Carbohydrate Supplementation and Prolonged Intermittent High-Intensity Exercise in Adolescents: Research Findings, Ethical Issues, and Suggestions for the Future

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Table of Contents

Abstract

In the last decade, research has begun to investigate the efficacy of carbohydrate supplementation for improving aspects of physical capacity and skill performance during sport-specific exercise in adolescent team games players. This research remains in its infancy, and further study would be beneficial considering the large youth population actively involved in team games.

Literature on the influence of carbohydrate supplementation on skill performance is scarce, limited to shooting accuracy in adolescent basketball players, and conflicting in its findings. Between-studies differences in the exercise protocol, volume of fluid and carbohydrate consumed, use of prior fatiguing exercise, and timing of skill tests may contribute to the different findings. Conversely, initial data supports carbohydrate supplementation in solution and gel form for improving intermittent endurance running capacity following soccer-specific shuttle-running. These studies produced reliable data, but were subject to limitations including lack of quantification of the metabolic response of participants, limited generalization of data due to narrow participant age and maturation ranges, use of males and females within the same sample, and non-standardized pre-exercise nutritional status between participants.

There is a lack of consensus regarding the influence of frequently consuming carbohydrate-containing products on tooth enamel erosion and development of overweight / obesity in adolescent athletes and non-athletes. These discrepancies mean that the initiation, or exacerbation, of health issues due to frequent consumption of carbohydrate-containing

products by adolescents cannot be conclusively refuted. Coupled with the knowledge that consuming a natural, high-carbohydrate diet ~3-8 h before exercise can significantly alter substrate use and improve exercise performance in adults, a moral and ethical concern is raised regarding the direction of future research in order to further knowledge while safeguarding the health and wellbeing of young participants.

It could be deemed unethical to continue study into carbohydrate supplementation while ignoring the potential health concerns and the possibility of generating similar performance enhancements using natural dietary interventions. Therefore, future work should investigate the influence of pre-exercise dietary intake on the prolonged intermittent, high-intensity exercise performance of adolescents. This would enable quantification of whether pre-exercise nutrition can modulate exercise performance, and if so, the optimum dietary composition to achieve this. Research could then combine this knowledge with ingestion of carbohydrate-containing products during exercise to facilitate ethical and healthy nutritional guidelines for enhancing the exercise performance of adolescents.

This article addresses the available evidence regarding carbohydrate supplementation and prolonged intermittent, high-intensity exercise in adolescent team games players. It discusses the potential health concerns associated with frequent use of carbohydrate-containing products by adolescents and how this affects the research ethics of the field, and considers directions for future work.

1. Introduction

Several studies have demonstrated an ergogenic effect of carbohydrate supplementation immediately before, and during, prolonged intermittent, high-intensity exercise designed to replicate the physiological demands of team games, particularly, but not exclusively, soccer.[1-9] The ergogenic effect has been most consistently observed on time to exhaustion during intermittent running,[3-5,7] but improvements in sprint performance[1,8,9] and performance of sport-specific skills[1,10,11] has been documented. All of this research used adult participants.

Approximately 3.4 million children (≤ 11-13 years, Tanner stages 1 and 2)[12] and adolescents (maturational stage between childhood and adulthood, ~12-18 years, Tanner stages 3 and 4)[12] aged 6-16 years regularly participated in soccer, rugby, or field-hockey in England and Scotland between 2002-2007.[13-15] In soccer alone, the world-wide youth (<18 years) participation rate is estimated at ~22 million.[16] However, the actual figure is likely to be considerably higher as not all young participants are affiliated with national or international organizations, and therefore would not be considered in official statistics. There is also evidence that athletic adolescents regularly consume carbohydrate-containing supplements, although this is not as well documented as for adults.[17] Braun et al.[18] reported that 69% of 164 elite German athletes (mean age 13.3 – 21.7 years) across multiple sports consumed sports drinks and 64% consumed other carbohydrate preparations (bars, powders, gels, and carbohydrate-protein combinations). The prevalence of supplement use in the athletes was significantly greater than in the general German population aged 14-24 years (16-24% prevalence).[19] Slater et al.[20] found that out of 160 national-level Singaporean athletes (age range < 15 years to > 35 years) sports drinks were the most popular supplement, used by

39% of respondents. Currently, insufficient data exists to estimate how much more carbohydrate athletic adolescents are ingesting in their diet due to supplementation. However, it is clear that the high participation rate in youth team games, and evidence of carbohydrate supplementation practices by adolescent athletes, is not matched by an associated research output investigating the performance and physiological responses of adolescents during team games with or without carbohydrate supplementation.

