Military combat movements and exercises: is there a role for adopting sports nutrition carbohydrate recommendations during exercise?

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Abstract

The daily energy requirements for specialist military troops can reach 5000 kcal during training and wartime deployment. Maintaining energy balance is important for health and physical and mental performance in this population, who can effectively be considered as high-performance endurance athletes. In this regard, a balanced diet consisting of 50-60% carbohydrate (CHO), 20-25% protein and 25-30% fat is recommended for endurance athletes in the sporting world. Carbohydrate intake is regarded as a key dietary constituent of the high-performance athlete, as this substrate provides the sole fuel source during high intensity exercise. However, achieving such high CHO intake rates can be challenging, especially when military personnel are in the field. In sports nutrition, athletes commonly use dietary CHO supplements to reduce this deficit. There may be lessons and insight from nutrition and metabolism in sport that could provide Royal Marines, Medical Officers and other embedded medical professionals with strategies to increase CHO intake during intense training or combat situations.

This review will highlight the exercise demands of infantry soldiering; it will suggest supplementary strategies to increase CHO intake, in addition to dietary intake, and will describe the metabolic effects of CHO ingestion during prolonged activity in the context of military exercise.

Introduction

The day to day energy demands of military training are well established and often exceed the energy requirements of the general population. In this regard, daily energy expenditures within a military context vary greatly and can be as high as 5000 kcal during special forces training.[1] Maintaining energy balance is important for health and performance, and it is concerning that energy deficits have been recorded during wartime deployments.[1,2] In terms of energy requirement, specialist troops such as Royal Marines can be considered as elite endurance athletes and may benefit from targeted nutrition, similar to sporting athletes, to maintain energy balance and preserve physical and cognitive performance.[3,4]

Carbohydrate (CHO) intake is regarded as a key dietary constituent of the high-performance athlete.[4] The dietary CHO requirements of elite athletes should be 50–60% of daily energy expenditure,[3] which is consistent with current military dietary reference values from the Defence Nutrition Advisory Service.[5] On military exercises or deployments this may be difficult to achieve. Combat rations will meet the macronutrient requirements of general troop activity, but on exercises with higher intensity exercise this may be inadequate. Despite well-established nutrition guidelines in elite athletes the timing, dose and type of CHO consumed during exercise is still subject to debate and may translate into improved performance where high intensity exercise is sustained for prolonged periods. The aim of this review is to summarise the current evidence for CHO supplementation during exercise and to apply the potential of this dietary ergogenic aid to military troop deployments.

Energy requirements of infantry soldiering

Royal Marines troop movements are characterised by long periods of low intensity activity interspersed with sustained periods of high intensity exercise, usually running. As the range of exercise parameters in the military context is vast, the subject of this review will focus on land-based infantry exercise. The daily energy requirement of troops in garrison are only moderately higher than the general UK population guidelines (2,700 kcal in males, 2,131 kcal in females),[5,6] but is higher in specialist infantry courses[7] and special forces training,[1,8] reaching 4,600–5,000 kcal. Furthermore, mean daily energy expenditure during wartime deployment in the Royal Marines was reported as 3600 kcal. However, depending on specific physical demands, energy expenditure may reach 4700 kcal during days of intensive patrolling with load carriage.[2] Energy intake in soldiers in these studies did not, however, meet energy requirements, indicating a clear need to increase energy intake to maintain physical and cognitive performance. It should be noted that the discrepancy between energy intake and expenditure may be methodological, as the limitations of self-reported diet diaries has been well documented.[9,10] However, despite this limitation, the energy demands of infantry soldiering during intensive wartime deployment and training exercises may not be met by current practice.

Energy requirement data for Royal Marines specific tasks such as battle drills is scarce. Therefore, it is difficult to provide specific CHO recommendations to maximise military specific exercise performance. Soldiers undergoing the 10-day exercise phase of the section commanders' battle course, an 8 week course for non-commissioned officers in the British Army, may be required to perform >4 hours of exercise per day above 40% of heart rate reserve (HRR).[7] For a 20 year old athlete or soldier with a resting heart rate (HR) of 60 beats per min this is equivalent to 4 hours of exercise at a HR above 116 beats per min. In addition, soldiers also spent between 20 and 50 minutes daily performing at an exercise intensity >60% HRR (equivalent to HR = 144 in the example above). Any high intensity exercise, which demands greater CHO utilisation than low intensity exercise, in this study was likely to be intermittent running, and interspersed during bouts of moderate intensity exercise, for example during patrolling and simulated battle drills.

