EFFECTS OF MILD DEHYDRATION ON THERMOREGULATION, PERFORMANCE AND MENTAL FATIGUE DURING AN ICE HOCKEY SCRIMMAGE

by

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ABSTRACT

EFFECTS OF MILD DEHYDRATION ON THERMOREGULATION, PERFORMANCE AND MENTAL FATIGUE DURING AN ICE HOCKEY SCRAMMAGE

Mark Edward Linseman
University of Guelph, 2011

Advisor:
Professor L.L. Spriet

This study investigated the effects of progressive dehydration by 1.5-2.0% body mass (BM) (NF) on core temperature (Tc), heart rate (HR), on-ice performance, and mental fatigue during a 70-min scrimmage, compared to maintaining BM with a carbohydrate-electrolyte solution (CES). Compared to CES, Tc was significantly higher throughout the scrimmage in NF. Players in NF had reduced mean skating speed and time at high effort between 30-50 min of the scrimmage. Players in NF committed more puck turnovers and completed a lower percentage of passes in the last 20 min of play. Post-scrimmage shuttle skating time was higher in NF. Hockey fatigue questionnaire total score and Profile of Mood States fatigue score was higher in NF. The results indicate that mild dehydration compared to maintaining BM with a CES resulted in increased Tc, decreased skating and puck handling performance, and increased mental fatigue during an ice hockey scrimmage.
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<td>Adenosine triphosphate</td>
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<td>BM</td>
<td>Body mass</td>
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<td>bpm</td>
<td>Beats per minute</td>
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<td>CES</td>
<td>Carbohydrate electrolyte solution</td>
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<tr>
<td>CHO</td>
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<td>Free fatty acid</td>
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<td>USG</td>
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<td>VO_{2max}</td>
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CHAPTER 1: REVIEW OF LITERATURE

The aim of this review of literature is to describe the intense nature of the game of ice hockey, and the reasons for hockey players to avoid dehydration and take in carbohydrate (CHO) during practices and games. An assessment of current hydration and nutrition practices of ice hockey players is provided. A review of the pertinent literature will provide information regarding the effects of dehydration and CHO intake on high intensity intermittent exercise and team sports, and identify gaps in knowledge as they pertain to ice hockey.

Physiological demands of ice hockey

Ice hockey is a sport in which players on two opposing teams skate on a sheet of ice and attempt to score a puck into the opposing team’s net, while also attempting to prevent the opposing team from scoring. A regulation-length game consists of three 20-minute (min) periods, with a 10-15 min break between each period. There are 5 players and one goaltender on the ice at one time on each team. While the three forwards are mainly responsible for scoring goals and the two defensemen are primarily responsible for preventing the opposing team’s players from scoring, all players are involved in both. Each team’s goaltender stands in front of the net and is directly responsible for preventing goals from being scored. The review of literature and subsequent study in this thesis focuses on forwards and defensemen. Depending on the level of hockey, there are either 9 or 12 forwards and 6 defensemen on each team. Players are able to exert themselves maximally for a short period of time and then return to the bench to rest. A
typical “shift” on the ice lasts 30-85 s, followed by a recovery period of 2-5 min (Montgomery 1988; Cox et al. 1995).

Speeds can reach in excess of 8 m·s$^{-1}$ during all-out skating efforts, with average speeds over the course of an entire game around 4 m·s$^{-1}$. In one game, players skate between 3500 - 6000 m (Green et al. 1976, Akermark et al 1996). Depending on position, players spend 30 to 50% of a 60-min game on the ice. Defensemen usually spend more time on the ice than forwards, but at a lower speed (Logan-Sprenger et al. 2011a, Green et al. 1976).

Ice hockey is a sport consisting of short bursts of high intensity effort separated by extended periods of rest, and requires contributions from both glycolytic and oxidative energy systems (Montgomery 1988). In other words, hockey players need to have a combination of both speed and endurance.

During a game, average on-ice heart rate (HR) has been measured between 85-90% of maximum (Green et al. 1976, Green 1988, Montgomery 1988), and on-ice blood lactate levels have been shown to increase by four to five times the resting value (Green et al. 1976). After repeated bouts of intermittent supramaximal skating efforts, similar to the maximal effort exerted intermittently by a player throughout a game, a 10-fold increase in blood lactate, a 60% decrease in creatine phosphate, and an 18% decrease in muscle adenosine triphosphate (ATP) and were observed (Green 1978a).

Defensemen usually spend more time on the ice, and have shorter break times between shifts, but skate at a lower average speed (Green et al. 1976; Akermark et al. 1996). One study reported a 10-15 bpm lower average HR for defensemen than forwards (Green et al. 1976) while another reported no difference (Green 1978b). No differences
in muscle lactate production or glycogen depletion have been reported between positions in any studies.

The average work intensity during on-ice time has been estimated at 70-80% maximal oxygen uptake (VO\textsubscript{2max}) based on treadmill determinations of the relationship between HR and oxygen uptake (Green et al. 1976). It is reasonable to assume an appreciable amount of time is spent at or above VO\textsubscript{2max}. Attempting to use skating speed to quantify oxygen cost is problematic and leads to gross underestimations. A player is only skating at an elevated intensity for ~15% of their time on the ice (Bracko et al. 1998). However, almost 10% of the player’s time on the ice is also spent “struggling for a puck or position”, which requires a high upper body effort. Other actions such as quick turns and changes of direction, passing and shooting, all require high levels of effort but do not contribute to a player’s speed. Taken together, this indicates that accurately quantifying energy expenditure during a hockey game is very difficult.

Given the intense physiological requirements of ice hockey, it would be expected that those players who are in better physical condition would perform better. Over the years, players have put more emphasis on proper physiological conditioning and strengthening. Since 1979, VO\textsubscript{2max} in forwards has steadily increased, while height and weight have increased for defensemen (Quinney et al. 2007). In the past ~10 years, player body fat % has decreased (Quinney et al. 2007). This allows players to skate faster at a given effort. Adding 5% excess mass to a hockey player resulted in a 4% decrease in skating speed (Montgomery 1982). Some physiological characteristics may be related to a player’s overall hockey skill. The VO\textsubscript{2max} of NCAA division 1 players was significantly correlated to the number of scoring chances they had in a game (Green
et al. 2006). Strength is another key component that may determine player performance. When compared to junior-level players, professional players could lift significantly more weight, had greater jump height, and better performance in a 10-m sprint (Hoff et al 2005).

In addition to the high physiological demand placed on the ice hockey player, there is also a large cognitive requirement. Teams create various offensive and defensive strategies to be employed during the game, and players must be in the correct position and be able to properly execute these strategies. Players must also be attentive and alert in order to make good decisions regarding passing the puck to another teammate without interception, and shooting and aiming the puck toward the goal.

Players will inevitably fatigue as a hockey game progresses. Toward the end of a hockey game, muscle lactate production significantly increases, and average skating speed has been shown to decrease (Green et al. 1976, Akermark et al. 1996). Reasons for fatigue during ice hockey may include dehydration, decreased thermoregulation ability, glycogen depletion, and mental fatigue. Ice hockey is played in a relatively cool environment, but the intense nature of the sport combined with the large amount of equipment covering a player’s body contributes to high sweat losses (Palmer and Spriet 2008, Logan-Sprenger et al. 2011a), a reduced ability to dissipate heat (Noonan et al. 2007), and the possibility of significant dehydration. CHO is the primary fuel during high intensity aerobic and anaerobic work. During ice hockey, CHO and especially muscle glycogen, is the primary fuel used (Green 1988). A significant depletion of muscle glycogen toward the end of a game would contribute to fatigue. It is also possible
that mental perception of fatigue could contribute to decreased performance, especially in the later stages of a game.

**Sweat losses and thermoregulation during ice hockey**

Despite the fact that ice hockey is played in relatively cool conditions (<20 °C), players experience large sweat losses during a practice or game. If fluid replacement is inadequate, significant dehydration can occur. Commonly, total sweat loss is calculated as net body mass (BM) loss plus fluid intake, minus urine output (Baker et al. 2009). This method was shown to be highly repeatable among the same population of hockey players on different test days (Palmer et al. 2010). Evidence from other sports indicates that a BM loss of 1.5-2% seems to coincide with decreased performance (Edwards et al. 2007, Baker et al. 2007, Maxwell et al. 1999).

During an NHL pre-season practice, players lost an average of 1.3 ± 0.3 L·h⁻¹ of sweat (Godek et al. 2006a). In two separate studies of elite junior hockey practices, players lost an average of 1.4-1.8 L·h⁻¹ (Palmer and Spriet 2008; Palmer et al. 2010). In some intense practice situations, and especially during games, sweat losses are even higher. NHL players lost 2.15 ± 0.17 L of sweat during an intense 1-h practice (Spriet et al. 2008). During an OHL regular season game, players lost an average of 3.2 ± 0.2 L in an average of 19 and 24 min on the ice for forwards and defensemen, respectively (Logan-Sprenger et al. 2011a). There was no significant correlation between playing time and sweat loss, and no difference in sweat losses among forwards and defensemen.

All studies that have examined sweat rate among hockey players have reported large variation between subjects. Sweat rate is dependent on several factors, including exercise intensity, training status, heat acclimation, environmental temperature,
equipment, and individual variability (Godek et al. 2006a, Palmer and Spriet 2008, Palmer et al. 2010). During an OHL game, sweat losses ranged from 1.7 to 6.1 L·h⁻¹ (Logan-Sprenger et al. 2011a).

Ambient temperature in these studies ranged from 8.6 to 14.6 °C. A major factor that contributes to high sweat losses in hockey despite a cool environment is the large amount of equipment worn, which covers almost the entire body except the face and hinders sweat evaporation. Noonan et al. (2007) had hockey players participate in an intermittent high intensity cycling protocol that mimicked the pattern of exertion in a normal hockey game. In one trial, players wore full hockey gear, while in the other they did not. When wearing full gear, players lost twice as much sweat compared to not wearing hockey gear. Additionally, the area under the curve for core temperature (Tc), which provides a measure of the total thermal strain experienced by the subjects, was significantly higher in the later stages of the exercise protocol when players were wearing full gear.

A significant increase in Tc was observed in collegiate-level hockey players 40 min into a pre-season practice (Batchelder et al. 2010). Tc increased from rest by ~1 °C to 38.37 °C. Maximum individual Tc was 39.04 °C. No indication was given as to the intensity of the practice, although the relatively low sweat rate of 0.83 ± 0.5 L·h⁻¹ suggests that it was not very intense. If sweat rates were similar to those seen in a regular season OHL game, the associated Tc increase could be much higher.

**Dehydration during intermittent exercise: Effect on physiology, performance, and mental fatigue**
During continuous submaximal exercise, dehydration due to sweat loss and incomplete fluid replacement leads to decreased physiological function. At the same exercise intensity, Tc and HR increase, and stroke volume and blood volume decrease, as dehydration increases. Significant increases in Tc and HR are seen with dehydration as low as 1% (Montain and Coyle 1992).

Dehydration during intermittent exercise has similar consequences. Young male basketball players completed 2 h of intermittent submaximal exercise in the heat, while either receiving fluid to maintain BM, or to dehydrate by 2% BM (Dougherty et al. 2006). Following exercise, HR and Tc were significantly higher when subjects were 2% dehydrated (DEH) compared to when subjects ingested fluid to maintain BM (EUH). HR in the DEH trial was 160 ± 17 bpm, and 139 ± 17 bpm in the EUH trial. Tc in the DEH trial was 38.22 ± 0.37 °C, and 37.54 ± 0.41 °C in the EUH trial.

A graded effect of dehydration on Tc and HR similar to that measured by Montain and Coyle (1992) was seen in male basketball players exercising intermittently in the heat for 3 h (Baker et al. 2007). During exercise, players were given fluid in order to either maintain BM, or dehydrate by 1, 2, 3, or 4%. Post-exercise HR was significantly higher than the control trial at all levels of dehydration, and increased with dehydration level. Post-exercise Tc was significantly higher than the control trial when dehydration was 2% or higher, and progressively increased from 2-4% dehydration. Basketball-specific sprint and shooting performance decreased as dehydration increased.

Dehydration can negatively affect an athlete’s mental perception of fatigue. In the above two studies, the players’ rate of perceived exertion (RPE) was affected by dehydration. Baker et al (2007) found that RPE was significantly higher than the control
trial when BM loss reached 3 or 4 %. Players in the Dougherty et al (2006) study had higher RPE at the end of the exercise with 2% dehydration. Players also reported feeling significantly more “lightheaded” following exercise while dehydrated.

Maxwell et al. (1999) demonstrated that repeat sprint performance can be negatively affected by just 1.5% dehydration. Subjects completed 20-s intervals of maximal running, separated by 100 s of rest, while either remaining hydrated or becoming dehydrated by 1.5% BM. The goal was to complete as many 20-s intervals as possible until exhaustion. Total maximal sprint time was significantly lower when subjects were dehydrated.

Dehydration during intermittent cycling may negatively affect muscle strength. Subjects in a study by Noonan et al. (2007) completing a simulated ice hockey protocol on a cycle ergometer at 12 °C lost 2.57 ± 0.2% BM as sweat when riding in full hockey equipment, compared to 1.18 ± 0.1% BM loss when not wearing hockey equipment. Mean and peak power were reduced by >10% in a post-trial sprint test when subjects were wearing equipment. HR was increased during the intervals, as well as during rest between the intervals, and RPE for legs, chest and overall body were significantly higher when wearing equipment.

It is possible that dehydration and/or increased Tc during ice hockey could result in increased muscle glycogen use. Decreased muscle glycogen concentration was measured after 2 h of submaximal cycling in a temperate environment when male subjects were dehydrated by ~3% BM compared to when subjects maintained BM (Hargreaves et al. 1996). Local muscle and core temperature were also significantly higher when dehydrated. A more recent study found a similar result during 2 h of
submaximal cycling in females who dehydrate by 2% BM (Logan-Sprenger et al. 2011b). However, no differences in muscle glycogen concentration were found in a recent male study involving dehydration and intermittent cycling exercise designed to simulate a hockey game (Palmer et al. 2011).