Pre-pubertal children and adolescents oxidize more fat at a given relative exercise intensity than adults.[21-24] This appears to be inversely related to maturation.[24-26] Increased fat oxidation may be due to higher intramuscular triglyceride levels, higher free fatty acid turnover during exercise, or an underdeveloped glycolytic system,[25] although the latter suggestion is becoming increasingly challenged.[27] Endogenous carbohydrate use is lower in children and adolescents compared with adults.[26,28] Despite this, body mass-relative exogenous carbohydrate oxidation rates of ~0.17-0.26 $g.kg^{-1}$ body mass (BM) have been reported in 9-17 year old males.[23,29,30] This is comparable to trained, and higher than untrained, adult males.[31] The relative provision of exogenous carbohydrate to total energy requirement may also be significantly greater in boys (~16-30%)[23,26,29,30] than men (~10-20%).[30-32] Exogenous carbohydrate oxidation rate is sensitive, and inversely related to, pubertal status,[26] but may still be significantly greater in mid- to late-pubertal boys than adults.[26] No significant difference in exogenous carbohydrate oxidation rate has been observed between girls aged 12 and 14 years.[33] However, participants in this study only differed slightly in maturation status, which may have masked differences. The potential influence of the menstrual cycle should also be considered, as estrogen and progesterone may increase fatty acid availability, attenuating carbohydrate oxidation.[34]

Increased exogenous carbohydrate oxidation in young people may be due to maturational differences in glucose transport, particularly regarding insulin-sensitive glucose transporter type 4 (GLUT4) protein recruitment, and a greater rate of intestinal absorption of ingested carbohydrate,[30] although this is doubtful.[35] Insulin-stimulated glucose transport from the blood appears to be higher in pre-pubertal children than pubertal children or adults.[36] This may be associated with a period of insulin resistance that occurs during puberty,[36] and/or an inverse relationship between maturation and GLUT4 recruitment.[37]

The different metabolic responses of young people to exercise suggests their carbohydrate requirements may be different to those of adults.[38] However, most available work has compared adults with pre-pubertal children; adolescents and adults need to be compared under identical conditions to quantify the influence of biological changes during the transition to adulthood on endogenous and exogenous substrate utilization.[38] It does appear that data from adult studies should not be applied to adolescents, and research must be conducted using adolescents as participants. In recent years, this research output has begun, but remains scarce.

This article evaluates the available evidence on carbohydrate supplementation immediately before, and during, prolonged intermittent, high-intensity exercise in adolescent team games players. Potential health concerns associated with frequent use of carbohydrate-containing products are discussed, along with the impact of these concerns on research ethics. Suggestions are made for the direction of future work. It is not the purpose of this article to discuss mechanisms of enhancement with carbohydrate supplementation, and the reader is referred elsewhere for this information.[39]

Searches in MEDLINE (PubMed) were performed using the terms ‘carbohydrate adolescent prolonged intermittent exercise’, ‘carbohydrate adolescent intermittent exercise’, ‘carbohydrate adolescent team games’, ‘carbohydrate adolescent endurance exercise’, ‘carbohydrate adolescent exercise capacity’, and ‘carbohydrate adolescent sprint performance’. These searches were repeated with the term ‘adolescent’ replaced with ‘young people’ and ‘child’. The ‘related citations’ service in PubMed was explored for each highlighted abstract, and the reference list of each article was hand searched. Searches were not date-limited as the total research output is manageable without using this limitation. Only studies related to team games exercise, and employing adolescent team games players, were incorporated. Studies that did not make a direct comparison between a carbohydrate supplement and water or a placebo were excluded. Based on these criteria, five articles were selected.[40-44]

2. Carbohydrate supplementation immediately before and during prolonged intermittent, high-intensity exercise in adolescent team games players

2.1 Carbohydrate supplementation research

All studies discussed in this section are summarized in Table I. Two studies have investigated the influence of carbohydrate ingestion on skill performance of adolescents completing a basketball-specific protocol.[40,41] Dougherty et al.[40] found a significant improvement in shooting accuracy when 12-15 year old participants remained euhydrated with a 6% carbohydrate drink compared with water or an induced state of dehydration equivalent to 2% body mass (no fluid was consumed during this trial). This indicates an additive effect of carbohydrate over fluid alone. To induce body mass loss, participants completed 2 h of intermittent treadmill and cycle exercise at 35^{o}C and 20% relative humidity, then rested for 1 h prior to the basketball protocol. This would likely have increased the fatigue the participants felt during the protocol. It is unclear why the investigators did not induce body mass loss by passive heating which may have ameliorated some of the potential effects of fatigue, although it is possible that passive heating was denied in the ethical approval process. In addition, a no fluid trial cannot be blinded successfully against fluid intake trials.