Royal Marines are regularly required to undertake long marches while carrying significant loads. Oxygen consumption ($\dot{V}O_2$) during walking with a 25 kg load is significantly greater than unloaded walking when walking speeds exceed 6 km.h^{-1},[11] or the gradient exceeds 4%.[12] In these studies, $\dot{V}O_2$ during walking protocols was between 16–28 ml.kg^{-1}.min^{-1} which can be classified as moderate intensity (below the lactate threshold)[13] and therefore considered steady state exercise. The addition of a backpack load to walking energy expenditure also increases the metabolic cost of walking by 25–40%.[14,15] However, the higher value provided was measured in participants not fully accustomed to load carriage exercise,[14] whereas the lower value in this range was reported in infantry soldiers during a field based military march. Royal Marines are required to exercise under both loaded and unloaded conditions, and Grenier *et al.*[15] also reported that marching with a further load designed to simulate road marching compared with light weight infantry battle marching (37 vs. 25 kg) required a 10% greater energy requirement. However, despite this range, walking under load carriage is unlikely to place the overall energy demands of exercise into the high intensity domain in well trained troops. Under these conditions, the availability of glycogen, which is a limited fuel store in the human body, may be a limiting factor to sustained performance and high intensity exercise. Both sustained and high intensity exercise are commonly experienced by infantry troops in battlefield situations, and further increase the metabolic demand of exercise. Therefore, as CHO may reduce the demand on limited glycogen stores,[8] strategies to increase CHO ingestion should be explored.

Specific carbohydrate requirements for infantry soldiering

The United States military special operations forces nutrition guide advises infantry soldiers to aim to consume 15–30 $g.h^{-1}$ of CHO during periods of prolonged exercise.[4] This partially falls in line with the guidelines for athletes from the American College of Sports Medicine,[3] which advises up to 60 $g.h^{-1}$ for endurance exercise. However, recent evidence has promoted a recommendation for intense or further prolonged (e.g. 'ultra-endurance' exercise) of up to 90 $g.h^{-1}$ of multiple transportable CHO, namely glucose and fructose mixtures (2:1 ratio).[16] However, the distribution of energy intake around exercise to meet the demands of infantry exercise has received little attention, and lacks specific nutritional recommendations required to support the demands of exercise.

Carbohydrate provision of 16 $g.h^{-1}$ has been shown to reduce $\dot{V}O_2$ drift (indicating an increase in energy expenditure) during treadmill walking with a 25 kg load.[17] This reduction may in part be explained by increased CHO oxidation, which has a more efficient oxygen cost per mole of liberated adenosine triphosphate (ATP).[18] Given that prolonged unloaded walking relies on a greater utilisation of fat than CHO,[19] it may seem that supplementing with exogenous CHO will not produce an extra performance or metabolic benefit to typical Royal Marines movements. However, despite reporting higher total CHO oxidation with CHO snacks and a high CHO diet during prolonged walking compared with a low CHO diet and low CHO snacks, Ainslie *et al.*[19] did not report glycogen oxidation data. Therefore, it is possible that the lower CHO oxidation with a high fat diet was due to a substantially lower pre-exercise liver and muscle glycogen content. Either way, protecting limited glycogen stores or being able to increase CHO oxidation should benefit Royal Marines. Recent findings from our laboratory suggest that exogenous CHO ingestion during prolonged exercise may spare muscle glycogen, and that this effect is sensitive to the dose of ingested CHO.[20] Protecting endogenous glycogen by maintaining adequate CHO intake may be beneficial to the infantry soldier. This may be further beneficial where CHO or food availability might become limited, or where a bout of high intensity exercise is required.