**Fluid replacement and dehydration: Current habits of hockey players**

In order to limit dehydration during practices and games, players must take in adequate amounts of fluid. During a 1-h practice, elite junior hockey players had a mean fluid intake of 1.0 ± 0.1 L, and lost ~0.8% BM (Palmer et al, 2008). Players were allowed to drink *ad libitum*, and numerous breaks were taken during which players could drink. Since sweat rate is highly variable, it is useful to identify individual subjects who are particularly susceptible to dehydration. It is clear that many players are not able to maintain adequate hydration. 14 of the 44 players lost 1-2% BM, and 1 player lost >2%. Most players drank less than 1 L·h⁻¹, including fluid taken in immediately before the practice.

It appears as though players are more susceptible to dehydration during game situations. In a university regular-season game, 8 players lost an average of ~3% BM, playing between 19 and 28 min (Green 1978b). This high average BM loss could be a reflection of the more intense nature of a hockey game relative to a practice, and/or the relative lack of attention paid to in-game hydration in the 1970s. A more recent study suggests that during a game, players on average are better at limiting BM losses (1.3 ± 0.3% BM loss), but many players were still not hydrating properly, as 8 of the 24 players in the study lost between 1.8 and 4.3% BM (Logan-Sprenger et al. 2011a) during a game. Some players drank as little as 500 mL of fluid over the entire game. Players have even
more chances to drink during a game because more than half of their time is spent resting on the bench. It is possible that players are too focused on the game itself and do not pay proper attention to hydration.

No significant differences in sweat loss or % BM loss between forwards and defensemen were found in practices or games (Palmer and Spriet 2008, Logan-Sprenger et al. 2011a).

The first step in limiting the effects of dehydration during exercise is beginning exercise well hydrated. On average, ~50% of ice hockey players arrive to the rink hypohydrated, indicated by a urine specific gravity (USG) of >1.020 (Palmer and Spriet 2008, Logan-Sprenger et al. 2011a). Fortunately, many players do drink in the dressing room immediately before a practice or game, and as long as there is enough time, most will start the practice or game well hydrated.

**Muscle glycogen depletion in ice hockey**

During high intensity intermittent exercise such as ice hockey, CHO and especially muscle glycogen, is the primary fuel used (Green et al. 1988). Glycogen depletion could negatively affect ice hockey performance.

A study by Green (1978a) examined glycogen depletion in response to either high intensity intermittent or submaximal continuous ice skating. In the intermittent condition, 4 subjects skated at 120% VO$_{2\text{max}}$ for 1 min, followed by 5 min of rest. This was repeated 10 times. In the continuous condition, 4 subjects skated at 60% VO$_{2\text{max}}$ continuously for 60 min. The intermittent protocol is more representative of the pattern of activity during an actual hockey game. Muscle glycogen concentration was reduced by 70% in the intermittent condition, compared to only 29% in the continuous condition.
Following a varsity hockey game, muscle glycogen concentration decreased by an average of 60% in 8 players who spent an average of 30 min on the ice (Green 1978b).

Interestingly, glycogen depletion was not correlated with time on ice. An explanation for this would be that when a player stays on the ice too long during a shift, he/she will most likely revert to gliding or skating at an easy pace because he/she is too tired to skate at a high intensity. Glycogen depletion was not different between forwards and defensemen.

The primary fibre type utilized in intermittent skating and an actual hockey game was found to be different. Type II fibres showed the greatest depletion (loss of dark staining) during intermittent high intensity skating (Green 1978a). No Type IIB fibres stained dark and 63% stained light, and only 5% of Type IIA fibres stained dark. Type II fibres are primarily involved in maximal force production, and the depletion of these fibres, even when Type I fibres are not depleted, has been associated with decreases in maximal muscle power production (McCartney, 1986), which could have negative effects on the ability to sprint and make other dynamic moves involved in ice hockey.

Following a hockey game, Type I fibres were almost completely depleted, while Type II fibres were less depleted, with ~20% staining dark (Green 1978b). This is similar to an endurance running study that found an almost complete depletion of Type I fibres and a ~75% depletion of type II fibres, at volitional exhaustion (Tsintzas et al. 1996). Since players are self-paced during a hockey game, a depletion of Type I fibres could translate into a reduction in skating speed or effort late in a game. Indeed, Green et al (1976) reported a ~5% decrease in skating speed in the third period of a hockey game. The fact that players in a game are able to pace themselves likely contributed to the
difference in fibre type depletion compared to intermittent skating at a specific supra-
maximal intensity. Taken together, these studies demonstrate that depletion of either
fibre type is possible in a game, depending on the time spent skating and the intensity of
that skating.

Blood glucose levels increased during intermittent skating (Green 1978a), and
increased slightly during a game (Green 1978b). Plasma free fatty acid (FFA)
concentration was doubled by the end of both intermittent high intensity skating (Green
1978a) and a hockey game (Green 1978b). Elevated FFA may suppress glucose uptake
by the working muscles, which may lead to a decreased performance (Tsintzas et al.
1996).

Based on the glycogen depletion patterns in the two studies cited, hockey requires
both endurance and high intensity performance. Depending on the nature of the game,
depletion of Type I and/or Type II muscle fibres is possible and could affect endurance as
well as the ability to perform maximally. These effects would be especially pronounced
at the end of a game.

Glycogen depletion is highly variable among individuals (Green 1978a, 1978b).
This suggests that, like sweat loss, special attention must be paid to those individuals who
are at a higher risk of glycogen depletion during ice hockey.

Mental fatigue cannot be excluded as a factor leading to fatigue during ice
hockey. High plasma FFA levels may be associated with decreased central nervous
system (CNS) function during intense exercise (Welsh et al. 2002). Additionally, rate of
perceived exertion (RPE) increases as intermittent high intensity exercise progresses
(Palmer et al. 2011, Logan-Sprenger et al. 2011b), which could lead to decreases in performance.

**Carbohydrate intake during intermittent exercise: Effect on physiology, performance, and mental fatigue**

It is widely accepted that CHO intake during prolonged endurance exercise contributes to improved time to exhaustion and exercise performance (compared with placebo) (Coyle et al. 1986, Tsintzas et al. 1996). There are several proposed mechanisms for these improvements: maintenance of high rates of CHO oxidation, prevention of large drops in blood glucose and sparing of endogenous glycogen (Jeukendrup 2004).

Similarly, CHO intake during high intensity intermittent exercise may help to delay fatigue, improve performance and reduce the perception of fatigue. Possible mechanisms include a sparing of Type II muscle fibres to preserve muscle strength and power (Nicholas et al. 1999), maintenance of higher rates of CHO oxidation for muscle metabolism as well as cognitive function (Foskett et al. 2008), or a positive effect of CHO sensation on the brain through CHO receptors in the oral cavity (Chambers et al. 2009).

Ice hockey requires high anaerobic power and strength, as well as high endurance capacity. In a study by Davis et al. (1997), nine men cycled at 120-130% VO$_{2\text{max}}$ for 1 min, followed by 3 min of rest. This was repeated until subjects were unable to continue. In one trial, subjects ingested a bolus of 18% carbohydrate-electrolyte solution (CES) 20 min before exercise, and then a 6% CES every 20 min during exercise. In the control trial, subjects ingested a flavoured placebo drink at the same intervals. When subjects
ingested CES, time to fatigue was ~33% higher (89.5 ± 19.0 min) than when ingesting flavoured water containing no CHO (58.1 ± 7.0 min). This type of exercise protocol is very representative of ice hockey, and suggests that CHO intake may be especially important in delaying fatigue later in a game. It should be noted that the subjects began exercise in a fasted state, which is not representative of how an athlete would normally begin exercise, and could overestimate the effect of CHO ingestion (Jeukendrup 2004).

A recent study examined the effect of CES ingestion during intermittent running when muscle glycogen stores were already high (Foskett et al. 2008). Six recreationally active males performed an exercise protocol designed to mimic the intermittent nature of a soccer game. All subjects ate a high-CHO diet for 2 days leading up to each trial. The protocol involved 15 min of high and medium intensity running, and walking, followed by a 3-min break. After six repetitions of this, subjects continued the 15-min intermittent exercise protocol with no breaks until fatigue. In one trial, subjects ingested CES immediately before exercise, and at 15-min intervals until the end of exercise. In the control trial, subjects ingested a taste-matched placebo at the same intervals. All subjects ran for longer in the CES trial (158 ± 28.4 min) than in the control trial (131 ± 19.7 min). However, 15-m sprint performance during trials was not significantly different between groups. Muscle glycogen at fatigue was not different between trials, suggesting that muscle glycogen depletion was not the reason for fatigue during this intermittent exercise protocol. CES trial subjects displayed significantly higher plasma glucose concentration late in the exercise, suggesting a higher rate of CHO oxidation contributed to the increased performance. The differences seen in this study may also have been due to a
sparing of Type II muscle fibres in order to prolong the ability to produce the high forces
required during the exercise (Nicholas et al. 1999).

Other studies have found differences in sprint performance with CHO ingestion
(Welsh et al. 2002). In a 4x15-min intermittent running protocol similar to Foskett et al
(2008), subjects ingesting CHO had an improved 20-m sprint time in the last “quarter” of
the protocol. They also had a longer time to fatigue in a shuttle run to fatigue following
the intermittent protocol.

In a sport such as hockey, where mental concentration and focus are important,
lower perception of fatigue, especially later in a game, could help to prevent reductions in
playing performance. In the intermittent cycling study by Davis et al (1997), leg RPE
was significantly lower when subjects ingested CES. One study that did find a reduction
in Type II fibre utilization when ingesting CHO, found no difference in RPE during the
exercise (Foskett et al. 2008). There were no performance differences in this study,
suggesting that players’ perceived exertion plays a role in determining their ability to
perform.

The Profile of Mood States (POMS) questionnaire consists of a series of
adjectives representing various “mood states”: vigor, fatigue, tension, confusion and
anger. Adjectives are placed randomly into a list, and subjects must choose a number
between 1-5 to express how much of each adjective they are feeling. The higher the
number, the more they are feeling that adjective. The study by Welsh et al. (2002) used a
short-form version of the POMS questionnaire to assess mental fatigue at the beginning
and middle of the exercise protocol, and at fatigue. When ingesting CES, subjects had
significantly lower scores in the “fatigue” section of the POMS at the time of fatigue.
Maintenance of higher blood glucose (Foskett et al. 2008) and lower plasma FFA (Welsh et al. 2002) with CHO intake may improve cognitive function during exercise. Recent neuro-imaging studies have found a positive effect of CHO sensation on the brain through CHO receptors in the oral cavity (Chambers et al. 2009).

**Optimal carbohydrate intake during intermittent exercise**

There appears to be a maximal amount of CHO that the body is able to absorb in a given amount of time. Depending on the type of CHO and the amount ingested, the body can absorb between 1.0-1.75 g·min\(^{-1}\) (Jentjens and Jeukendrup 2005). A combination of fructose and glucose results in maximal absorption. Studies have reported performance benefits with as little as 15 g·h\(^{-1}\) of CHO ingestion (Smith et al. 2010), but a common recommendation is between 40-75 g·h\(^{-1}\). This is the amount used in most studies showing increased performance (Jeukendrup 2004). It does not appear that ingesting more than 75 g·h\(^{-1}\) has any more benefit than ingesting less, and there is no relation between body mass and required CHO intake (Jeukendrup 2004). A recent study found that ingesting 60 g·h\(^{-1}\) of CHO during 2 h of submaximal cycling resulted in a greater improvement in subsequent time trial performance compared to ingesting 15 or 30 g·h\(^{-1}\) (Smith et al. 2010). Ingestion of 15 and 30 g·h\(^{-1}\) each resulted in increased performance compared to ingestion of a taste-matched placebo.

It is likely some of the performance benefits observed with CHO ingestion during short-duration high intensity exercise are not due to metabolic alterations, but rather a positive effect of CHO sensation on the brain through CHO receptors in the oral cavity (Chambers et al. 2009). Many protocols used are under 1 h of exercise. During a game, hockey players are usually not on the ice longer than 30 min, but that time on ice is
spread out over 2.5-3 h. It may not be sufficient to only rinse the mouth with CHO when exercise is spread out over this duration, since muscle glycogen may be limiting.

An important factor to consider when determining the amount and form of CHO to use during ice hockey is convenience. Given the intense nature of ice hockey, players are usually very tired upon returning to the bench, and some players may not get a chance to fully recover while on the bench. Taking in large amounts of CHO, or CHO in solid form, is not ideal because it may simply be difficult to do, and may result in stomach discomfort. A CES is the ideal method of ingesting CHO during a fast-paced sport such as ice hockey, since it provides fluid and CHO at the same time. A CES can be provided in a drink bottle for quick and easy consumption after every shift. Generally, these drinks contain 5-8% CHO. Drinks with higher concentration of CHO impede clearance from the gut and are often too sweet and therefore difficult to ingest. A CES will usually contain electrolytes, particularly sodium, which will increase the player’s drive to drink and help the body hold onto the ingested fluid (Shirreffs et al. 1996). A CES containing a mixture of glucose and fructose is ideal for maximum absorption (Jentjens and Jeukendrup 2005).

**Carbohydrate intake: Current habits of hockey players**

Until recently, little attention has been paid to CHO ingestion during team sports such as ice hockey. As a result, most hockey players are not accustomed to drinking sports drinks during practices and games. Elite junior ice hockey players given *ad libitum* access to both water and CES, drank CES only before practice and took in an average of 24 g of CHO. The players drank only water during the 1 h practice (Palmer and Spriet, 2008). During a regulation 3-period, 60-min game, a different group of elite
junior hockey players consumed an average of 0.8 L of CES prior to the game and during intermissions (Logan-Sprenger et al. 2011a). This amount of CES corresponds to 48 g of CHO. Once again only water was drunk during the game.

