effects on performance, fluid replacement during loaded marching in temperate conditions should be at least double that consumed when marching unloaded. This will ensure that soldiers are consuming equal to or greater than the fluid they are losing meeting the recommendations made by the American College of Sports Medicine [6]. With the greater sweat loss, there is consequence of greater electrolyte loss (primarily sodium chloride and potassium). The inclusion of electrolytes within fluid replacement beverages should be considered in order to minimize electrolyte imbalances and the associated medical conditions (e.g. muscle cramps and hyponatremia) as well as aid retention of fluid intake. It is important, however, to take into account the substantial individual differences in sweat rate, it is vital to adjust fluid and electrolyte replacement needs to meet the requirements of the individual.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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Declared none.

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