In a study designed to replicate the demands of very prolonged discontinuous exercise, Harger-Domitrovich *et al.*[21] investigated the effect of 32–42 $g.h^{-1}$ CHO ingestion on performance and fuel use. CHO ingestion resulted in a significant 33% reduction in muscle glycogen utilisation. The exercise protocol involved 50 minutes of exercise per hour [10 hours] consisting of moderate intensity walking, cycling and upper body ergometry. However, despite the similar aerobic intensity to military tasks,[22] whether this directly translates to the demands of military exercise requires clarification due to the differences in exercise mode to those encountered by Royal Marines. In contrast, Foskett *et al.*[23] found that CHO ingestion (90 $g.h^{-1}$ maltodextrin) did not influence muscle glycogen oxidation during intermittent running to fatigue following a 90-minute run. Whilst this may be interpreted as an important finding in this context, a number of factors must also be considered. The nature of exercise to fatigue, or near fatigue, is one which is important to Royal Marines troops. However, the high intensity exercise encountered by infantry troops engaging in battle drills is unlikely to be prolonged to the extent investigated by Foskett *et al*.[23] During longer battlefield engagements, there may be opportunity for soldiers to ingest exogenous CHO as this is not a time intensive activity. Further, a bout of prior exercise (for example a load carrying march) may influence muscle glycogen oxidation, and it remains to be seen if these findings would be replicated if exogenous CHO or a high CHO diet or feed was provided during and before previous exercise. Methodological difficulties with the muscle biopsy technique also limit interpretation of the rate of muscle glycogen oxidation. Therefore, the ingestion of CHO during exercise may have attenuated the initial rate of muscle glycogen oxidation during exercise,[23] but at fatigue, when the differentiation of muscle glycogen was made, muscle glycogen stores are likely to be depleted regardless. Whilst further evidence is required to explain the direct effects of CHO ingestion during and prior to exercise that Royal Marines troops may experience, it appears that CHO provision may allow greater CHO utilisation, thereby increasing exercise intensity and performance. It further stands, that preservation of muscle (and to some extent, liver) glycogen will allow higher intensity exercise to be maintained if access and availability of CHO and food is reduced. Therefore, Royal Marines should maintain adequate CHO intake both through dietary sources and exercise supplements.

Carbohydrate ingestion during simulated marching has also been shown to improve indirect markers of physiological stress, indicating that the exogenous CHO adds to endogenous fuel availability. Byrne *et al.*[24] found that ~60 $g.h^{-1}$ of CHO provision reduced the physiological demand of 3 hours of fixed intensity loaded walking. Heart rate was slightly reduced there was a reduction in the rating of perceived exertion (RPE) and increased plasma glucose concentrations. However, despite not reporting a direct measure of exogenous CHO oxidation or endogenous fuel utilisation, the effects observed in this study are likely to have been caused by the CHO provision. Although not directly related to exercise fuel utilisation, Pasiakos *et al.*[10] found post-exercise (5 days of ski marching) hepcidin, an indicator of exercise stress, was increased in a control (rations only) group relative to a CHO supplement group. Daily energy expenditure during this study was ~6500 $kcal.day^{-1}$, showing exacerbated energy deficit and complications where energy intake is severely inadequate and further highlighting the importance of getting as close to energy balance as possible. Therefore, there may be an added long-term benefit of CHO supplementation by increasing overall energy intake to manage recovery and inflammation and reduce the energy deficit caused by extremely demanding exercise.

Metabolic effects of CHO ingestion during prolonged exercise

Carbohydrate ingestion during exercise is well established in the performance sport and exercise world due to its undoubted ergogenic effect.[25] The mechanisms underpinning the ergogenic benefit of CHO ingestion are likely multi-factorial but a key factor is maintaining blood glucose as the primary fuel source for the brain during exercise.[26,27] This may help sustain central neural drive and prevent fatigue during exercise. Under conditions of high energy demand, such as exercise, or when food intake is low, liver glycogen phosphorylase activity increases, resulting in plasma glucose production from glycogen. This reduces liver glycogen[28] but high dose CHO ingestion has been shown to attenuate or prevent this decline.[29,30] However, it should be noted that the participants in a study by Bosch *et al.*[31] ingested a breakfast before exercise, which will have replenished liver glycogen following the overnight fast. When fasted, as shown by Coyle *et al.*[32] a sparing effect may be diminished as there is less glycogen to spare, explaining the fall in plasma glucose during exercise with placebo ingestion. Therefore, in periods when access to meals is reduced, troops should ingest rapidly digested forms of CHO if exercising to supplement plasma glucose concentrations and to reduce liver glycogen depletion.