Despite the preference of elite hockey players to drink only water during hockey practices and games, it was found that, given *ad libitum* access to only CES during a regular 90-min practice, elite junior players drank the same amount of fluid as they did in another practice when water was available. Clearly, it is more of an issue of provision or availability than of preference. If sports drinks were provided on the bench during games, most players would use them. More recently, a large number of players can be seen drinking a CES during professional competitions, which indicates player habits may be changing. Players may benefit from a more steady supply of CHO during a practice or game, in order to maintain high levels of CHO oxidation and/or prevent large decreases in muscle glycogen. It is possible that CHO taken in during intermittent exercise is used during periods of rest to synthesize muscle glycogen (Jeukendrup 2004).

In addition to replacing water lost due to sweat, and providing a source of exogenous CHO, a CES replaces some of the electrolytes lost in sweat. The primary electrolyte lost in sweat is sodium (Na⁺). Na⁺ helps aid hydration by allowing the body to hold onto more fluid, and by increasing the drive to drink. Since many players do not currently drink a CES during practices and games, large Na⁺ losses are incurred. Average sodium losses of 2000-2600 mg have been reported in junior players in practices and games (Palmer and Spriet 2008, Logan-Sprenger et al. 2011a). Ingestion of Na⁺ with fluid following exercise helps the body to retain more of the fluid taken in and rehydrate
more effectively (Shirreffs et al. 1996). This is an important consideration for hockey players, who often play or practice on consecutive days.

**Dehydration and carbohydrate intake during “Stop-and-Go” sports: Effect on physiology, performance, and mental fatigue**

It is clear from previous research that dehydration negatively affects physiological function, performance and mental status during intermittent exercise, while CHO intake during intermittent exercise improves performance and mental status. During ice hockey, many players become dehydrated, use a significant amount of muscle glycogen, and only some take in CHO, mostly before exercise.

To gain some insight into what may be expected in that case, we can refer to studies involving soccer and basketball players. As in hockey, performance in these sports requires the ability to sprint intermittently with lighter intensities of activity or rest in between - the so-called "stop-and-go sports". The aim of these sports is to move an object towards a goal, and maintain mental focus for performance.

**Dehydration**

Basketball players beginning a 4 x12-min set of basketball drills dehydrated by 2% BM displayed decreased performance compared to when they were hydrated, in shooting, and basketball-specific sprinting and lateral movement drills (Dougherty et al. 2006). Dehydrating players to levels between 1% and 4% BM loss before a similar set of basketball drills revealed possible dehydration “thresholds” for drill performance. Sprinting performance was impaired at 2% BM loss and above, while agility and shooting performance were negatively affected at 3% BM loss and above (Baker et al. 2007).
When examining athletes in a real-life sporting environment, it is often not possible to control their work intensity. It is important in these cases to keep all variables in mind when trying to assess differences in performance, physiology and mental fatigue. An elevation in Tc or HR may simply be due to an increased level of exertion in one trial, rather than a treatment effect, whereas a lack of differences in physiological variables may be due to the treatment allowing for higher exertion in one trial without a further effect on physiology.

In the basketball drill study by Dougherty et al. (2006), mean Tc and HR in dehydrated subjects were significantly higher at the end of the drill protocol. Mean Tc in dehydrated subjects was 38.64 ± 0.35 °C, and 38.14 ± 0.43 °C in hydrated subjects. Mean HR at the end of the drill protocol was ~5 bpm higher in the dehydrated group. These differences accompanied a decrease in drill performance (and presumably exertion level) in dehydrated subjects. Therefore, if drill performance had been equal, it is possible that increases in Tc and HR would have been even more exaggerated.

RPE at the end of this protocol was not significantly different between trials. Since the goal of some of these drills was to go as fast as possible, it may be that the similar RPE levels reflect some kind of mental fatigue threshold. Dehydrated players may have reached this threshold at lower levels of exertion than when hydrated, resulting in an inability to perform at the same level.

The study by Baker et al. (2007) reported a slightly different scenario. Throughout the drill session, Tc and HR were not significantly different at any level of dehydration. All measures of mental fatigue were significantly higher halfway through and at the end of the drill sessions when subjects were 3 and 4% dehydrated. Sprint
performance decrements in this study were observed at dehydration levels as low as 2% BM loss. In this case, the decreased effort level when dehydrated probably masked any differences in physiological stress. Decreases in performance drills involving more of a mental component (agility, shooting) were seen at 3 and 4% dehydration, which coincided with increases in mental perception of fatigue.

These studies provide good insight into the complex nature of real-life sport testing. Both of the studies examined player performance while maintaining a given level of dehydration throughout the protocol. However, in an actual game or practice situation, the athlete will progressively become more dehydrated with improper fluid intake. Furthermore, it would be valuable to measure physiological and performance changes during an actual game, rather than during sport-specific drills.

To investigate the effects of progressive dehydration on soccer game performance, Edwards et al. (2007) observed male soccer players participating in an intense 45-min continuous cycle ergometer exercise, followed by a 45-min 8-on-8 soccer match. Following the soccer match, subjects performed an intermittent running test to exhaustion, followed lastly by a test of mental concentration. Subjects received either no fluid (NF), or water (FL) to replace ~80% of sweat losses. Throughout the protocol, when ingesting fluid, the 11 soccer players lost an average of 0.73 ± 0.4 % BM, while in the NF trial they lost 2.4% BM. Tc was not different between trials following the 45-min cycling protocol. This is most likely due to the subjects not dehydrating significantly during the cycling protocol. However, following the soccer match, Tc was higher in the NF trial (>39 °C) compared to the other two trials. No significant differences in HR between trials were seen at any point. RPE at the end of the protocol was significantly
higher in NF compared to the FL trial. Post-match drill performance in the NF trial
decreased by 15% compared to the FL trial. A mental concentration test was given
following each trial, in which subjects had to identify random numbers appearing on a
screen. No differences were found, but it could be due to the task being too simple. It
would be more useful to examine a sport-specific mental concentration task.

The study also employed a third trial, in which subjects were allowed to
periodically rinse their mouths out with water, but not actually replace any fluid losses
This is a common practice among players in many sports and is thought to have a positive
mental effect. However, no differences in physiological stress, performance, or mental
fatigue, measured by RPE, were seen compared to the NF trial, indicating that this
practice may not be of much benefit.

When attempting to quantify effects of dehydration during exercise, it is
important to consider the hydration of the control group. In the two basketball studies
mentioned earlier, BM was monitored and maintained throughout the protocol
(Dougherty et al. 2006; Baker et al. 2007). The soccer study by Edwards et al. (2007)
ensured that subjects lost less than 1% BM on average. A soccer match study comparing
hydration with a CES with dehydration due to denial of fluids, found that Tc during the
match was not significantly different between trials. At the end of the match, subjects in
the dehydrated group had lost 1.75kg, or 2.6% BM. Subjects in the CES group had lost
1.14 kg, which is equal to ~1.7% BM (Guerra et al. 2004). Given the finding that even a
1% BM loss can result in negative physiological effects (Montain and Coyle 1992,
Logan-Sprenger et al. 2011b), it is not surprising that a significant difference was not
observed.
Carbohydrate intake

The two basketball drill studies discussed previously each included a trial in which players hydrated with a CES throughout the drill protocol. In both studies, no physiological differences were seen between CHO trials and water trials. One study reported improvements in shooting percentage and sprint drill performances when ingesting CES, but the other did not report differences. This could be a reflection of the individual nature of glycogen depletion, CHO utilization, and cognitive benefits of CHO intake. The study that observed performance differences involved 12-15 year-old boys, whereas the study not seeing differences used 17-28 year-old males. Interestingly, in the study in which performance differences were seen, subjects were fed a low CHO snack (25 g CHO) before the start of the protocol. In the other study, subjects arrived in a fasted state. This is contrary to what would be expected, since normally performance benefits are more pronounced when subjects ingest CHO during exercise after an overnight fast. Perhaps the CHO ingested prior to the study by Dougherty et al. (2006) allowed for increased CHO utilization during the drill session.

It is possible that decreased mental fatigue contributed to the increased performance in the study by Dougherty et al. (2006). In this study, subjects ingesting CES had significantly lower sensations of “lightheadedness”, “upper body fatigue”, and “total body fatigue” at the end of the protocol, compared with the other 2 trials. In the study by Baker et al. (2007), no improvements in mental status were observed in the CHO trial.

Although soccer involves more prolonged submaximal effort than hockey, it still involves intermittent periods of high intensity effort and extended periods of low effort.
A study examining CHO intake prior to and during a 90-min soccer match found that muscle glycogen utilization was lower when subjects ingested CHO compared with placebo (Leatt and Jacobs 1989). However, all subjects in this study dehydrated by 2-3% BM and no performance measures were taken.

Carbohydrate intake during ice hockey: Previous research

Laboratory studies examining intermittent exercise protocols give valuable insight into the effects of dehydration and CHO ingestion on performance, physiology and mental fatigue. However, these laboratory studies do not take the place of field studies observing actual sport performance. Comparison of exercise tests to exhaustion on a cycle ergometer to on-ice skating, showed that skating VO$_{2\text{max}}$ and maximum HR were significantly higher than maximum values attained in the laboratory (Durocher et al. 2010). This is perhaps a reflection of an increased level of motivation during sport-specific performance, which cannot be reproduced in the lab.

Two studies have examined the effect of CHO intake before and/or during ice hockey, and its effect on physiology and performance. A study by Akermark et al (1996) examined the effect of feeding professional hockey players a high-CHO diet (60% CHO) for 3 days in between “challenging” ice hockey games compared to players who ingested a mixed diet (40% CHO). Muscle glycogen content was higher before Game 2 in the high-CHO group (99 mmol·kg$^{-1}$) compared to the mixed-diet group (81 mmol·kg$^{-1}$). Following Game 2, average glycogen content was not different between groups (~45 mmol·kg$^{-1}$). Time-motion analysis indicated that the group given the high-CHO diet covered 30% more skating distance during the game than the mixed diet group.
Additionally, skating distance significantly decreased by 14% from period 1 to period 3 for the mixed diet group, and significantly increased by 11% in the high-CHO group.

During the games, players in both groups had *ad libitum* access to both water as well as a 5% CES. The authors indicated that there was no difference in total fluid intake between groups. This is interesting because it shows that performance benefits can still be seen when only pre-game CHO intake is modified. It also must be noted that this study did not use a cross-over design, so it is possible that individual differences accounted for some or all of the performance differences observed. No measures of mental fatigue were made in this study, but since players were not blinded to the treatments, it is possible that higher mental fatigue contributed to the decreased performance in the low-CHO diet group.

Simard et al. (1988) manipulated CHO intake both before and during an ice hockey game, to measure differences in glycogen depletion and performance. During the ~3 h before, and at 20 and 40 min into a 60-min collegiate-level ice hockey game, 7 subjects ingested 100 g of glucose and roughly 500 mL fluid, or an equivalent volume of placebo. Two separate hockey games were used in the study, and subjects served as their own controls. All subjects were fed a standard meal 4.5 h before the game. Time on ice and distance covered were significantly higher in the CHO group compared to the control group (5.6% and 10.2% higher, respectively). Mean skating speed was similar between trials. In the third period, subjects in the CHO group covered 11.5% more distance, although the difference was not statistically significant.

Post-game muscle glycogen content was significantly lower than pre-game content in both groups, but was similar between groups (47.7% in control group, 41.8%
in CHO group). Since distance covered was higher in the CHO group, the authors calculated that utilization of muscle glycogen was ~10% higher in the control group. Presumably, the CHO group was able to utilize the exogenous CHO and spare muscle glycogen relative to distance covered. An increased blood glucose level measured in the CHO trial compared to the control trial supports this suggestion. Neither of the two studies examined the depletion of type I and II muscle fibres separately.

In summary, hydration and CHO intake are two extremely important nutritional strategies in order to achieve maximal performance in sports involving high-intensity intermittent exercise. Mild dehydration of only 1% BM loss can have negative physiological effects, and dehydration of 1.5-2% BM loss and above has been shown to decrease performance and cause increased mental fatigue. CHO intake before and during intermittent exercise including ice hockey, can positively affect performance by allowing for greater oxidation of CHO, and/or preventing large drops in muscle glycogen. CHO intake also appears to decrease mental fatigue, which may help improve performance.

**Knowledge gap**

Several studies have shown that CHO intake prior to and/or during an ice hockey game results in higher CHO utilization, and increased performance compared to ingesting a placebo. However, one study did not indicate any difference between trials in CHO intake during the game, while another gave large quantities of CHO only between periods during the game. A more realistic and perhaps more ideal approach would be to allow players to take in a steady amount of CHO throughout the game, in the form of a CES.

Little is known regarding the effect of dehydration on thermoregulation, HR, mental fatigue, or sport-specific performance during ice hockey. The Simard et al.
(1988) study gave subjects the same amount of fluid in each trial and did not take any measures of hydration. Given the large incidence of dehydration reported among elite hockey players, establishing the consequences of this is very important.

The only performance measures examined in the two studies of CHO intake and hockey were time on ice and distance covered. As suggested by Green et al. (1976), using only these parameters to assess performance may be misleading. First, an appreciable amount of effort during ice hockey is expended while performing actions that do not contribute to greater distance covered: struggling for puck possession or position, quickly changing directions, and passing and shooting. Second, a large percentage of time spent on the ice is spent gliding or skating at an easy pace. As a result, greater time on ice is not always indicative of greater effort exerted. Therefore utilizing these measures, along with some sort of measure of time on ice spent at a high level of exertion is warranted in order to get a better idea of differences in effort level between trials. Tc and HR can also provide insight into level of exertion.

The idea of what exactly constitutes “sport-specific performance” in ice hockey is not a definite one. The ability to cover more distance or skate at a higher speed is just one element of performance in ice hockey. Being able to make proper decisions with the puck is crucial, especially in the later stages of a game. Untimely puck turnovers at the end of a close game can cost a team a win, whereas increased passing and shooting proficiency can contribute to a win. Given the multiple variables at play during an ice hockey game that could mask certain measures of performance, hockey-specific drills are another valuable way to assess performance and have been used in other sports to assess effects of dehydration and CHO intake. Combined with in-game skating and puck-
handling performance, a more comprehensive view of overall ice hockey performance is
provided.

