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REVIEW ARTICLE

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CHALLENGES FOR ENDURANCE PERFORMANCE IN WARM CONDITION

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ABSTRACT

Endurance performance of athlete in warm condition is decided by various factors like fluid balance and energy source, mainly aerobic capacity performer is challenged manifold to compensate the need of associated tissue involved in movement and organs like muscles by supply of oxygen and ATP metabolism. These factors are effected considerably even with exponential change in exercise of moderate to intensive intensity. While exercise in warm weather the level of difficulties to maintain the performance of endurance activity is exaggerated with loss of body fluid through sweat, increase in core body temperature, metabolic heat production due to oxidation of carbohydrate, accumulation of blood lactate and decrease in blood glucose level to impairment of physical performance. Thus main aim of this review article is to highlight the various threats for elite endurance athlete and coaches and to provide them in-depth understanding the risks due to bio physiological dynamic changes in nutshell occurring during endurance performance in warm condition.

Key Words: Carbohydrate, Dehydration, Hyperthermia, Endurance performance, Fluid balance.

INTRODUCTION

Generally the energy demand on onset of low intensity exercise increase to manifold compared with resting condition and carbohydrate and fat oxidation accelerated further until exercise intensity reach of about 65% VO_{2max} after which a decline in the fat oxidation is clearly observed (Achten*et al*, 2002 and 2003). In contrast fat metabolism switch to carbohydrate metabolism as function of aerobic work rate at high intensity (Romijn*et al*, 1993 and Van Loon *et al*, 2001), thus muscle glycogen become most important substrate for energy when the intensity of exercise increases above approximately 50% VO_{2max} (Romijn*et al*, 1993 and Van Loon *et al*, 2001). However prolong exercise at intensities of 65-85% VO_{2max} is associated with physiological changes like depletion of muscle glycogen store (Karlsson*et al*, 1971.,Leatte*et al*, 1989 and Tzintzas*et al*, 1996), hypoglycaemia (Coggan *et al*, 1987., Coyle *et al*, 1986), increased core temperature by addition of metabolic heat, dehydration (Armstrong *et al* 1985., Burge *et al*, 1993). In addition the significant rise in the rate of muscle glycogen depletion, hypoglycaemic (Parkin *et al*, 1999.,Teattersone*t al*, 2000., Fink *et al*, 1975) and accumulation of lactic acid (Casa *et al*, 2000) in muscle and blood is observed to exaggerate the experience of fatigue during strenuous exercise in heat, as well as the hypo hydration as a result of inadequate restoration of fluid loss which considerably reduce the plasma volume leading decreased venous return.

Is it Hyperthermia or Dehydration or Carbohydrate depletion effects Exercise in warm condition?

It is observed most of the athletes prefer to train and compete in warm climates, but on contrast it is widely agreed that the performance or the capacity of the athletes to continue the physical activity for longer duration is impaired more in a warm environmental condition than in cold condition (Hargreaves et al, 2008). Even at modest environmental temperature, some reduction in exercise capacity is apparent and the decrement in performance is progressively greater as the heat stress increases (Galloway and Maughan, 1997; Parking *et al*, 1999) by increasing the physiologic demands to cause fatigue or cessation of activity.

Exercise from sub maximal to maximal intensity in a hot environment is associated with dehydration and hyperthermia which are having a strong negative effects on the exercise performance, at least when the exercise duration exceeds a few minutes (Montain and Coyle, 1992; Sawka and Montain, 2000). Given that practical consideration of thermoregulatory responses of athlete participating in hard exercise prospectively result in metabolic heat production that can be balanced by heat loss by sweat evaporation when the ambient temperature is low (Hargreaves, 2008). This clearly indicates that athletes involve in high intensity sports like soccer, cycling and running have high rate of heat production that requires to be dissipated may increase the body core temperature due to failure of adequate heat dissipation mechanism. As this mechanism of sweating is very much influenced by gradient difference between the skin and ambient temperature, when the ambient temperature exceeds the skin temperature; heat is gained from the environment.

If the temperature is high and accompanied with high humidity, heat loss process is curtailed and body temperature may rise inexorably in spite of high rate of sweat secretion onto the skin. Hence the shift of sweating mechanism for longer time can deplete the fluid balance considerably and situation will be more severe when the humidity is high without the wind to cool the surface of the skin by evaporation of drips wastefully from the skin (American College of Sports Medicine, 1996). Suzuki (1980) observed the decrement of performance from 91 min (40° C) to 19 min (0° C) exercise time at 66% VO_{2max} was performed. Thus clearly indicates the influence of ambient temperature's effect on the capacity to exercise by determining the sweating process.