Carvalho et al.[41] reported that the shooting accuracy and sprinting performance of 14-15 year old male basketball players was not significantly influenced by *ad libitum* consumption of an 8% carbohydrate solution or water compared with no fluid ingestion during a 90-min basketball-specific training session. Participants' pre-exercise hydration status was assessed by measurement of body mass, which may not be reliable.[45] Additionally, that the shooting tests were performed after training reduces ecological validity. There were also issues with control of environmental conditions that could have influenced the data. Finally, the selection of a no fluid, water, and carbohydrate trial means a potential placebo effect cannot be discounted, although the lack of significant effect of the carbohydrate solution somewhat negates this.

The exercise protocol of Carvalho et al.[41] did not include prior exercise. Furthermore, participants consumed fluid *ad libitum* rather than in specific volumes. The rate of carbohydrate ingestion in the Dougherty et al.[40] study could not be calculated. Therefore, it cannot be discounted that differences in the rate and/or absolute intake of carbohydrate may account for the different findings. Additionally, participants in the Dougherty et al.[40] study performed skill tests during the protocol, in contrast to Carvalho et al.[41]

PLEASE INSERT TABLE I HERE

Phillips et al.[42] published the first study investigating carbohydrate supplementation immediately before, and during, laboratory exercise designed to replicate the physical demand of soccer in adolescent team games players. The authors used a modified version of the Loughborough Intermittent Shuttle Test consisting of four blocks of 15-min intermittent shuttle running followed by an intermittent run to exhaustion. This modification was made as adolescents commonly play soccer for a shorter duration than adults (approximately 60 min vs. 90 min).[46] While ecological validity was not maximized, as the run to exhaustion was completed after the 60-min of intermittent exercise, it was improved by using this shorter protocol. Fifteen team games players aged 12-14 years (10 males and 5 females) ingested a 6% maltodextrin solution and a placebo matched for taste, color, and mouth feel in a randomized, counterbalanced, double-blind fashion. Ingestion volumes were the same as previous adult work (5 $ml.kg^{-1}$ BM in the 5-min pre-exercise period and 2 $ml.kg^{-1}$ BM at the end of each 15-min exercise block).[7] Participants ran on average 24.4% longer when consuming carbohydrate. Blinding statistics demonstrated that a placebo effect was an unlikely cause of this finding (47% of participants correctly identified both solutions). No significant treatment effect was reported for sprint times or any physiological variables except for heart rate at exhaustion, which was significantly greater in the carbohydrate trial.

In a follow up study, Phillips et al.[43] investigated the influence of different carbohydrate concentrations (2%, 6%, and 10% maltodextrin solutions) on the same variables as their initial study. The identical exercise protocol and measurements, and the fact that the participants (n = 7, 5 males and 2 females) all took part in the first study, strengthens between-study comparisons. The 6% solution significantly improved time to exhaustion by 34% compared with the 10% solution, and by 14.6% compared with the 2% solution, although this was not statistically significant. Time to exhaustion was a non-significant 17.1% longer with the 2% solution compared with the 10% solution. There was no significant influence of carbohydrate concentration on sprint times or physiological responses.

A third study from the same laboratory, again using the same protocol and measurements, compared a maltodextrin gel to a taste and texture-matched placebo gel.[44] The age range and maturation status of participants was similar to the previous investigations. Body-mass relative gel ingestion rate was equal to that of Phillips et al.[42] and Phillips et al.[43] (6% trial), enabling a direct comparison between the efficacy of an isoenergetic carbohydrate solution and gel.[44] The carbohydrate gel significantly increased mean time to exhaustion by 21.1%, with no treatment effect on sprint time or physiological responses. The authors asked participants to guess which gel they consumed before exercise and again on completion of the protocol. Only 36% of participants correctly guessed both gels pre-exercise, and 18% post-exercise. This suggests successful gel blinding, and indicates that exercise did not enable participants to more accurately choose the gel that was administered.