Finally, mental perception of fatigue has been shown to affect performance in
other sports such as soccer and basketball, but has not been investigated during an ice
hockey game.
CHAPTER 2: STATEMENT OF THE PROBLEM

The purpose of this study was to compare the effects of progressive dehydration to 1.5-2% BM loss arising from denial of fluid vs. remaining hydrated (~0.5% BM loss) with a CES on the following during/after a 70-min, 5-on-5 non-stop scrimmage:

- Tc and HR during the scrimmage
- Average skating speed and time spent at high effort during the scrimmage *
- Puck-handling performance during the scrimmage
- Hockey-specific drill performance following the scrimmage
- Mental fatigue following the scrimmage

* The scrimmage was divided into 3 time periods for analysis: 0-30, 30-50, and 50-70 min. These time periods were chosen because the main time of interest was the last 20 min, which here is taken to simulate the last period of a hockey game.

Proper hydration and CHO intake are the two primary concerns for ice hockey players during practices and games. Sweat losses causing dehydration of even 1% BM loss can negatively affect thermoregulation and cardiac output. Dehydrating by 1.5-2% BM loss is associated with decreased performance and increased mental fatigue. CHO intake can positively affect maintain or improve performance and mental perception of effort during high-intensity intermittent exercise, by increasing the amount of CHO utilized, and/or attenuating decreases in muscle glycogen.

Currently, many ice hockey players lose >1.5 % BM during game play, and most players take in only small amounts of CHO prior to games, and none during actual game play. These types of players are of primary concern in this research.
Ingestion of a CES during ice hockey is suggested as the best way to maximize performance, since it will provide both fluid to maintain hydration, and a steady source of exogenous CHO to be used during exercise. Of course, special attention must be paid to the individual hydration requirements of players, as sweat losses are highly individual. It is recommended that players ingest sufficient fluid in order to minimize BM losses during a practice or game.

This study was designed to be as realistic as possible. Subjects were allowed to eat as they normally would before each trial, and were not given any instruction on how to behave during the ice hockey game.

**Hypotheses:**

When progressively dehydrating to 1.5-2% BM compared to maintaining BM with a CES, subjects will display:

1) Increased Tc and HR with an equal or lower effort level during the scrimmage, or decreased effort level with an equal or increased Tc and HR during the scrimmage, especially in the last 20 min.

2) Decreased puck-handling performance in the last 20 min of the game.

3) Decreased hockey-specific drill performance following the game.

4) Increased mental fatigue following the game.
CHAPTER 3: METHODS

Subjects

Sixteen high-level male hockey players volunteered to participate in the study. Subjects played hockey at least 2 times per week prior to, and during, the testing period (including the testing itself) and none were using any conflicting medications. The subjects’ mean (± SEM) age, weight, height and years of competitive ice hockey experience were 21.3 ± 0.2 years, 80.1 ± 2.5 kg, 182 ± 1.2 cm, and 10.4 ± 1.0 years respectively. All players had previously played at least ‘A’ level or high school competitive hockey. Four players had played at the ‘AAA’ level, and one played Jr. C. Two goalies participated in the 5-on-5 scrimmage section of the trials, but were not included in data analyses. All subjects were informed of the experimental protocol and associated risks of the study, both orally and in writing, before written informed consent was obtained. The Research Ethics Board of the University of Guelph approved the study.

Study design

Subjects reported to the University of Guelph hockey rink (mean temperature, 3.0 ± 0.1 °C; mean relative humidity, 44 ± 0.2%) on the same day each week for 9 weeks (Figure 1). Week 1 was an informal orientation to the protocol of pre-trial measurements, as well as an introduction to the on-ice performance drills. The next 2 visits were used to familiarize the players with the entire experimental protocol, and to measure each player’s individual sweat rate during the protocol in order to establish each player’s necessary fluid intake to maintain BM. Weeks 4 to 7 were used to carry out the
experimental trials. Weeks 8 and 9 were experimental trials used to collect any data that had been missed, due to subject illness or equipment malfunction.

The study consisted of two trials: consumption of a carbohydrate-electrolyte solution (CES) or no fluid consumption (NF). Prior to the CES trial, subjects received individually labeled bottles containing a specific amount of commercially available sports drink (Gatorade: 5.8% CHO, 20 mmol·L⁻¹ sodium, 11 mmol·L⁻¹ chloride, 3 mmol·L⁻¹ potassium, trace calcium). They were instructed to drink throughout the trial in order to limit body mass (BM) losses to <0.5% of their pre-trial BM. During the NF trial, subjects were not allowed to drink anything from the time they arrived at the rink until the end of testing. Each subject served as his own control, and no subject was tested on consecutive weeks.

Each week, all 16 players and 2 goalies participated in a 70-min 5-on-5 scrimmage. Players were separated into 2 teams of 8 players each. Each week, 4 players were tested (2 CES subjects, 2 NF subjects) and 4 players were not tested on each team. The 8 tested subjects completed 3 on-ice performance drills before and after the scrimmage, and two post-trial questionnaires to assess mental fatigue (Figure 2). Subjects were instructed to not communicate with each other while completing the questionnaires. During the scrimmage, non-tested players were provided with individually labeled bottles containing CES to limit BM losses to <0.5%.

All players were instructed to maintain their normal exercise levels but to refrain from intense exercise and caffeine and alcohol consumption 48 h before each trial. Players were allowed to eat as they would normally, and completed food and fluid intake questionnaires to ensure the same food and fluid intake the morning of testing. Each
week, players were instructed to drink at least 500 mL of fluid in the 60 min before arriving to the rink, in order to begin exercise in a hydrated state.

**Familiarization trials**

The first visit to the rink was an orientation to the flow of pre-trial measurements, and a demonstration and practice of the 3 on-ice performance drills. The next 2 weeks were used to familiarize the players with the entire testing protocol: pre-trial measurements, pre-scrimmage performance drills, 5-on-5 scrimmage, post-scrimmage performance drills, post-trial measurements and mental fatigue assessment questionnaires. These trials were also used to establish each player’s individual sweat rate over the entire protocol. The player’s fluid intake requirements for the CES trial were determined by their sweat rate in the familiarization trial. For example, if a player lost 1.5 L of sweat in the familiarization trial, they were given 1.5 L of fluid in their CES trial. Each player performed the full experimental protocol on one week out of 2, and on the other week, participated in only the scrimmage.

**Experimental protocol**

Figure 2 provides an overview of the experimental protocol. The NF and CES trials followed the same protocol.

*Pre- and post-trial measurements:* All 8 tested subjects swallowed an ingestible thermistor (HQ Inc., Palmetto, Fla.) 6-8 h before arrival at the rink. Upon arrival to the rink at 8:00 am, subjects were instructed to empty their bladder and a urine sample was collected to establish pre-trial hydration level. The subjects were weighed on a Zenith weigh scale (LG Electronics Canada, Mississauga, Ont.), accurate to ± 0.1 kg, while wearing only dry shorts, and baseline core temperature (Tc) was measured.
All subjects completed a food and fluid intake questionnaire to ensure that their morning diets and fluid intake were similar between trials. The time between BM weighing and the start of the first set of on-ice performance drills was ~15-30 min. The time between the baseline Tc measure and the start of the 5-on-5 scrimmage was ~60 min.

Subjects were fitted with HR monitors (Polar Electro, Finland), for HR collection during the 5-on-5 scrimmage. Absorbent patches (3M Tegaderm + Pad, London, Ont.) were affixed to subjects’ foreheads for mid-scrimmage sweat sample collection. Fluid bottles for CES trial subjects were weighed and placed onto the bench. CES trial subjects were allowed to drink from the start of the pre-scrimmage performance drills, until the end of the post-scrimmage performance drills. Experimenters monitored each subject’s fluid intake throughout to ensure proper hydration. Subjects were instructed not to spit out any of the fluid or use it to rinse their faces. Separate water bottles were provided for players who wished to rinse their mouth or wash their faces.

Upon completion of the post-scrimmage performance drills at ~11:10 am, subjects immediately removed their equipment, dried off completely, and emptied their bladder if necessary. Subjects were then weighed wearing only dry shorts for sweat rate calculation, and their bottles were weighed to determine fluid intake.

Performance drills: At 8:50 am, the 8 tested subjects took the ice for a regimented 10-min warm-up consisting of easy skating, stretching, and regular intervals of hard skating on whistles. The 8 subjects were split into two groups, which were kept constant for all testing. Within each group, individual subjects performed drills in the same order each time (Figure 3). Following the 5-on-5 scrimmage, at ~10:50 am, the 8
tested subjects returned to the ice to complete the same set of performance drills again. Time taken to complete each drill session, not counting the 10-min pre-trial warm-up, was ~20 min.

For the shooting accuracy drill, one of the nets was fitted with a target board with holes in each corner (Figure 4). Sixteen pucks were lined up 6 m away from the net. Subjects were instructed to target each corner one at a time, a total of four times each. One point was given for hitting a bottom target, and two were given for a top target. This was determined from the shooting drill results from the familiarization trial, where the bottom target was hit roughly twice as often as the top. Point values were doubled if a player was able to hit three or more targets in a row. The same experimenter was present each time to judge whether a puck had gone through a target.

In the slalom puck handling drill, subjects were instructed to carry a puck through an out-and-back zig-zag course of pylons, attempting to complete the course as quickly as possible, while not losing the puck or hitting the cones (Figure 3). A penalty of 0.5 s was added to the time of those players who hit a cone. Each subject completed the drill twice, with 2 min between bouts. Subjects were informed that only their fastest time would be counted.

In the shuttle sprint skating drill, subjects were instructed to skate as hard as possible, without a puck, back and forth between the blue and red lines over a total distance of 126 m (Figure 3). Experimenters monitored subjects to ensure they stopped in the correct location at each line. All subjects complied with this rule and did not need to repeat any bouts. Each subject completed the drill twice, with 2 min between bouts.
Subjects were informed that both bouts would be counted in their performance assessment.

5-on-5 scrimmage: The 8 non-tested players and 2 goalies arrived to the rink at 9:00 am. From 9:30 am to 10:40 am, all 16 players and 2 goalies participated in a 70-min, 5-on-5 scrimmage. Each team had five forwards and three defensemen, and players were assigned to the same position for the duration of the study period. Games were played to 5 goals. The team with the highest number of game wins was declared the winner each week. In order to ensure proper motivation, a monetary incentive was awarded to each player and goalie on the winning team. During the scrimmage, the players had no strict guidelines for duration of shifts. No formal breaks were taken at any point during the scrimmage. Players rested during their time on the bench and during brief on-ice breaks when a puck went out of play or a goal was scored.

The Tc for each tested player was recorded at the end of each shift using a handheld recording device held against the subject’s back. Subjects were not informed of their Tc when the measurement was taken, in order to prevent any influence on their behaviour or perception of fatigue. Sweat patches were removed roughly halfway through the scrimmage (NF: 30 ± 3 min; CES: 35 ± 3 min). Scrimmages were videotaped using two stationary video cameras (Panasonic MiniDV, Panasonic Canada, Mississauga, Ont.) capturing each half of the ice separately, for subsequent time-motion analysis. Video was collected at 25 frames per s, and a resolution of 720 x 480.

Mental fatigue questionnaires: Subjects completed two questionnaires following post-trial measurements: a hockey-specific fatigue questionnaire (HFQ), and a short-form version of the Profile of Mood States (POMS) questionnaire. The HFQ consisted of 6
fatigue-related questions (e.g., “Did you feel overheated on the ice?”). Subjects were required to respond to each question with a number between 1 and 10. A higher score was associated with a higher feeling of that measure of fatigue. The POMS questionnaire consisted of a list of 18 adjectives. Subjects were required to rate how much each adjective applied to them at that time. A score of 1 meant “Not at all”, while a score of 5 meant that the word “extremely” applied to them. Each word belonged to one of 3 “subsections”, each representing a different mood state: Vigor, confusion and fatigue. Subsections were analyzed separately and as a total.

**Time-motion analysis**

Following the experimental trials, the experimenter reviewed video of each tested subject and recorded time-motion data: time spent on the ice (TOI), on-ice break time, time spent off the ice, distance covered, mean skating speed, number of shifts, and time spent at “high” and “low” effort. Other hockey-specific performance data were also recorded: time spent with the puck, number of turnovers, number of takeaways, number of passes attempted and completed, and number of shots attempted.

“On-ice breaks” were defined as time spent on the ice during which play was stopped, either because of a goal or because the puck went out of play. During this time, distance covered was not collected.

“High effort” was defined as time spent actively skating $> 4.2 \text{ m} \cdot \text{s}^{-1}$, time spent skating at visibly high efforts, and time spent at visibly high exertion, e.g., fighting in the corner for the puck, sudden bursts from a stationary position, and executing sudden, sharp turns. A speed of $4.2 \text{ m} \cdot \text{s}^{-1}$ was chosen as a cutoff for “high effort” after reviewing video of all subjects and observing that a speed of $4.2 \text{ m} \cdot \text{s}^{-1}$ or higher was consistently...
associated with visible signs of “high effort”. This measure was included in the analysis in addition to mean skating speed, according to a recommendation by Green et al (1976) who argued that using only skating speed would underestimate energy expenditure. The authors recommended recording quick turns and short bursts of speed, and fighting for the puck. No body checking was allowed in this scrimmage. Time at “low effort” (time spent skating at <4.2 m·s⁻¹, time spent gliding, stopped, or skating at a visibly easy pace) was also documented.

“Turnovers” were defined as a player giving the puck directly to a player on the opposing team, either by having the puck stolen, or by passing the puck to that player. One exception was if the puck was given up near the offensive goal because of an aggressive movement or pass towards the goal. “Takeaways” were counted as any time a player either directly or indirectly caused an opposing player to commit a turnover. Passes counted as “completed” if the player successfully directed the puck towards the intended teammate, regardless of whether that teammate was able to accept the pass.