Moreover the athlete who experience even slight dehydration through sweating will concomitantly experience a significant increase in core body temperature above that experience during similar exercise conditions when euhydrated condition (Montain and Coyle 1992; Gaonzalez*et al*, 1995, 19997 and, 1998). In addition to this temperature rise the production of additional heat due to metabolism also compounds core body temperature accumulation which induces the reduction of endurance exercise during prolong exercise (MacDougall *et al*, 1999; Adams *et al* 1975; Suzuki, 1980). In fact high sweat rate may be necessary during high intensive exercise (Armstrong *et al*, 1991; Brouns, 1991) to ensure adequate dissipation of excessive metabolic heat produced; unfortunately many individuals have an inefficient sweating mechanism.

t is reported in long distance race the faster runners tend to lose sweat at a higher rate than the slower runners irrespective to finishing time. Thus, among competitors in all sporting events, it is obvious there will considerable variation in rate of sweat secretion between individuals (Cheuvront et al, 2007). Marathon runners competing under the same conditions and with the same fluid intake at low (10°C) ambient temperature may lose from as little as 1% to as much as 6% of the body weight during a race (0.7–4.2kg of body mass for a 70kg man) (Maughan& Miller, 1984).

At high ambient temperatures, sweat losses equivalent to 8% body weight may occur in marathon runners these amounts to 5–6L of water for a 70kg individual (Maughan&Shirreffs 1998). During prolonged performance, fluid loss especially during high temperature, about 580 Kcal is lost for every litre of sweat evaporated (Naghii, 2000) with and 80% of energy metabolised is liberated as heat (20% is utilised for mechanical work) and 80-90% of heat is lost through the sweating (Armstrong *et al*, 1991; Brouns, 1991).

However, given that hyperthermia and dehydration are synergistic to fatigue and aerobic exercise capacity (Caldwell *et al*, 1984) as a consequence of this in heat the serious athletes are pushed to be dehydrated by losing large volume of body fluid and the people who are less tolerant of hyperthermia and they usually collapse or fatigue at core temperature in range of 38.5°-39.5° C (Montain and Coyle, 1992; Sawka and Coyle' 1999; Cheuvront, 2001; Cheuvront and Haymes, 2001; Sawka*et al* 2001). This is clearly evident even in the heat acclimated runners the occurrence of fatigue was found when the core temperature reached approximately 40°C and dehydration was not much greater (Gonzalez-Alonso *et al*, 1999b; Nielsen *et al*., 2001; Neilsen and Nybo, 2003). But in exercise of short duration, the effects of hyperthermia are less clear, in fact some degree of dehydration may be beneficial in an event such as the high jump where body mass must be moved against gravity. Where as in long duration exercise of above one-hour duration is linked with large fluid loses via sweat evaporation to dissipate the heat as mechanism of heat dissipation to reduce thermal effects on the body. (Below *et al*, 1995)

Consequently the reduction in performance or capacity of endurance exercise is a part due to progressive dehydration that usually increases the core temperature by reducing skin blood flow (Coyle and Monatain, 1992a, b; Gonzalez-Alonso *et al*, 1995) to dissipate the heat by sweat evaporation (Kenney and Johnson, 1992, which put strain on cardio respiratory function (Gonzales-Alonso *et al*, 1999a), which is best evidenced by reduction in stroke volume. Dehydration of 1% loss of body weight during exercise induces increase in heart rate by 5-8 beats.min^{-1} and cardiac output declines significantly (Gonzalez-Alonso, 1998).

Furthermore, from the observation of Gonzalez-Alonso et al (1998) it is reported dehydration without the hyperthermia reduces the stroke volume by 7-8% and that hyperthermia without dehydration also reduces stroke volume by 7-8%. However the combination of dehydration and hyperthermia elicits synergistic effects in reducing stroke by more than 20% and it is noted that competitive athletes who exercise at high intensity in sports such as running, cycling and soccer have high rates of heat production that requires dissipation to the environment to prevent progressive heat storage and elevation of core temperature to above 39° degree Celsius. So during exercise in heat dehydration and hyperthermia can have profound effects on reducing the stroke volume and muscle blood flow, thus limiting oxygen delivery to exercising skeletal muscle.

Considerably the loss of 2% in body weight in the form of sweat have been reported to result in impairment of exercise tolerance ((Armstrong *et al*, 1985; Maughan*et al* 1998; Nielsen *et al*, 1984; Walsh *et al*, 1994) and losses of 5% of body weight can decrease the capacity for work by nearly 30% (Saltin*et al*, 1988). The loss of each millimetre of body fluid during exercise through sweat evaporation can lead to heat loss or dissipation of approximately 0.6 Kcal (Sawka*et al*, 1983) and it will take 8-9 min for the ingested fluid to reach in sweat gland for cooling the body during exercise in heat (Armstrong, 1991). Therefore dehydration may be more important concern than substrate depletion in causing fatigue during prolonged exercise, particularly in warm conditions with high ambient temperature where fluid losses are high and where it is impracticable to replace the losses during the exercise period.