Similarities between these studies enable a more detailed inspection of the data. Cohesive analysis demonstrates an apparent sound degree of between-study reliability (Table II). It therefore appears that these studies generated reliable, comparable data. Despite this, there are some limitations. For ethical and consensual reasons associated with use of invasive procedures, the exercising metabolic responses of participants could not be determined. This would have added an extra dimension by possibly quantifying or refuting mechanisms for observed effects. Ethical restrictions also prevented quantification of biological maturation using Tanner stages; however, maturation was estimated using time from peak height velocity.[47] The results cannot confidently be extrapolated to adolescents outside of the age range and biological maturation of the participants involved. Therefore, more research is required investigating different ages and maturational states. The use of males and females may have increased data variance due to potential between-gender differences in exercising physiological and metabolic responses.[22,34] Gender comparisons could not be undertaken as an insufficient number of females were recruited for robust statistical analysis. While pre-exercise nutritional status was standardized within-participants, it may have been different between-participants, which could have increased data variance (section 2.2).[48,49] However, an ergogenic effect of carbohydrate ingestion in the absence of a pre-exercise fasting period may be a more ecologically valid finding, as it is unlikely that athletes will prepare for training or competition by fasting. It would also have been beneficial to include a placebo trial in the Phillips et al.[43] study.

PLEASE INSERT TABLE II HERE

2.2 Pre-Exercise Nutritional Status

Endurance capacity and repeated sprint performance during prolonged intermittent, high-intensity running are significantly enhanced following ingestion of a pre-exercise carbohydrate-rich meal compared with low pre-exercise carbohydrate intake[50] or fasting.[51] This may be due to greater pre-exercise muscle glycogen availability[48,49,52] and an associated greater rate of carbohydrate oxidation during exercise.[49,53,54]

Pre-exercise carbohydrate feeding along with carbohydrate ingestion during exercise (combined carbohydrate feeding) has generated conflicting findings, with some reporting significant improvements in steady-state endurance running capacity and performance compared with carbohydrate ingestion during exercise or a fasting trial.[54,55] Other work has reported no significant improvement in cycling or running performance with combined carbohydrate feeding compared with carbohydrate ingestion during exercise alone.[56,57] Discrepancies may be due to differences in the timing and composition of the pre-exercise feeding, the composition, amount, and timing of carbohydrate ingested during exercise, and the exercise intensity and duration. However, it does appear that pre-exercise nutritional status can significantly influence substrate availability and exercise performance, and may alter the influence of carbohydrate ingested during exercise. While most of this work has used steady-state protocols, the greater oxidation of carbohydrate during intermittent exercise at the same relative intensity[58] indicates a similar effect could be expected during this form of exercise. Therefore, the pre-exercise nutritional status of participants should be considered, and must be disclosed by researchers, to facilitate clearer interpretation of study findings.

3. Potential health concerns of carbohydrate supplementation in adolescents

The research in section 2 provides novel data to support carbohydrate supplementation for improving aspects of physical capacity and skill performance in adolescent team games players. Therefore, it is tempting to call for continued study into the manipulation of variables such as carbohydrate composition, solution osmolality, and carbohydrate ingestion rate in order to further develop carbohydrate intake guidelines for the youth team games population. Indeed, this research would be valuable in determining the optimal carbohydrate supplementation regime for adolescent team games players. However, focusing solely on optimizing the composition of a carbohydrate product consumed immediately before and during exercise is to ignore two key factors. The first is that a nutritional supplement should be viewed as a complement to an individual's diet, usually to correct inherent dietary deficiencies, rather than a primary source of nutritive intake. Therefore, natural dietary intake should be quantified, and altered if required, to optimize its impact on exercise performance and reduce the emphasis on supplementation (section 2.2). The second is the potential health issues associated with frequent consumption of carbohydrate-containing products.

3.1 Dental Erosion

A small number of studies have investigated the relationship between regular consumption of sports drinks and erosion of tooth enamel.[59] Research focusing specifically on adolescents, and adolescent athletes in particular is even sparser.