To measure distance covered, specialized grids were overlaid onto computer screens and aligned with the video of each rink half. Two computer screens were used in order to capture both halves of the rink. In order to track the player’s position in time, video analysis software (VirtualDub, downloaded from virtualdub.org) was used and the frame number, and “x” and “y” locations on the specialized grid, were recorded each time the subject visibly changed speed or direction, or performed one of the hockey-specific performance measures. Data points were not recorded at a set frequency, as variable sampling was sufficient and more efficient for capturing changes in speed, effort, and performance measures. Data for each subject were collected one at a time, and the
experimenter had no knowledge of which trial the subject was performing in the video. One shift from several randomly selected subjects was measured twice in order to assess repeatability of measurements for mean skating speed and time at high effort. Measurements for mean skating speed did not vary by more than 0.05 m·s\(^{-1}\). The greatest variance in time at high effort was 4 s over a 300-s shift.

**Measurements**

Rink temperature and relative humidity were measured with a Fisherbrand Traceable Digital Thermometer (Fischer Scientific, Ottawa, Ont.) placed on the boards during each trial. USG was analyzed immediately following collection with a portable refractometer (ATAGO USA Inc., Bellevue, Wash.). Subjects with USG <1.020 were classified as “euhydrated” (Sawka et al. 2007). Post-trial urine samples were collected and measured for volume, if the subject provided any urine. Within 2 h of the end of each trial, sweat samples were centrifuged and analyzed for sodium concentration with a sweat conductivity analyzer (Wescor, Logan, Utah). Motion-activated timing devices accurate to 0.01 s (Brower Timing Systems, Draper, Utah) were placed at the start/finish line of the slalom and shuttle skating drills to measure elapsed time. Prior to testing, ingestible thermistors used to measure Tc during the scrimmage were measured in 37 °C and 39 °C water baths, and were consistently accurate to within 0.03 °C.

**Calculations**

Percent BM loss was calculated as net BM loss divided by pre-trial BM. Sweat rate was calculated from net BM loss (assuming 1 kg = 1 L) plus fluid intake minus urine output per h of exercise. Respiratory water loss, substrate mass loss, and the generation of water from oxidation have been shown to exert little influence on the sweat rate.
calculated from changes in BM (Baker et al. 2009). Sodium loss was calculated as forehead [sodium] multiplied by molecular weight of sodium and the volume of sweat lost. For this calculation, forehead sweat sodium values were adjusted to estimate whole-body [sodium] by multiplying the value by 0.61, and subtracting 2.98 (Baker et al, 2008). Individual sodium intake was calculated by multiplying the CES [Na] by the molecular weight of sodium and the total volume of CES consumed. Mean skating speed during the scrimmage was calculated as distance covered (m) divided by TOI (s).

**Data Analysis**

Two subjects were excluded from the analyses. One subject did not dehydrate enough in the NF trial, losing only 1.1% BM. From previous research, dehydration of 1.5% and above has been associated with decreased performance and increased mental fatigue. All other subjects in this study lost at least 1.4% BM. We were unable to measure Tc in the NF trial on a second subject despite two attempts.

The on-ice scrimmage was divided into 3 time periods: 0-30 min, 30-50 min, 50-70 min. These time periods were chosen because the main time of interest was the last 20 min, which here is taken to represent the last period of a hockey game.

Tc was measured from tested players after each shift during the scrimmage. The average number of data points taken in the scrimmage was $12.6 \pm 0.6$ in NF, and $12.4 \pm 0.5$ in CES. Raw Tc data points were put into 5-min bins and averaged from 5 to 65 min. There were not enough data points obtained exactly at 0 or 70 min for these time points to be included. Pre-trial Tc values were not significantly different between groups so these were not included in the statistics. HR data were recorded throughout the
scrimmage at 5-s intervals. HR data were not collected from two subjects during the CES trial, so reported HR data are from 12 subjects.

In the shuttle drills, 3 players fell during one of their post-scrimmage bouts: two subjects fell in their second post-scrimmage bout in CES, and one subject fell in the first bout of the NF trial. Data from these subjects were not included in analysis of shuttle drill performance.

Statistics

Environmental data, player sweat data, mean scrimmage time-motion data (TOI, distance, mean skating speed, time at high effort), baseline and peak Tc, mean on-ice HR, and post-trial fatigue questionnaire scores were analyzed using a paired 1-tailed t-test (sig < 0.05). “Period-by-period” time-motion, HR and Tc data, and in-game performance data were analyzed using a 2-way ANOVA with repeated measures [treatment (NF, CES) x time]. In-game performance data for the last 20 min were analyzed using a paired 1-tailed t-test (sig < 0.05). Pre- and post-scrimmage shuttle drill performance times (2 bouts each) were analyzed separately using a 2-way ANOVA with repeated measures [treatment (NF, CES) x time]. With all 2-way repeated-measures ANOVAs, a Student Newman-Keuls test was used to test for significance when a significant F-ratio was obtained. Relationships between variables in each trial were investigated using Pearson’s correlation coefficients. Differences between different groups of subjects were analyzed using an unpaired t-test (sig < 0.05).
<table>
<thead>
<tr>
<th>Week</th>
<th>Protocol</th>
</tr>
</thead>
</table>
| 1    | **Informal orientation**  
Run-through of pre-trial measurements and on-ice drills |
| 2,3  | **Familiarization trials and sweat rate measurement**  
Run-through of entire testing protocol  
Measured individual sweat rates to determine CES fluid intake |
| 4-7  | **Testing trials**  
8 subjects tested each day  
At least 2 weeks between each subject’s 2 trials |
| 8,9  | **Spillover trials**  
Re-tested subjects if necessary |

**Figure 1.** Weekly testing outline. CES: carbohydrate-electrolyte solution.

**Figure 2.** Experimental design. Carbohydrate-electrolyte solution (CES) trial subjects were permitted to drink between the beginning of the pre-scrimmage performance drills and the end of the post-scrimmage performance drills. BM: Body mass; USG: Urine specific gravity; Tc: core temperature; HR: heart rate
Figure 3. Pre- and post-scrimmage performance drills. The slalom and shuttle drills were performed twice in succession, with a 2-min break for each subject. The slalom drill was performed with a puck and the shuttle drill was performed without a puck.

Figure 4. Net target board for shooting accuracy drill. An experimenter was present to ensure that only pucks entering the net in the corner areas were counted as successful attempts.
CHAPTER 4: RESULTS

Pre-trial measures

There was no difference in pre-trial USG between groups (NF: 1.018 ± 0.002; CES: 1.020 ± 0.002). However, pre-trial BM was significantly higher in NF (80.4 ± 2.7 kg), compared to CES (79.6 ± 2.7 kg).

Sweat testing data

Players lost 1.94 ± 0.1% BM in NF, and 0.12 ± 0.1% BM in CES. BM losses in the NF trial ranged from 1.4 to 3.3 % BM and from -0.5 to +0.7 % BM in CES. CHO intake was higher in CES compared to NF. There were no differences in sweat loss, forehead sweat sodium concentration ([Na⁺]), or salt loss between trials (Table 1). The sweat testing data were collected over the entire experimental trial, including the pre-scrimmage performance drills, the 70-min scrimmage, and the post-scrimmage drills, over roughly 2.5h.

Mean time-motion and physiological measures

Peak Tc was significantly greater in NF (Table 2). Mean TOI and distance covered over the entire 70-min scrimmage were not different between trials (Table 2). Mean skating speed was significantly lower in NF. Time spent at high effort and mean on-ice HR were not different between trials (Table 2).

“Period-by-period” time-motion and physiological measures

Tc was significantly higher in NF at all time points during the scrimmage starting at 5 min (Figure 5). Time at peak Tc was 43.7 ± 2.6 min in NF, and 48.6 ± 3.6 min in
CES (p=0.11). Tc was 0.34 and 0.25 °C higher in NF compared to CES at 40 and 65 min, respectively.

Mean skating speed and time spent at high effort were significantly lower in NF between 30 and 50 min of the scrimmage, with no differences in the last 20 min (Table 3). In the NF trial, mean skating speed and time at high effort decreased significantly for each time period. In CES, speed and time at high effort was not different between 0-30 and 30-50 min, but significantly decreased at 50-70 min. Time on ice was not different between 30 and 50 min (NF: 687 ± 25 s; CES: 706 ± 25 s).

Performance drills

Pre-scrimmage shuttle drill times in NF (Bout 1: 25.72 ± 0.25 s; Bout 2: 26.52 ± 0.31 s) were not different from CES (Bout 1: 25.48 ± 0.35 s; Bout 2: 26.72 ± 0.34 s). Bout 2 times were increased significantly in both trials. Post-scrimmage bout 2 shuttle time was slower in NF (27.16 ± 0.35 s), than in CES (26.50 ± 0.35 s) (Figure 6). Post-scrimmage shuttle time significantly increased in bout 2 vs. bout 1 in NF, but not in CES (Figure 6). Mean post-scrimmage shuttle time was also significantly higher in NF (26.81 ± 0.32 s) compared with CES (26.33 ± 0.26 s). No differences were observed between trials in the slalom skating or target shooting performance drills (Table 4).

In-game puck handling performance

Players committed more turnovers per min with the puck, and completed a lower percentage of passes in the last 20 min of the scrimmage in NF (Figure 7). There was a trend towards less time with the puck per min on ice in the last 20 min (NF: 3.1 ± 0.4 s; CES: 3.6 ± 0.4 s; p=0.08) (Figure 7, Table 5). No differences existed in the first 50 min
for turnovers, passing, number of takeaways, or number of shots at any point in the scrimmage (Table 5).

**Post-trial mental fatigue**

NF subjects had significantly higher scores in the fatigue subsection of the POMS questionnaire, compared to CES (Table 6a). NF subjects had significantly higher scores for two of the six fatigue-related questions in the HFQ (p < 0.05), and scores showing a trend toward significance for the remaining four questions (p < 0.08). Total HFQ score was higher in NF compared to CES (NF: 37.1 ± 1.6; CES: 29.5 ± 2.8; p < 0.05) (Table 6b).

**Correlations**

Between-trial difference in peak Tc was significantly correlated with the difference in post-scrimmage shuttle drill time (r = 0.70, p < 0.01), and the difference in post-scrimmage HFQ total score (r = 0.69, p < 0.01) (Figure 7A, B). An increase in post-scrimmage HFQ total score (NF vs. CES) was significantly correlated with a decrease in total time at high effort in the scrimmage (r = -0.7, p < 0.01) (NF vs. CES), and an increased time taken to complete the post-scrimmage shuttle drill (r = 0.65, p < 0.05) (NF vs. CES) (Figure 7C, D). The NF-CES difference in time spent at high effort from 30-50 min of the scrimmage was negatively correlated with dehydration (% BM loss) (r = -0.73, p < 0.01) and the CES-NF difference in time spent at high effort from 30-50 min of the scrimmage was positively correlated with CES intake (r = 0.71, p < 0.01) (Figure 7E, F).

**Individual analysis**

There was a high level of variability for many variables in this study. Furthermore, since time on ice and skating intensity was not controlled, these variables
influenced other variables differently for each subject. By examining each subject individually, it became clear that some subjects were more sensitive to the negative effects of dehydration in the NF trial and/or the positive effects of CES intake and maintenance of hydration in the CES trial. Subjects were divided into 2 groups: “high sensitivity” (H) and “low sensitivity” (L). This was based on between-trial differences in Tc, mean skating speed, time at high effort, mean post-scrimmage shuttle time, and mental fatigue. Mental fatigue was taken as HFQ total plus the fatigue section score from the POMS questionnaire. Each group contained 7 subjects. Correlation plots (Figure 8) denote H subjects (dark circles) and L subjects (grey circles).

**Subject characteristics: H vs. L**

H group subjects had significantly greater mean BM (86.1 ± 3 kg) and height (185 ± 1 cm) compared to L subjects (74.0 ± 3 kg; 179 ± 1 cm). There was no difference between age years of hockey experience between groups.

**Pre-trial measures: H vs. L**

The L group had a significantly higher pre-trial BM in NF (74.5 ± 3.1 kg) compared to CES (73.4 ± 3.0 kg), whereas there was no difference in the H group. There were no differences in pre-trial USG between trials or groups (Table 7).

**Sweat testing data: H vs. L**

H subjects had significantly higher sweat loss, fluid intake, CHO intake and salt loss compared to L subjects (Table 8). In the CES trial, H subjects had significantly higher sweat loss per kg BM compared to L subjects. There was no difference in sweat loss per kg in the NF trial. In the NF trials, dehydration was the same in both groups (H,
2.06 ± 0.23% BM; L, 1.83 ± 0.13% BM). There was also no difference between groups in dehydration in CES.

**Mean time-motion and physiological measures: H vs. L**

Peak Tc was significantly higher in NF for the H group compared to the L group (Table 9).

*H group:* Baseline Tc was not different between trials (Table 9). Peak Tc was significantly higher in NF, but mean on-ice HR was not different (NF, 178 ± 2 vs. CES, 176 ± 2 bpm). Over the 70-min scrimmage, H subjects had a significantly lower speed, and spent less time at high effort in NF. Time on ice and distance covered was not different between trials (Table 9).

*L group:* There were no differences in baseline Tc, peak Tc, or mean on-ice HR (NF, 173 ± 2 vs. CES, 175 ± 3 bpm). L subjects did spend significantly more time at high effort in NF than in CES, but there were no differences in time on ice, distance covered, or skating speed between trials (Table 9).

**“Period-by-period” time-motion and physiological measures: H vs. L**

*H group:* Tc was significantly elevated throughout the scrimmage in NF (Figure 9A) and 0.6 °C higher vs. CES at 45 and 65 min of the scrimmage. There were no differences in mean on-ice HR at any time point. Mean skating speed was lower in the last 20 min of NF, and decreased with time in NF. Mean speed decreased significantly only from 0-30 to 30-50 min in CES (Figure 10A). Time spent at high effort was lower from 30-50 min in NF compared to CES (Figure 10C). H subjects spent a lower percentage of time on ice at high effort in NF in the final 40 min compared with CES. Percent time at high effort decreased over time in NF, but not in CES (Figure 10E).
L group: There were no differences in Tc (Figure 9B) and on-ice HR at any time point between trials. Mean skating speed was lower from 30-50 min in NF (Figure 10B). Time at high effort was not different at any time points (Figure 10D). Percent time on ice at high effort was significantly higher from 50-70 min in NF, and did not decrease over time. In CES, percent of time at high effort was significantly lower at 50-70 min compared to 0-30 min (Figure 10F).