Though the apparent benefit of elevation in body temperature by 1-2° C during warm up before facilitates performance during competition and training (Buskirk, 1969) is reported to prevent muscle injuries. It is very rare that dehydration would not cause hyperthermia any significant rise in dehydration will concomitantly leads to hyperthermia, but hyperthermia was prevented with dehydration by 4% of body weight when the exercise was performed in environmental temperature was below 5 degree Celsius and convective cooling was further enhanced by exposing the bare skin to speed wind (Gonzalez *et al*, 1998), where as in many athletic conditions the average heat production ranges between 800-1200W.

Effect of Carbohydrate during Exercise in heat: During the exercise in heat in addition to the effect of hyperthermia and dehydration on the endurance performance, it is been seen that the carbohydrate metabolism play a very important role during prolonged exercise as the glucose is the preferred fuel for skeletal muscle contraction (Douen*et al*, 1990) that is why the reliance on the carbohydrate as a source energy is increased as the intensity increases. Therefore in order to continue prolong exercise carbohydrate store is very essential. With the increase in intensity the active muscle mass becomes progressively more dependent on carbohydrate as source of energy, intramuscular stores of the glucose in the form of glycogen are strongly correlated to exercise endurance (Coggan *et al*, 1988).

Though in earlier studies reported that ingestion of carbohydrate during prolonged exercise has a glycogen sparing effect (Febbraio*et al*, 1994; Hargreaves *et al*. 1996) during prolonged exercise, but the same effects of carbohydrate ingestion during exercise in heat are not much observed. On contrary the need of the carbohydrate in endurance athletes are fairly constant in different environmental conditions, but exercise in heat result in a shift in substrate utilization towards the greater reliance on the carbohydrate (CHO) metabolism. This effect of increased carbohydrate oxidation is mainly due to increased muscle glucose utilization (Febrraio*et al*, 1994; Hargreaves *et al*, 1996). Again this shift in energy metabolism was attributed by enhanced sympathetic nervous activity in response to heat-stress (Febbraio*et al,* 1994), as reflected in increased plasma adrenaline concentrations (Johnsson*et al,* 1986). Therefore it is very necessary and important for the athlete who must perform for extended periods in hot environment to adequately replenish not only the lost body fluid by water consumption but also carbohydrate losses incurred during activity.

Besides there were trend of observations (Friztsche*et al*, 2000; Morris *et al*, 2003) of higher core temperature at the end of sustained exercise in carbohydrate trial than the placebo trial in heat (Davis *et al*, 1988); similar findings during 2 hr of exercise resulted in elevated core temperature in two trial of CHO with and without fluid. Comparatively CHO with fluid resulted 0.75°C lower core temperature than with fluid CHO trial (Fritzsche*et al*, 2000). Based on this claim of CHO feeding induce the dehydration during exercise in heat Horswill*et al* (2008) reported that there was no effect on metabolic rate or core temperature during 1 hr of steady state exercise by trained endurance male athletes at 30°C when carbohydrate was ingested with fluid volume. Febbario*et al* (1994) also reported that the exercise in the heat mainly associated with elevated core temperature accompanied with greater reliance on carbohydrate as a fuel for activity and also due to heat stress hepatic glucose production was increased with no alternation in glucose disappearance which lead higher blood glucose concentration (Angus *et al*, 2001; Hargreaves 1996) may be because of this CHO availability is not a limiting factor for exercise in heat only when the heat stress is un compensable, but the CHO supplement would important during exercise in heat when heat stress is compensable (Yaspelkis*et al*, 1991).