Commercially-available sports drinks have a pH of 3-4[60] and an erosive potential similar to diet cola but less than cola or orange juice.[61,62] Ingestion of sports drinks has been causally linked to dental erosion in adult athletes.[63,64] Consumption of acidic solutions when the mouth is dry or oral saliva content is attenuated, as can occur during exercise,[64] can exacerbate dental erosion.[65]

Conversely, other research has documented that consumption of sports drinks is not causally linked to tooth enamel erosion in athletic or non-athletic adolescent populations.[66,67] This might suggest that attempting to isolate one aspect of dietary intake and draw inferences may be too simplistic, particularly when it is considered that sports drinks are no more acidic than a variety of other common drinks.[59] Intrinsic (tooth resistance, saliva production /

composition, mouth anatomy, gastric reflux) and extrinsic (diet, lifestyle, dental hygiene, regularity of dental check-ups) factors, and the contact time between the solution and the teeth[60] influence susceptibility to dental erosion.[68] The complexity of influencing factors is perhaps one of the key reasons why more research is needed.[69] This is particularly relevant given the recent statement from the American Academy of Pediatrics[60] that routine ingestion of sports drinks by adolescents should be avoided or restricted due, in part, to the potential for increased dental erosion. It was further recommended that water, rather than sports drinks, be promoted as the principal source of adolescent hydration. There is ambiguity here, as the recommendations do not differentiate between athletic or non-athletic populations. The apparent discrepancy between these statements and the research discussed above certainly warrants further investigation. Currently, the interaction of intrinsic and extrinsic risk factors coupled with different levels of carbohydrate supplement consumption on the risk of dental erosion in the athletic and non-athletic adolescent population is not sufficiently understood.

3.2 Development of Overweight or Obesity

Numerous prospective, longitudinal, and intervention studies have reported a significant association between consumption of sugar-sweetened drinks and the development of overweight / obesity in children and adolescents.[70-73] However, very little work has examined the impact of physical activity levels on this association, and no studies have specifically investigated the relationship in adolescent athletes. Mundt et al.[74] conducted the only study so far to investigate the relationship between sugar-sweetened drink consumption, physical activity, and fat mass development in children and adolescents. Fat mass was inversely related to physical activity levels, with no significant association between sugar-sweetened drink consumption and fat mass at any age. This suggests that physically active, or athletic, adolescents may not increase fat mass with sugar-sweetened drink ingestion. However, the average daily energy intake of the participants, even with sugar-sweetened drink consumption, was notably lower than national age-matched means. This may have masked any potential influence of consumption on the development of fat mass. More work is required, as the results of a single study, particularly with a potentially confounding factor, does not represent sufficient evidence on which to base inferences, particularly regarding adolescent health.

While the nature of the association is still under debate, current evidence indicates a positive relationship between sugar-sweetened drink consumption and the development of overweight / obesity in young people.[73] However, it is not yet possible to isolate the specific impact of ingesting carbohydrate-containing products such as sports drinks on this potential relationship, or how the relationship may be influenced by physical activity or athletic status. While there is currently no research evidence to show clearly that athletic adolescents are at increased risk of overweight / obesity with carbohydrate supplementation, there is also no clear evidence to show that they are not at increased risk. More data is required on the interaction of physical activity levels and consumption of carbohydrate-containing products of differing compositions and at different rates in adolescent athletes. This is supported by the statement of Mundt et al.[74] that there may be an as-yet unidentified threshold level of sugar-sweetened drink consumption required to influence fat mass. Until this data is available, the only ethically acceptable course of action is to progress supplementation research cautiously, and to consider a potential influence of sugar-sweetened drinks on the development of adolescent overweight / obesity.

4. Impact of potential health concerns on the ethics of carbohydrate research in adolescents

The potential health concerns of ingesting carbohydrate-containing products, while still under debate, are a cause for concern when researching carbohydrate supplementation in the youth population. It is deemed ethically acceptable for adolescents to participate in research if the relevant knowledge cannot be gained using adults, if they are exposed to no more than negligible risk of harm, and if their interests always prevail over those of the research.[75] It is inappropriate to apply adult exercise and substrate metabolism data to adolescents.[25-30] Additionally, from the perspective of individual research studies, minimizing the risk of harm and protecting the interests of young participants is a pre-requisite for ethical approval.