Performance drills: H vs. L

Pre-scrimmage shuttle drill times were not significantly different between trials in either group (Table 10). Post-scrimmage bout 2 shuttle time was significantly higher in NF (27.42 ± 0.45 s) compared to CES (26.60 ± 0.55 s) in the H group (Figure 11A). There were no differences in post-scrimmage shuttle drill performance between trials in the L group (Figure 11B). There were no differences in pre- or post-trial performance for the shooting accuracy or slalom puck-handling drills for either group (data not shown).

Post-trial mental fatigue: H vs. L

The fatigue and confusion subsections of the POMS questionnaire and all sections of the HFQ were scored significantly higher after NF in the H group (Table 11a, b). Total scores for the POMS questionnaire and HFQ were also higher for H subjects. There were no differences in scores between trials in any subsections of the POMS questionnaire in the L group (Table 11a). Whole body fatigue was significantly lower after NF compared to after CES (Table 11b) and no other HFQ scores were significantly different between trials in the L group.
**Correlations: H vs. L**

Sweat loss was correlated with pre-trial BM (Figure 12A). Between-trial difference (NF-CES) in HFQ total score was correlated with mean pre-trial BM (Figure 12B). In Figure 12, dark circles denote H subjects and grey circles denote L subjects.

**Grouping procedure**

Subjects were separated into “high sensitivity” (H), and “low sensitivity” (L) groups. This was based on differences between trials in 5 measurements: mean skating speed, time at high effort and peak Tc during the scrimmage, post-scrimmage shuttle drill performance, and post-trial fatigue scores (total HFQ score plus the score for the fatigue section of the POMS questionnaire). For each measurement, a score of +1 was given if the subject displayed a difference between trials that supported the initial hypotheses (decreased speed, effort, or drill performance, increased Tc or post-trial fatigue scores in NF). A score of 0 was given if no difference existed. A score of -1 was given if the difference was the opposite of the hypotheses. For each variable, the NF trial measurement was expressed as a percentage of the CES trial measurement. A “difference” was defined as at least 2 times the SE of the percentage difference. Scores could range from -5 to +5. H group subjects (n=7) had a score of +3 or higher, except for one subject, who had a score of +2. All L group subjects (n=7) had a score of 0 or lower (Figure 13).

50
Table 1. Mean sweat testing data.

<table>
<thead>
<tr>
<th></th>
<th>NF</th>
<th>CES</th>
</tr>
</thead>
<tbody>
<tr>
<td>% BM loss</td>
<td>1.94 ± 0.13 *</td>
<td>0.12 ± 0.09</td>
</tr>
<tr>
<td>Fluid intake (L)</td>
<td>0.00 *</td>
<td>1.36 ± 0.11</td>
</tr>
<tr>
<td>Sweat Loss (L)</td>
<td>1.53 ± 0.13</td>
<td>1.46 ± 0.10</td>
</tr>
<tr>
<td>Forehead Sweat [Na⁺] (mmol/L)</td>
<td>86 ± 4</td>
<td>88 ± 5</td>
</tr>
<tr>
<td>Sodium loss (mg)</td>
<td>1664 ± 155</td>
<td>1835 ± 185</td>
</tr>
<tr>
<td>CHO intake (g)</td>
<td>0 *</td>
<td>82 ± 7</td>
</tr>
</tbody>
</table>

Values are ± SEM, n = 14. * significantly different from CES (p < 0.05)

NF: No fluid; CES: Carbohydrate-electrolyte solution; BM: Body mass; CHO: carbohydrate.

Table 2. Mean scrimmage time-motion and physiological data.

<table>
<thead>
<tr>
<th></th>
<th>NF</th>
<th>CES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOI (s)</td>
<td>2479 ± 76</td>
<td>2422 ± 81</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>8661 ± 271</td>
<td>8591 ± 261</td>
</tr>
<tr>
<td>Skating speed (m/s)</td>
<td>3.52 ± 0.11</td>
<td>3.57 ± 0.10</td>
</tr>
<tr>
<td>Time at high effort (s)</td>
<td>611 ± 36</td>
<td>626 ± 36</td>
</tr>
<tr>
<td>Mean on-ice HR (bpm)</td>
<td>176 ± 2</td>
<td>176 ± 2</td>
</tr>
<tr>
<td>Baseline Tc (°C)</td>
<td>37.08 ± 0.07</td>
<td>37.09 ± 0.10</td>
</tr>
<tr>
<td>Peak Tc (°C)</td>
<td>38.92 ± 0.11 *</td>
<td>38.69 ± 0.10</td>
</tr>
</tbody>
</table>

Values are ± SEM, n = 14. * significantly different from CES (p < 0.05)

† n = 12; NF: No fluid; CES: Carbohydrate-electrolyte solution; TOI: Time on ice; HR: heart rate; Tc: core temperature.
Table 3. Mean skating speed and time spent at high effort during three “periods” of scrimmage.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Speed (m/s)</th>
<th>Time at high effort (s) †</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>3.66 ± 0.10</td>
<td>201 ± 12</td>
</tr>
<tr>
<td>30-50</td>
<td>3.45 ± 0.12 * ^</td>
<td>159 ± 11 * ^</td>
</tr>
<tr>
<td>50-70</td>
<td>3.35 ± 0.12 ^</td>
<td>155 ± 11 ^</td>
</tr>
</tbody>
</table>

Values are ± SEM, n =14. * significantly different from CES (p < 0.05). ^ significantly different from 0-30 min in same trial. NF: No fluid; CES: Carbohydrate-electrolyte solution. † 0-30 min-data normalized to fit with other time periods (0-30 min data x (2/3)).

Table 4. Slalom and shooting performance data.

<table>
<thead>
<tr>
<th>Slalom</th>
<th>NF</th>
<th>CES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre (s)</td>
<td>32.27 ± 0.6</td>
<td>32.15 ± 0.5</td>
</tr>
<tr>
<td>Post (s)</td>
<td>32.50 ± 0.6</td>
<td>32.35 ± 0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shooting</th>
<th>NF</th>
<th>CES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>Bottom</td>
<td>3.5 ± 0.3</td>
</tr>
<tr>
<td>Top</td>
<td>2.1 ± 0.3</td>
<td>1.7 ± 0.2</td>
</tr>
<tr>
<td>Points</td>
<td>8.8 ± 1.1</td>
<td>7.2 ± 0.7</td>
</tr>
<tr>
<td>Post</td>
<td>Bottom</td>
<td>4.2 ± 0.5</td>
</tr>
<tr>
<td>Top</td>
<td>2.0 ± 0.4</td>
<td>2.1 ± 0.4</td>
</tr>
<tr>
<td>Points</td>
<td>9.9 ± 1.4</td>
<td>10.3 ± 1.7</td>
</tr>
</tbody>
</table>

Values are ± SEM, n =14. No significant differences between trials were observed.

NF: No fluid; CES: Carbohydrate-electrolyte solution; Pre: pre-scrimmage times; Post: post-scrimmage times; Bottom: Bottom net targets; Top: Top net targets.
Table 5. In-game puck handling performance during three “periods” of scrimmage.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>NF</th>
<th>CES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time w puck (sec / min on ice)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-30</td>
<td>3.3 ± 0.4</td>
<td>3.5 ± 0.4</td>
</tr>
<tr>
<td>30-50</td>
<td>3.4 ± 0.4</td>
<td>3.7 ± 0.4</td>
</tr>
<tr>
<td><strong>50-70</strong></td>
<td><strong>3.1 ± 0.4</strong></td>
<td><strong>3.6 ± 0.4</strong></td>
</tr>
<tr>
<td>Turnovers (# / min with puck)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-30</td>
<td>4.3 ± 1.5</td>
<td>4.6 ± 0.8</td>
</tr>
<tr>
<td>30-50</td>
<td>3.3 ± 0.7</td>
<td>2.6 ± 0.3</td>
</tr>
<tr>
<td><strong>50-70</strong></td>
<td><strong>3.1 ± 0.7</strong>*</td>
<td><strong>1.6 ± 0.3</strong></td>
</tr>
<tr>
<td>Pass completion (% complete)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-30</td>
<td>60 ± 5</td>
<td>61 ± 4</td>
</tr>
<tr>
<td>30-50</td>
<td>74 ± 6</td>
<td>62 ± 6</td>
</tr>
<tr>
<td><strong>50-70</strong></td>
<td><strong>51 ± 8</strong>*</td>
<td><strong>78 ± 5</strong></td>
</tr>
<tr>
<td>Takeaways (# / min on ice)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-30</td>
<td>0.23 ± 0.05</td>
<td>0.27 ± 0.05</td>
</tr>
<tr>
<td>30-50</td>
<td>0.21 ± 0.03</td>
<td>0.26 ± 0.04</td>
</tr>
<tr>
<td><strong>50-70</strong></td>
<td><strong>0.25 ± 0.05</strong></td>
<td><strong>0.21 ± 0.04</strong></td>
</tr>
<tr>
<td>Shots taken (# / min with puck)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-30</td>
<td>3.4 ± 0.6</td>
<td>3.4 ± 0.6</td>
</tr>
<tr>
<td>30-50</td>
<td>2.1 ± 0.4</td>
<td>2.6 ± 0.6</td>
</tr>
<tr>
<td><strong>50-70</strong></td>
<td><strong>2.0 ± 0.4</strong></td>
<td><strong>2.0 ± 0.3</strong></td>
</tr>
</tbody>
</table>

Values are ± SEM, n =14. * significantly different from CES (p < 0.05). Values in bold are also presented in Figure 8. NF: No fluid; CES: Carbohydrate-electrolyte solution.

Table 6a. Profile of Mood States questionnaire.

<table>
<thead>
<tr>
<th>Subsection score (max)</th>
<th>NF</th>
<th>CES</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue (30)</td>
<td>19.4 ± 1.0</td>
<td>15.1 ± 1.3</td>
<td>0.007</td>
</tr>
<tr>
<td>Confusion (25)</td>
<td>8.5 ± 0.9</td>
<td>7.8 ± 0.9</td>
<td>0.17</td>
</tr>
<tr>
<td>Vigor (30)</td>
<td>13.6 ± 1.1</td>
<td>14.6 ± 1.1</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Table 6b. Hockey Fatigue Questionnaire.

<table>
<thead>
<tr>
<th>Fatigue element (/10)</th>
<th>NF</th>
<th>CES</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overheated</td>
<td>5.3 ± 0.6</td>
<td>3.6 ± 0.6</td>
<td>0.001</td>
</tr>
<tr>
<td>Arm fatigue</td>
<td>5.4 ± 0.6</td>
<td>4.3 ± 0.6</td>
<td>0.04</td>
</tr>
<tr>
<td>Whole body fatigue</td>
<td>7.7 ± 0.3</td>
<td>6.6 ± 0.5</td>
<td>0.056</td>
</tr>
<tr>
<td>Winded</td>
<td>6.5 ± 0.6</td>
<td>5.3 ± 0.6</td>
<td>0.06</td>
</tr>
<tr>
<td>Leg fatigue</td>
<td>8.1 ± 0.5</td>
<td>6.8 ± 0.6</td>
<td>0.07</td>
</tr>
<tr>
<td>Lightheaded</td>
<td>4.1 ± 0.7</td>
<td>3.0 ± 0.6</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Values are ± SEM, n =14. p < 0.05 indicates a significant difference between trials. NF: No fluid; CES: Carbohydrate-electrolyte solution.
Table 7. Pre-trial hydration and BM for H and L groups.

<table>
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<tr>
<th></th>
<th>H</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NF</td>
<td>CES</td>
</tr>
<tr>
<td>USG</td>
<td>1.019 ± 0.003</td>
<td>1.022 ± 0.003</td>
</tr>
<tr>
<td>BM (kg)</td>
<td>86.4 ± 3.2 ^</td>
<td>85.7 ± 3.1 ^</td>
</tr>
</tbody>
</table>

Values are ± SEM, n=7 (H), n=7 (L). * significantly different from CES (p < 0.05).
^ significantly different from same trial in LS (p < 0.05).

H: High sensitivity; L: Low sensitivity; USG: Urine specific gravity; BM: Body mass;
NF: No fluid; CES: Carbohydrate-electrolyte solution.

Table 8. Mean sweat testing data for H and L groups.

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NF</td>
<td>CES</td>
</tr>
<tr>
<td>Fluid intake (L)</td>
<td>0.00 *</td>
<td>1.62 ± 0.15 ^</td>
</tr>
<tr>
<td>Sweat Loss (L)</td>
<td>1.77 ± 0.22 ^</td>
<td>1.73 ± 0.15 ^</td>
</tr>
<tr>
<td>Sweat Loss (mL/kg)</td>
<td>20.4 ± 2.4</td>
<td>20.2 ± 1.5 ^</td>
</tr>
<tr>
<td>Forehead Sweat [Na⁺]</td>
<td>91 ± 8</td>
<td>87 ± 7</td>
</tr>
<tr>
<td>Sodium Loss (mg)</td>
<td>2114 ± 274 ^</td>
<td>1990 ± 210 ^</td>
</tr>
<tr>
<td>CHO intake (g)</td>
<td>0 *</td>
<td>97 ± 9 ^</td>
</tr>
</tbody>
</table>

Values are ± SEM, n=7 (H), n=7 (L). * significantly different from CES in same group (p < 0.05).
^ significantly different from same trial in LS (p < 0.05).

H: High sensitivity; L: Low sensitivity; CHO: Carbohydrate; NF: No fluid; CES: Carbohydrate-electrolyte solution.
Table 9. Mean time-motion and physiological data for H and L groups.