Carbohydrate ingestion leads to higher exogenous and total CHO oxidation with glucose compared with water, but this is limited up to an ingestion rate of ~60 $g.h^{-1}$.[33] For doses below 60 $g.h^{-1}$, there appears to be a CHO dose effect, with greater ingestion rates producing greater oxidation.[34] However, there is little evidence to suggest that glucose ingestion of relatively low dose will attenuate muscle or liver glycogen utilisation. Adding fructose to CHO solutions increases exogenous CHO oxidation and may produce exogenous CHO oxidation rates up to 70% greater than with glucose alone.[35-37] This also translates to improved exercise performance.[20] However, exogenous CHO oxidation appears to be limited by the transport of these sugars across the intestinal wall.[38] Glucose and fructose are transported across the intestinal wall by non-competitive transport proteins and there is a greater expression of the sodium dependent glucose transporter 1 (SGLT1) responsible for glucose (and galactose) transport, than the glucose transporter 5 (GLUT5) responsible for fructose transport. The consequence of increasing exogenous CHO oxidation with glucose-fructose ingestion on liver and muscle glycogen oxidation is less clear. Data from our laboratory suggest that the rate of glucose-fructose ingestion may be important to being able to 'spare' muscle glycogen,[39] which is likely to be essential for exercise performance. In this regard, a dose of 90 g.h^{-1} is the most beneficial during moderate to high intensity exercise. It should be noted, however, that this new evidence also suggests that ‘over-dosing’ ingested glucose-fructose i.e. above the intestinal saturation rates, may paradoxically cause greater glycogen oxidation. During infantry type exercise this effect may be detrimental to sustaining performance when or if fuel availability becomes restricted and troops should avoid consuming more than 90 g.h^{-1}.

Earlier evidence also supports the use of CHO mixtures in running, which is more applicable to exercise done by military troops. Despite Tsintzas *et al.*[40-42] using much lower doses than those which would saturate the intestinal transport proteins, time to exhaustion and CHO oxidation were positively affected by CHO ingestion and resulted in a reduction in muscle glycogen oxidation. The sparing effect seen in these studies may be due to the exercise mode, but it cannot be ruled out as a consequence of the CHO drinks, although the former of these explanations seems more plausible. More research is required to underline the CHO ingestion regimens to specific military type exercise, but based on our current understanding it would be recommended that troops ingest 60–90 g.h^{-1} of a glucose-fructose mixture when the energy demand of exercise is increased beyond a low intensity. It is also recommended that consuming excessive amounts of CHO (not exceeding 90 g.h^{-1}) should be avoided. Exogenous CHO oxidation is not affected by the ingested food form of CHO, with solutions, semi-solid solutions (i.e. gels) or solid snack bars providing equal provision of CHO for oxidation.[43] Therefore, the provision of CHO supplements may be dictated by practicalities such as weight, cost, food preference or operational ease of use. Although this evidence from an elite sporting environment may be useful in understanding optimal CHO strategies, it must be acknowledged that military personnel often do not have the same structured exercise plan due to their need to be responsive and agile.

A possible neurological effect? The role of CHO mouth rinse

During exercise lasting less than one hour, glycogen availability is unlikely to be a limiting factor to exercise performance, but several studies have shown a small performance effect of CHO ingestion,[44-47] or oral exposure to CHO.[48-52] Carter *et al.*[48]

published an influential paper identifying a possible neurological signalling mechanism to CHO in the mouth. In these studies, participants did not ingest the CHO solutions, but ‘mouth rinsed’ the CHO solution for 5-10 seconds. The mouth rinse condition saw a small but significant (3%) improvement in performance. The mechanism of this effect is thought to be based in the central nervous system, as both glucose and the less sweet maltodextrin stimulate the frontal operculum, orbitofrontal complex and striatum in the brain, the areas responsible for reward and motor control. The consequence of this stimulation is to reduce perception of effort and subsequently pacing during the trial exercise. Furthermore, no neural activation was reported when participants mouth rinsed with an artificially sweetened solution, suggesting that the response to sweetness and CHO is separate, perhaps due to different receptors in the mouth. Therefore, when exercise duration is short (less than 1 hour) CHO ingestion does not appear to have a direct oxidative benefit on glucose concentrations but may reduce perception of effort and therefore be beneficial.