Research discussed in sections 3.1 and 3.2 suggests that the initiation, or exacerbation, of negative health issues in adolescents by carbohydrate supplement use cannot be conclusively discounted. This represents a moral and ethical dilemma of how best to continue research in this field. It could be argued that it is unethical to deny a young athlete the opportunity to improve their performance through evidence-based carbohydrate supplementation. However, ignoring the fact that detrimental health outcomes, even potential ones, associated with this practice cannot be discounted would be irresponsible, and would violate two key criteria for the ethical conduct of adolescent research (exposure to no more than negligible risk of harm, and ensuring participants interests prevail over those of the research). Regarding the already published work, it is important that researchers are aware of the moral and ethical importance of evaluating the impact the findings may have on the youth population. It is imperative that as well as the positive findings, the potential negative aspects and knowledge limitations of the research are communicated at all opportunities. This should include feedback provided to individual research participants, the research paper, conference presentations, general public communications, and personal conversations with study investigators.

With these concerns in mind, a key question arises regarding the work discussed in section 2. Research exists in adults to support the ingestion of appropriate pre-exercise meals for facilitating exercise enhancement (section 2.2). Frequent consumption of carbohydrate-containing products such as sports drinks may also significantly increase the risk of dental erosion, dependent in part on other risk factors, and the risk of developing overweight / obesity, in adolescents. Therefore, should adolescent team games players be encouraged to consume carbohydrate-containing products prior to every training session and match? Until research can quantify the potential health issues with less ambiguity, and due to the still minimal research output investigating carbohydrate supplementation in adolescents, the likely answer, from the perspective of safeguarding the moral and ethical standards of the research and its participants, is no.

This does not mean that the findings in section 2 are unimportant, should be ignored, or should not be developed. On the contrary, this work has provided a foundation and stimulus for further study, and it is vital that this study grows and progresses, due to the large youth population involved in team games and who are greatly underrepresented in the scientific literature. However, it is important that research progresses not just with knowledge development as the goal, but in tandem with the aim of furthering knowledge in the most practical, applicable, and ethical fashion.

5. Future Research Requirements

From the discussion in sections 3 and 4, perhaps the most obvious and advantageous avenue, from a knowledge development, moral and ethical perspective, would be to investigate the influence of pre-exercise nutritional interventions on adolescent performance during prolonged intermittent, high-intensity exercise. Studying the influence of pre-exercise meals of differing energy content, energy composition, and glycaemic index would enable quantification of whether pre-exercise dietary intake can modify exercise performance in adolescents, and if so, the optimum composition of natural foods required to maximize performance. Development of this research could then combine pre-exercise diet with ingestion of carbohydrate-containing products during exercise, as has been done in adults.[55,56] This would enable development of guidelines for optimal pre- and during-exercise carbohydrate ingestion that place a strong emphasis on sound dietary practices in conjunction with an appropriate supplementation strategy, rather than focusing solely on supplementation.

6. Practical Implications and Educational Messages

The research discussed in section 2 initiates a new direction in pediatric exercise physiology research. The findings provide insight into the relationship between a participant population and form of exercise that frequently interact on a large scale, but until recently have received almost no concurrent attention from the sports science research community. The work initiates knowledge into carbohydrate supplementation and adolescent team games exercise, and begins to bridge the gap between participation in team games and the scientific knowledge to enable those participants to maximize their enjoyment and performance potential. The findings could be used to inform and support the ongoing carbohydrate ingestion practices of adolescent team games players of the age, skill level, and maturation range used in the studies. They could also be used to encourage adolescent athletes to explore carbohydrate as a method of exercise enhancement where previously they had not.

The issues discussed in section 4 and the directions proposed in section 5 should be seriously considered by researchers wishing to contribute to the body of knowledge in this field. This is of particular importance when considering the target population of the research, and that the potential health issues associated with frequent consumption of carbohydrate-containing products in adolescents, and factors that may influence these issues, have not been fully elucidated. Implementing these suggestions would enable the development of a research culture, and the formulation of carbohydrate ingestion guidelines, that seek to enhance the prolonged intermittent, high-intensity exercise performance of adolescents while also safeguarding their health and well-being.

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Table I Summary of research investigating the influence of carbohydrate supplementation immediately before and during prolonged intermittent, high-intensity exercise on the physical capacity, physiological responses, and skill performance of adolescent team games players.