Carbohydrate feeding for Exercise: It is well reported on the benefits of carbohydrate ingestion for athlete during exercise alone and as well the ingestion is of mixture of water and electrolytes (Convertino*et al*, 1996; Casa et al, 2000). The benefits were expressed through performance and/ or reduced physiological stress, on an athlete's cardiovascular, central nervous and muscular systems. The positive effects of carbohydrate feeding carbohydrate in earlier studies of prolong exercise were typically observed in exercise duration of >2h of cycling (Bjorkman et al, 1984; Coyle *et al*, 1983; Hargreaves et al, 1984), as well running, performance (Ivy *et al*., 1983; Murray et al, 1989; Neufer*et al*, 1987). Some of these studies investigated endurance capacity (measured as time exhaustion at constant exercise intensity). Few studies have succeeded to observe positive effect with the time trial protocols in which the cyclist had to complete a certain set distance in shortest period of time. For example the improvement of 2.3% in performance in 40 km cycling time trial (~1 h) of well trained cyclist in the investigation of Jeukendrup and colleagues (Jeukendrup et al, 1997). From above studies reports to understand the mechanism behind the positive effect on the endurance performance, and it was postulated as there is greater contribution of exogenous carbohydrate from carbohydrate ingested in beverages, sport drinks or food, by sparing of liver glycogen, by prevention of hypoglycaemia, and the maintenance of high rate of carbohydrate oxidation necessary to sustain exercise intensity.

Whereas in exercise of 65-80% VO_{2max} in heat results in greater reliance on the carbohydrate due to high rate of carbohydrate oxidation leading to hypoglycaemia condition is observed at later stage of activity (Febbraio*et al* 1994; Hargreaves *et al*, 1996), which is again associated with increased muscle blood lactate. Therefore the carbohydrate feeding can spare the endogenous glycogen oxidation from the exercising muscles and this sparing mechanism from carbohydrate ingestion prevents the further depletion of liver glycogen, which is used in the later stage of the exercise.

The demands on body's carbohydrate stores i.e. muscle glycogen, liver glycogen and plasma glucose during the intensive exercise are somewhat different from the prolonged sub maximal exercise (Ahlborg*et al*, 1967; Bergstrom *et al*,1967; Coggan *et al* 1987) more recent studies have observed the positive effects on the performance relatively high intensity exercise (>75 VO_{2max}) lasting approximately 1 hr(Anantaraman, 1995; Below, 1995;Carter, 2003;). However some investigators observed the negative effect of carbohydrate feeding for high intensity exercise (Clark et al, 2000; Powers *et al*, 1990). For this Carter and colleagues (Carter *et al*, 2004) described that beneficial effect was unrelated to substrate availability because glucose infusion at high rates do not have effect on performance; rather Carter *et al* (2003) suggested that the effects might operate via central nervous system. In line of Carter and colleague's investigation of mouth rinsing protocol showed performance improvement of 2–3% even when that participant did not swallowed the carbohydrate.

Similarly the ingestion of carbohydrate (CHO) solution immediately before and during exercise is of benefit to performance by maintaining the blood glucose level (Coggan *et al*, 1987, Davis *et al*, 1992) or potential mechanism in reduction of muscle glucose utilization (Nicholas *et al*, 1999, Tzintzas*et al*, 1995 & 1996), when performing moderate to high intensive exercise. Investigation involving cycling (Burge *et al*, 1993., Coggan *et al*, 1987, Davis *et al*, 1992) and running protocol (Nicholas *et al*, 1999., Tzintzas*et al*, 1996) have shown that CHO intake enhances performance of high intensive exercise task of 1 h duration, compared to water or an artificially sweetened placebo.

Although the provision of CHO supplements as an ergogenic aid, during exercise have influenced the performance by altering the performance determinants by supplying substrate or fluid replacement (Jeukendrup*et al*, 2004). But in warm condition according to Fabbraio*et al* (1994) observation of greater rate of muscle glycogen depletion during exercise at an ambient temperature of 40ºC than at 20ºC. In addition the previous findings have shows that exercise capacity is reduced and for that CHO is not a limiting factor in hot (30ºC) environment compared with cooler (10ºC and 20ºC) environment (Galloway and Maurgan, 1997). However the studies conducted at around 20ºC in the absence of large heat stress the CHO solution composition is aimed at substrate provision rather than fluid replacement (Coyle *et al*, 1992).

In consistent to this Below *et al* (1995) examined whether water or carbohydrate alone, or in combination, would alter dynamics of cardiovascular and thermoregulatory responses to 50 min of exercise followed with task in heat (31.2º C, 54% humidity). In this cycling performance in heat was effected by the ingestion of large or small volume of fluid, they reported that large volume of fluid were more effective in improving performance regardless of carbohydrate content. To this Below *et al* (1995) added the ingestion of water or carbohydrate ingestion has independent and additive effect on the cycling performance in heat.

Conclusion

Thus the factor responsible for performance during exercise in warm and humid condition is not clearly delineated, is it the fluid replacement or substrate provision attenuates the dual effects of exercise and heat stress on the athlete's performance by optimizing the demands of exercise during performance. With critical observation of results of above studies involving running and cycling performance in humid large volume of fluid intake is been effective to reduce the risk of dehydration by retaining hydration level and improve the performance regardless of carbohydrate content.

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