It is also possible that mouth-rinsing affects appetite and energy expenditure. Deighton *et al.*[53] reported an increase in CHO oxidation and energy expenditure when mouth rinsing with a 6.4% maltodextrin solution during a one-hour treadmill walk. In the context of military exercise, the increase in energy expenditure was likely caused by the greater exercise capacity (distance walked) seen, indicating CHO mouth rinse improves walking performance.

A consequence of increased energy expenditure is a potential increase in appetite.[53] In situations where troops may have limited food available, the mouth rinse effect could have potentially negative consequences in subsequent activities, although this requires further elucidation. In order to achieve the potential effect via this mechanism, it is recommended to rinse 25 ml of a 6-8% CHO solution for ten seconds before either expectorating or ingesting. This can be used in lieu of ingesting a greater volume of CHO through foods or solutions during high or low intensity exercise lasting less than one hour in duration and can be measured as a large mouthful of a drink, or by holding a small mouthful of a CHO gel in the mouth.

Conclusions and recommendations

Infantry troops are regularly engaged in situations where acute and chronic energy requirements are high. In some instances, daily energy expenditure will exceed the energy provision of standard rations, placing the individual into negative energy balance. Negative energy balance has been associated with decreased cognition,[54] and more importantly, may have implications on recovery from exercise. Acutely, soldiers may also be required to engage in periods of intermittent and high intensity exercise, where energy demands can more than double, relative to the demands of walking, which although classified as low intensity, can be prolonged in nature and still carry a significant energy cost. In this scenario, CHO oxidation will enable a more rapid re-synthesis of ATP and without food ingestion, finite glycogen stores will quickly deplete, reducing the high intensity exercise capability of the troops. Furthermore, CHO ingestion also improves vigilance and reduces confusion in simulated military exercise.[55] This introduces a role for energy supplementation during field deployments for infantry troops, and specifically a role for CHO. Carbohydrate serves a rapidly oxidised fuel source and by elevating plasma glucose can increase the rate of cellular glucose uptake leading to increased CHO oxidation during exercise.

However, under conditions where soldiers are well fed, the role of acute CHO ingestion is unlikely to make a significant impact, especially if the demands of exercise are low, such as during marching, where soldiers should continue to snack according to appetite. This is in accordance with current military advice and practice. The role of CHO ingestion during exercise in typical infantry troop deployments is therefore likely to be useful during high intensity exercise where soldiers should aim to consume between 60-90 $g.h^{-1}$ of CHO. This can be achieved through any food source providing rapidly digested CHO which increases the practical delivery and provision of possible supplements. Sports nutrition guidelines generally recommend ingesting mixtures of glucose and fructose to achieve intake rates of 90 $g.h^{-1}$ as a mixture of these two sugars allows non-competitive transport across the brush border membrane of the small intestine. However, providing CHO solutions may not be practical due to the weight requirement and as such CHO provision can be made through semi-solid gels or solid snack type foods. If food is not available a CHO mouth rinse may be useful when a short ‘lift’ is required as this can provide a sensation of lower perceived exertion and increase total CHO oxidation from endogenous fuel sources, increasing the capacity to exercise at a higher intensity. The reality of high intensity exercise during troop movements suggest likely battlefield engagements where eating and drinking are unlikely to be possible. Therefore, if consuming CHO during exercise is not possible, soldiers should focus on consuming CHO in the diet to the usual recommendations (6 $g.kg^{-1}$) and use supplementation between meals to increase this intake to the upper limits (9-12 $g.kg^{-1}$) of the dietary recommendations for athletes.

Conflicts of interest

The authors declare no conflicts of interest.

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