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th></th>
<th>L</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NF</td>
<td>CES</td>
<td>NF</td>
<td>CES</td>
</tr>
<tr>
<td>TOI (s)</td>
<td>2497 ± 121</td>
<td>2470 ± 142</td>
<td>2462 ± 101</td>
<td>2374 ± 85</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>8639 ± 272</td>
<td>8782 ± 385</td>
<td>8682 ± 495</td>
<td>8400 ± 367</td>
</tr>
<tr>
<td>Speed (m/s)</td>
<td>3.48 ± 0.09 *</td>
<td>3.58 ± 0.09</td>
<td>3.55 ± 0.21</td>
<td>3.56 ± 0.19</td>
</tr>
<tr>
<td>High effort (s)</td>
<td>596 ± 39 *</td>
<td>667 ± 43</td>
<td>627 ± 63 *</td>
<td>585 ± 56</td>
</tr>
<tr>
<td>High effort (% TOI)</td>
<td>24 ± 1 *</td>
<td>27 ± 1</td>
<td>26 ± 3</td>
<td>25 ± 3</td>
</tr>
<tr>
<td>Baseline Tc (°C)</td>
<td>37.21 ± 0.05</td>
<td>37.02 ± 0.07</td>
<td>36.94 ± 0.11</td>
<td>37.16 ± 0.18</td>
</tr>
<tr>
<td>Peak Tc (°C)</td>
<td>39.13 ± 0.09 * ^</td>
<td>38.59 ± 0.10</td>
<td>38.71 ± 0.17</td>
<td>38.79 ± 0.17</td>
</tr>
</tbody>
</table>

Values are ± SEM, n=7 (H), n=7 (L). * significantly different from CES (p < 0.05). ^ significantly different from NF trial in LS group (p < 0.05).

H: High sensitivity; L: Low sensitivity; TOI: Time on ice; Tc: core temperature; NF: No fluid; CES: Carbohydrate-electrolyte solution.

Table 10. Pre-scrimmage shuttle drill times for H and L groups.

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th></th>
<th>L</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bout 1 (s)</td>
<td>Bout 2 (s)</td>
<td>Bout 1 (s)</td>
<td>Bout 2 (s)</td>
</tr>
<tr>
<td>NF</td>
<td>25.74 ± 0.39</td>
<td>26.77 ± 0.44 ^</td>
<td>25.68 ± 0.23</td>
<td>26.10 ± 0.33</td>
</tr>
<tr>
<td>CES</td>
<td>25.58 ± 0.56</td>
<td>26.82 ± 0.48 ^</td>
<td>25.31 ± 0.15</td>
<td>26.55 ± 0.49 ^</td>
</tr>
</tbody>
</table>

Values are in seconds, ± SEM, n=7 (H), n=4 (L). ^ significantly different from bout 1 of same trial (p < 0.05). H: High sensitivity; L: Low sensitivity; NF: No fluid; CES: Carbohydrate-electrolyte solution.
Table 11a. Profile of Mood States Questionnaire for H and L groups.

<table>
<thead>
<tr>
<th>Subsection (max)</th>
<th>H</th>
<th>L</th>
<th>H</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NF</td>
<td>CES</td>
<td>NF</td>
<td>CES</td>
</tr>
<tr>
<td>Fatigue (30)</td>
<td>18.7 ± 1.7 *</td>
<td>11.1 ± 1.1</td>
<td>20.0 ± 0.9</td>
<td>19.1 ± 1.1</td>
</tr>
<tr>
<td>Confusion (25)</td>
<td>7.7 ± 1.3 *</td>
<td>5.4 ± 0.4</td>
<td>9.3 ± 1.3</td>
<td>10.1 ± 1.2</td>
</tr>
<tr>
<td>Vigor (30)</td>
<td>13.9 ± 1.9</td>
<td>15.7 ± 1.8</td>
<td>13.4 ± 1.3</td>
<td>13.6 ± 1.2</td>
</tr>
</tbody>
</table>

Table 11b. Hockey Fatigue Questionnaire for H and L groups.

<table>
<thead>
<tr>
<th>Question ( / 10)</th>
<th>H</th>
<th>L</th>
<th>H</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NF</td>
<td>CES</td>
<td>NF</td>
<td>CES</td>
</tr>
<tr>
<td>Overheated</td>
<td>5.3 ± 0.7 *</td>
<td>2.4 ± 0.7</td>
<td>5.3 ± 1.1</td>
<td>4.7 ± 0.9</td>
</tr>
<tr>
<td>Whole body fatigue</td>
<td>8.4 ± 0.2 *</td>
<td>5.3 ± 0.6</td>
<td>7.0 ± 0.5 *</td>
<td>7.9 ± 0.3</td>
</tr>
<tr>
<td>Leg fatigue</td>
<td>8.6 ± 0.7 *</td>
<td>5.4 ± 1.0</td>
<td>7.7 ± 0.8</td>
<td>8.1 ± 0.5</td>
</tr>
<tr>
<td>Winded</td>
<td>6.6 ± 0.7 *</td>
<td>3.4 ± 0.6</td>
<td>6.4 ± 1.0</td>
<td>7.1 ± 0.2</td>
</tr>
<tr>
<td>Arm fatigue</td>
<td>5.9 ± 1.0 *</td>
<td>3.1 ± 1.0</td>
<td>5.0 ± 0.8</td>
<td>5.4 ± 0.5</td>
</tr>
<tr>
<td>Lightheaded</td>
<td>3.9 ± 1.1 *</td>
<td>1.4 ± 0.4</td>
<td>4.3 ± 0.8</td>
<td>4.6 ± 0.8</td>
</tr>
</tbody>
</table>

Values are ± SEM, n=7 (H), n=7 (L). * significantly different compared to CES (p < 0.05). H: High sensitivity; L: Low sensitivity; NF: No fluid; CES: Carbohydrate-electrolyte solution.
**Figure 5.** Tc throughout scrimmage. Values are ± SEM, n =14. * significantly different from CES (p < 0.05). Tc was significantly higher in NF from 5-65 min.

NF: No fluid; CES: Carbohydrate-electrolyte solution; Tc: core temperature.
Figure 6. Post-scrimmage shuttle drill performance. Values are ± SEM, n=11.

* significantly different from CES (p < 0.05). ^ significantly different from bout 1 in same trial (p < 0.05). NF: No fluid; CES: Carbohydrate-electrolyte solution
Figure 7. In-game performance in last 20 min of scrimmage. A) Pass completion %; B) Turnovers committed (per min with puck); C) Time with puck (sec / min on ice). Values are ± SEM, n=14. * significantly different compared to CES (p < 0.05). NF: No fluid; CES: Carbohydrate-electrolyte solution.
Figure 8. Correlations: Between-trial differences (NF-CES) in peak core temperature (Tc) and A) post-scrimmage shuttle drill time and B) Hockey Fatigue Questionnaire (HFQ) total score; HFQ total score and C) time at high effort, and D) post-scrimmage shuttle drill time; E) time at high effort from 30-50 min in No Fluid (NF) trial and %BM loss, and F) CES-NF difference in time at high effort from 30-50 min in carbohydrate-electrolyte solution (CES) trial and CES intake.
Figure 9. Tc throughout scrimmage for H (A) and L (B) groups. Tc was significantly higher in NF from 5-65 minutes in S group. Values are ± SEM, n=7 (H), n=7 (L).

* significantly different compared to CES (p < 0.05). H: High sensitivity; L: Low sensitivity; Tc: core temperature; NF: No fluid; CES: Carbohydrate-electrolyte solution.
**Figure 10.** Time-motion data throughout scrimmage for H (A,C,E) and L (B,D,F) groups. A,B) Mean skating speed (m/s); C,D) Time at high effort (s); E,F) % TOI at high effort. Values are ± SEM, n=7 (H), n=7 (L). * significantly different compared with CES (p < 0.05). *^ significantly different from 0-30 minutes of same trial (p < 0.05).

H: High sensitivity; L: Low sensitivity; TOI: Time on ice; NF: No fluid; CES: Carbohydrate-electrolyte solution. 0-30 min data were normalized to compare to other time periods.
**Figure 11.** Post-scrimmage shuttle performance for H (A) and L (B) groups. Values are ± SEM, n=7 (H), n=4 (L). * significantly different compared with CES (p < 0.05). H: High sensitivity; L: Low sensitivity; NF: No fluid; CES: Carbohydrate-electrolyte solution.

**Figure 12.** Correlations for A) Sweat loss and pre-trial body mass (BM); B) Between-trial difference in Hockey Fatigue Questionnaire (HFQ) total score and pre-trial BM.
<table>
<thead>
<tr>
<th>Subj #</th>
<th>Tc max</th>
<th>Hi effort (s)</th>
<th>Speed (m/s)</th>
<th>Shuttle Post avg (s)</th>
<th>HFQ Total + POMS Fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>CES</td>
<td>NF</td>
<td>CES</td>
<td>NF</td>
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<tr>
<td>1</td>
<td>38.43</td>
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<td>400</td>
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<td>2</td>
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<td>592</td>
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<td>745</td>
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<td>8</td>
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<td>544</td>
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</table>

**Mean % diff:** 100.60, 98.25, 98.41, 100.47, 143.68

**SE:** 0.3, 2.9, 0.8, 0.9, 16.9

**SE*2:** 0.7, 5.8, 1.6, 1.7, 33.8

**% diff:**

<table>
<thead>
<tr>
<th>Score</th>
<th>Score</th>
<th>Score</th>
<th>Score</th>
<th>Score</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
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<td>100.0</td>
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</table>

Hypothesis: Supports, Refutes, Neither
Previous studies of intermittent exercise and team sports such as soccer and basketball have found that 1.5-2% dehydration is associated with increased Tc and HR, decreased performance, and increased mental fatigue (Baker et al. 2007, Dougherty et al. 2006, Edwards et al. 2007). CHO intake improves performance and reduces mental fatigue when taken during intermittent exercise and team sports (Dougherty et al. 2006, Welsh et al. 2002, Foskett et al. 2008). Two ice hockey studies also reported lower muscle glycogen use and increased skating performance when CHO was taken before or during exercise (Akermark et al. 1996, Simard et al. 1988). However, no study has examined the effects of mild (1.5-2%) dehydration on Tc, HR, in-game and post-game performance or mental fatigue during a hockey game and no study has examined the effect of CHO intake on these same parameters during a game. Many hockey players become dehydrated during practices and games even when given access to fluids during a game. In one study, 1/3 of hockey players dehydrated by 1.8% BM or more during a 60-min game (Logan-Sprenger et al. 2011a). On average, hockey players take in only small amounts of CHO, usually only before a game (Palmer and Spriet et al. 2008). Based on separate findings from dehydration and CHO intake studies, remaining hydrated by ingesting CHO would appear to be the ideal method for optimal performance. Not surprisingly, sports drinks are formulated to meet these needs.

The aim of this study was to compare the physiological, performance and mental effects of dehydration by ~1.5-2% by drinking no fluid (NF) to ingestion of a
carbohydrate-electrolyte solution (CES) in order to maintain BM, during a 70-min 5-on-5 scrimmage and ice hockey performance drills.

The main findings of this study were that subjects in NF displayed increased Tc throughout the scrimmage, decreased speed and effort level between 30-50 min of the scrimmage, decreased in-game puck handling performance in the last 20 min, decreased post-scrimmage sprint skating performance, and increased post-scrimmage mental fatigue, compared to subjects in CES.

**Core temperature**

It was hypothesized that the majority of subjects would display an elevated Tc during the scrimmage, especially in the last 20 min of the game. Tc was elevated at all time points measured during the scrimmage (5 - 65 min) in NF compared to CES. There was no difference in on-ice mean HR at any time point between trials.

Peak Tc was 38.92 °C in NF and 38.69 °C in CES. 8 subjects in the NF trial had a peak Tc > 39 °C, while only 2 in the CES trial had a peak Tc > 39 °C. Tc did not reach dangerous levels (> 40 °C) in any subjects during either trial, and the peak difference between trials (0.34 °C) is not as large as has been reported in previous laboratory studies (Hargreaves et al. 1996, Logan-Sprenger et al. 2011b). This is not surprising since the players were able to pace themselves and could therefore choose to exert less effort if necessary. Most of the subjects who displayed an elevated Tc in NF also had a lower skating speed and time at high effort. If skating intensity had been kept constant between trials, the difference in Tc may have been greater.

Heat dissipation, and perhaps heat tolerance, was compromised due to the large amount of equipment worn. During submaximal exercise on a treadmill in the heat, 75%
of subjects discontinued exercise due to exhaustion when Tc reached 38.8 °C while wearing “full protective clothing” (Montain et al. 1994). In contrast, 75% of subjects wearing no clothing continued exercise until Tc reached 39.2 °C. The study was conducted in an extremely hot environment compared to the very cool environment in this study, but it does indicate that wearing a lot of clothing, or in the case of this study, hockey equipment, can affect heat tolerance. When hockey players participated in an intermittent cycling study designed to mimic hockey while wearing full equipment or just workout clothes, Tc was higher when wearing full equipment (Noonan et al. 2007).

A recent study of collegiate hockey players reported a mean Tc increase of ~1 °C after 40 min of a pre-season practice (Batchelder et al. 2010). In contrast, mean Tc increase in the present study was 1.6 °C in CES, and 1.85 °C in NF. The large difference in Tc increase between studies is likely due to the difference in intensity and motivation between a game situation with a reward for the winner, and a pre-season practice session. Furthermore, the level of dehydration may explain the differences between the previous study and the two trials in the present study. Subjects in the pre-season practice study drank fluid ad libitum and dehydrated by an average of 1.1% BM. In the present study, subjects in the CES trial lost an average of only ~0.1% BM, while subjects in the NF trial lost an average of 1.9% BM.

There was no correlation between % dehydration and Tc, but effort level was not controlled, and 13 of the 14 players lost between 1.4-2.2% BM, which is not a very large range. Previous studies found a graded effect when examining dehydration levels from 1-4% BM loss (Montain and Coyle 1992, Baker et al. 2007).
Tc elevation was not correlated with an increased time at high effort or an increased skating speed, and subjects dehydrated gradually throughout the trial. However, even a smaller level of dehydration could have contributed to the increase. Subjects began exercise well hydrated, but had been on the ice for ~35 min prior to the scrimmage, so it could be reasoned that many NF subjects had lost 0.5% BM at the beginning of the scrimmage. This level of dehydration may be enough to cause a significant increase in Tc during submaximal cycling (Logan-Sprenger 2011b). A reduced plasma volume may be responsible. During exercise, maintaining plasma volume contributes to delivering the proper amount of blood to the contracting muscles to maintain the exercise intensity, but also to deliver blood to the skin for heat dissipation (Montain and Coyle 1992). Core-to-skin heat transfer was restricted following diuretic-induced dehydration (2.7%BM) (Nadel et al. 1980). Interestingly, sweat rates were not different between trials in the present study, so it is likely that skin blood flow was comprised in the NF trial, and the lack of heat transfer to the periphery accounted for the increased Tc. It should also be noted that max Tc did not correlate with time on ice.