Study	Subjects	Protocol	Supplementation	Significant Findings	Limitations
Dougherty et al.[40]	15 male basketball players (mean 13.5 years)	2 h of intermittent treadmill and cycle exercise in 35°C heat and 20% relative humidity, 1 h recovery, then a simulated basketball match	Euhydration with a 6% carbohydrate solution Euhydration with water No fluid trial	Significant improvement in shooting accuracy when ingestion of carbohydrate compared with water ingestion and no fluid ingestion	2 h of exercise in the heat may have increased fatigue the participants felt during the basketball protocol Placebo effect cannot be discounted
Carvalho et al.[41]	12 national level male basketball players (mean 14.8 years)	90-min basketball specific training session, followed by performance drills (shooting and sprinting)	*Ad libitum* ingestion of an 8% carbohydrate solution *Ad libitum* ingestion of water No fluid ingestion	No significant influence of carbohydrate ingestion on shooting accuracy or sprint performance compared with water or no fluid ingestion	Pre-exercise hydration status assessed by changes in body mass only Performance drills were undertaken after the training session Issues with control of environmental conditions Placebo effect cannot be discounted
Phillips et al.[42]	15 (5 F) trained soccer, rugby, and field-hockey players (mean 12.7 years)	Modified LIST protocol (4 x 15-min blocks)	6% carbohydrate solutions 5 $ml.kg^{-1}$ BM prior to exercise 2 $ml.kg^{-1}$ BM every 15-min during exercise	24.4% longer time to exhaustion Sprint performance unchanged Significantly higher heart rate at exhaustion in carbohydrate trial	Metabolic measurements not taken Males and females used, which may increase data variance Pre-exercise nutritional status not standardised between-participants

Phillips et al.[43]	7 (2 F) trained soccer, rugby, and field-hockey players (mean 13.3 years)	Modified LIST (4 x 15-min blocks)	2%, 6%, and 10% carbohydrate solution 5 $ml.kg^{-1}$ BM prior to exercise 2 $ml.kg^{-1}$ BM every 15-min during exercise	34% longer time to exhaustion with 6% compared to 10% solution Strong trend for longer time to exhaustion with 6% compared to 2% solution, and 2% compared to 10% solution Sprint performance unchanged No influence on physiological responses	Metabolic measurements not taken Males and females used, which may increase data variance Pre-exercise nutritional status not standardised between-participants No placebo trial
Phillips et al.[44]	11 (1F) trained soccer, rugby, and field-hockey players (mean 13.5 years)	Modified LIST (4 x 15-min blocks)	Carbohydrate gel 0.8 $ml.kg^{-1}$ BM prior to exercise 0.3 $ml.kg^{-1}$ BM every 15-min during exercise	21.1% longer time to exhaustion Sprint performance unchanged No influence on physiological responses	Metabolic measurements not taken Males and females used, which may increase data variance Pre-exercise nutritional status not standardised between-participants

LIST = Loughborough Intermittent Shuttle Test**;** **F =** female**;** **BM =** body mass

Table II Summary of performance and physiological response data of all participants for the studies of Phillips et al.[42,43,44]. Data presented is that which was significantly influenced by treatment or time in at least one study. Data are mean ± SD.

	Phillips et al.[42]		**Phillips et al.[43]**			**Phillips et al.[44]**	
Intermittent Endurance Capacity	Carbohydrate	Placebo	2%	6%	10%	Carbohydrate	Placebo
Time (min)	5.1 ± 1.8	4.1 ± 1.6	4.8 ± 1.2	5.5 ± 0.8	4.1 ± 1.5	4.6 ± 2.0	3.8 ± 2.4
Percentage difference	+ 24.4		+ 17.1[a]	+34.1[a] +14.6[b]		+ 21.1	
Sprint Times (s)	2.63 ± 0.24	2.66 ± 0.25	2.55 ± 0.26	2.56 ± 0.26	2.58 ± 0.30	2.58 ± 0.16	2.61 ± 0.22
Heart Rate (beats per min)	169 ± 10	166 ± 10	162 ± 7	166 ± 6	165 ± 7	162 ± 7	161 ± 10
Ratings of perceived exertion	7.1 ± 1.5	7.1 ± 1.5	6.1 ± 1.5	6.3 ± 1.5	6.4 ± 1.6	6.7 ± 1.5	6.7 ± 1.5
Gastric Disturbances							
Gut fullness	3.9 ± 1.7	3.7 ± 1.7	4.7 ± 1.3	4.2 ± 1.7	4.0 ± 1.3	4.8 ± 1.8	4.1 ± 1.4
Gastric discomfort	3.8 ± 2.3	3.3 ± 2.2	2.9 ± 1.3	3.2 ± 1.4	2.9 ± 1.6	3.9 ± 2.1	3.8 ± 2.1

[a] compared to 10% trial; [b] Compared to 2% trial