Lastly, the increase in peak Tc in NF was correlated with an increase in HFQ total score, as well as the “overheated” question in the HFQ. This suggests that subjects were able to sense if they were overheating, and the associated mental fatigue may have influenced their performance.

**Heart rate**

No difference in on-ice, or off-ice mean HR was found in this study. This is in contrast to previous continuous and intermittent lab exercise studies that reported higher HR with 1-2% dehydration (Montain and Coyle 1992, Noonan et al. 2007). It has been
argued that the higher HR is a consequence of a lower stroke volume when mildly dehydrated in an attempt to maintain cardiac output. However, HR is more difficult to measure during actual sports where work rates are not controlled and breaks from exercise are variable (Green et al. 1976). Previous studies of dehydration during self-paced soccer or basketball games did not consistently report differences in mean HR (Edwards et al. 2007, Baker et al. 2007, Dougherty et al. 2006).

Unlike Tc, HR recovers relatively quickly when players rest between shifts. Since rest times could reach up to 5 min in this study, HR could decrease to almost 100 bpm in some cases, and would take some time to increase when the subject returned to the ice.

On-ice HR in both trials averaged ~176 bpm. VO\textsubscript{2max} was not measured in this study, but it can be estimated that this HR value corresponded to ~89% of the subjects’ max HR, assuming max HR = 220 – age.

In summary, Tc was higher in NF subjects at all time points during the scrimmage, and was likely the result of a reduced skin blood flow resulting from mild dehydration throughout the scrimmage. Peak Tc was close to 39 °C in NF, and this could represent a value at which many players would need to reduce effort in order to maintain comfort.

**Scrimmage skating performance**

Time at high effort and mean skating speed between 30 and 50 min of the scrimmage were 3.4% and 12.4% lower, respectively, in NF compared to CES. Contrary to the hypotheses, there were no significant between-trial differences in skating speed or time spent at high effort in the last 20 minutes of the scrimmage. This is in spite of the
fact that this is the time in the scrimmage when muscle glycogen would most likely be lowest, and dehydration would be greatest, especially in the NF subjects. A study comparing elite Swedish hockey players who consumed a high-CHO diet for 3 days between games measured a 30% greater total distance covered and an 11% greater skating distance in the third period of a game, compared to players who consumed a mixed diet (Akermark et al, 1996). It should be noted this study did not use a crossover design, which could have influenced the differences observed. In a study that did use a crossover design, collegiate players ingesting CHO prior to and during a game spent 5.6% more time on the ice and covered 10.2% more distance than when ingesting no CHO. There was also an 11.5% increase in skating distance in the 3rd period, but this difference was not significant (Simard et al. 1988). Both of these studies found significant muscle glycogen usage in all players at the end of the game, and significantly higher glycogen usage in the control groups compared to the CHO groups.

The decrease in effort midway through the game in NF is still important. The timing of the decrease coincides with the time at which Tc was at its peak. Players may have reduced effort in response to the higher Tc in NF. In both hockey studies that found skating differences in the last period of play, there were no differences in effort levels in the first two periods. Since hockey is a self-paced game and fatigue is accumulated throughout depending on effort level, the reduced effort seen in the present study midway through the game in NF may have been a conscious or unconscious strategy of those subjects in order to prevent a more drastic drop in performance in the last 20 min. The last part of a game is often the most important, but poor play in the first 2 periods can cause the game to be decided prior to the last period.
No measurements of muscle glycogen were taken in the present study, but it is possible that the muscle glycogen depletion of players in the NF trial, in particular depletion of Type II fibres, had reached “critical” levels for force production. Players in the present study participated in ~25 minutes of performance drills prior to the game in addition to the 50 minutes of scrimmage. CHO intake during the CES trial, as well as dehydration and the resulting Tc increase in NF, may have contributed to a large difference in glycogen use between trials (Hargreaves et al. 1996, Logan-Sprenger et al. 2011b). Tc peaked from 30-50 min for most subjects in NF.

Speed and time at high effort significantly decreased between 30-50 min compared to the first 30 min in NF but not in CES. Since the CES subjects were ingesting CHO throughout this time, it is possible they were able to spare more glycogen and prevent the drop in speed and high effort observed between 30-50 min of the NF trial. In the study by Simard et al (1988), blood glucose levels were significantly higher in the CHO group at the end of the game. It is possible that CHO intake in CES subjects in the present study prevented a drop in blood glucose levels associated with decreased performance (Simard et al 1988, Welsh et al. 2002). This higher blood glucose level may be indicative of higher CHO oxidation to aid performance (Nicholas et al. 1999). Reductions in blood glucose are also associated with decreased CNS function and mental fatigue (Welsh et al. 2002).

If muscle glycogen depletion in NF was the cause of the reduced effort between 30-50 min, it may have been expected that effort would be even further reduced in the last period of play. However, a lack of difference could be due to the fact that hockey is a self-paced activity, and other skill elements of the game mean that skating speed and
effort level are not the only determinants of success. Perhaps players in the CES trial were able to focus more on these other skill elements in the last period and did not need to maintain effort or speed to be successful. It is also possible that CES players ingested the highest amount of CHO in the early parts of the game, resulting in the largest difference in blood glucose levels from 30-50 min. Fluid intake may have decreased later in the game, leading to similar glucose levels from 50-70 min.

Players in both trials had significantly lower average speed and time spent at high effort in the 3rd period compared to the first period of the same trial. This is in agreement with previous studies. Average speed of varsity hockey players decreased by 5.2% in the 3rd period of a game compared to the first 2 periods when subjects drank ad libitum (Green et al. 1976).

In summary, the reduced effort observed midway through the scrimmage in NF coincides with the time at peak Tc and may reflect a compensatory reaction to attempt to delay mental and physical fatigue. The reduced effort may also be associated with differences in blood glucose concentration and/or muscle glycogen use.

**In-game puck handling performance**

Increased speed and time at high effort are advantageous in ice hockey, but are not the only elements of performance. This is the first study to compare players’ performance with the puck during the game when either dehydrated or when ingesting CES to maintain hydration. Several important aspects of puck handling were examined: time spent with the puck, the ability to steal the puck from an opposing player as well as to not allow an opposing player to steal it back, and pass completion percentage and
number of shots taken. The last period of a hockey game is when puck performance is most crucial, especially if the score is close.

NF subjects committed twice as many turnovers, and had a 25% lower pass completion percentage in the last 20 min of the scrimmage. NF subjects also tended to have puck for less time during this period. No differences existed during the first 50 min of the scrimmage.

The lack of difference observed in speed and effort from 50-70 min in the scrimmage could be partially explained with the differences in puck handling performance observed in that period. If players in the CES trial were able to complete more passes, and commit fewer turnovers, it may be expected that they would not have to put forth as much skating effort. In fact, it is possible that the NF subjects were required to exert more effort since they were chasing the puck more often, but the lack of difference indicates the NF subjects may have been too fatigued to increase their effort level.

These hockey-specific skills differ from skating speed and effort level in that they require cognitive as well as physical ability. When passing the puck, the player must correctly identify a teammate who is available to accept the pass, and then react quickly enough to deliver the puck to the teammate before an opposing player can take it away. For this reason, mental perception of fatigue must be an important aspect in determining hockey-specific performance. Previous studies have shown mental fatigue is increased when dehydrated, and decreased when taking in CHO, compared to remaining hydrated with water (Welsh et al. 2002, Dougherty et al. 2006). Mental fatigue was increased in NF subjects in the current study.
Two basketball studies used a timed shooting drill as part of a performance protocol (Dougherty et al. 2006, Baker et al. 2007). Similar to the in-game performance measures observed in this study, timed shooting requires proper decision-making, coordination and reaction time. When players were 2% dehydrated, shooting percentage in 3 shooting drills was impaired compared with remaining hydrated with water (Dougherty et al. 2006). Mental fatigue was not higher at the end of this protocol, but was higher halfway through. The other basketball study did not find a negative effect on shooting performance until subjects were 3% dehydrated (Baker et al. 2007). There were also no differences in mental fatigue until this level of dehydration. This suggests that the level of dehydration reached by most players in this study (1.4-2.3%) may not have been high enough to consistently lead to the performance decreases observed.

The results of several studies where subjects ingested CHO during performance drills suggest a link between CHO intake and mental fatigue that could be a factor in improving skill performance. When players ingested a CES to maintain hydration during the basketball drill sessions, one study found that both shooting performance and mental fatigue was improved compared with remaining hydrated with water (Dougherty et al. 2006). The other study found that CES ingestion did not enhance performance or mental status compared to water ingestion (Baker et al. 2007). A third study had subjects perform a timed and variable jumping task and found that performance, along with mental fatigue, was improved by CHO ingestion (Welsh et al. 2002).

In-game performance was highly variable among subjects. It is possible that the increase in mental fatigue and subsequent decreases in puck-handling performance in this study are linked with subjects’ individual responses to CHO intake. Recently, studies
have identified that the sensation of CHO on the tongue activates reward-related regions of the brain (Chambers 2009). This could have an effect on an athlete’s perception of fatigue, which would most likely help the athlete maintain focus and avoid decreases in cognitive performance tasks.

There were no between-trial differences in number of takeaways or number of shots taken. It is unclear as to the reason for this. Players took fewer shots during the game than the number of passes they attempted, so the smaller sample size may be a reason a difference was not observed.

Post-scrimmage shuttle drill performance

Effort and speed responses of players during an actual game can be masked by the other objectives of the game (puck movement, positioning, etc). Examining only speed and effort during a game does not provide an adequate overall assessment of performance. The shuttle skating drill involved skating as hard as possible back and forth between the blue and red lines on the ice for approximately 30 sec. Each subject repeated the drill twice, with ~2 min rest. The timing of the post-scrimmage drills represented the time at which maximal dehydration (and most likely glycogen depletion) had occurred.

There were several significant findings. First, the average time taken to complete the two bouts was 0.5 seconds, or 2% higher in the NF trial. Second, the time taken to complete the second of two bouts was 2.5% slower in the NF trial. Finally, there was significant slowing between bouts 1 and 2 in NF but not in CES. This indicates that NF players had decreased sprinting ability as well as poorer recovery between bouts.

These results are in agreement with a study using a similar shuttle running drill where performance time increased with only 1% dehydration compared with maintaining
BM with water. When subjects ingested CHO to maintain BM, no further performance differences were observed compared to hydration with water (Baker et al. 2007). Several studies have shown that when subjects have to perform intermittent shuttle runs within a given time limit, 1.5-2% dehydration caused a decrease in number of runs performed and/or performance in individual runs (Maxwell et al. 1999, Baker et al. 2007).

There was a significant correlation between the increased average time taken to complete the post-scrimmage shuttle drill in the NF trial, and increased peak Tc in NF, compared with CES. Several studies have reported increased muscle glycogen use with dehydration of 1-2% BM (Hargreaves et al. 1996, Logan-Sprenger et al. 2011b), which was associated with an increased muscle temperature, and Tc.

As discussed previously, it is possible that the combination of dehydration in NF and CHO intake in CES created a difference in muscle glycogen concentration and/or blood glucose concentration that influenced the differences seen. If CHO ingestion allowed CES subjects to spare more Type II muscle fibres, sprint skating performance would be expected to be better (McCartney et al. 1986). In a study of young basketball players, sprint drill performance was decreased when players were 2% dehydrated, and increased when players maintained BM with a CES, compared to maintaining BM with water.

Increased mean shuttle drill time in NF was correlated with the increase in HFQ total score in NF. In other words, subjects who reported feeling more fatigued throughout the NF trial also had poorer shuttle drill performance.
Importantly, there was no correlation between mean shuttle drill time and mean skating speed or time at high effort during the game. Poor performance in the shuttle drill was not merely a result of expending more effort throughout the scrimmage.

It is sometimes difficult to determine the practical implications of a small decrease in speed in a repeat sprint skating drill. In high level sports such as hockey, athletes are all already at an elite level, and so a 2.5% difference in performance becomes magnified. The average speed of all players in this drill was 4.8 m·s\(^{-1}\), and the highest speed of any player was 5.1 m·s\(^{-1}\). This represents a difference of only 6%. Furthermore, this sprint drill was only performed twice, and a 2.5% reduction in speed was seen in NF players in the second bout. If this drill had been repeated more times, it is reasonable to expect that time taken to complete the drill would continue to increase.

There were no differences between trials in target shooting or slalom puck handling performance. A previous study reported that timed basketball shooting performance was not hindered by dehydration until it reached 3% (Baker et al. 2007).

The slalom drill was highly variable. Players had trouble holding onto the puck, avoiding cones and maintaining balance. Each player performed 2 bouts but only 1 from each could be used because of errors.

Both the shooting and slalom drills had a higher cognitive component than the shuttle drill. Studies examining skilled drill performance when ingesting CHO have had mixed results (Baker et al. 2007, Dougherty et al. 2006, Welsh et al. 2002), perhaps due to a variable individual cognitive response to CHO intake.

In summary, NF subjects displayed a decreased shuttle drill performance following the scrimmage. This was not associated with increased effort level during the
scrimmage, but was associated with increased mental fatigue. Increased Tc and dehydration in NF, coupled with CHO intake in CES, may have contributed to a between-trial difference in post-scrimmage muscle glycogen content and/or blood glucose concentration, which may have decreased physical and mental function in NF subjects.

**Mental fatigue**

Players reported increased mental fatigue following the NF trial. Post-trial mental fatigue was assessed with two questionnaires given to subjects immediately after post-trial weighing. The Hockey Fatigue Questionnaire (HFQ) asked players to rate their feelings of fatigue throughout the trial. Players in NF had significantly stronger feelings of being overheated, and of arm fatigue. Feelings of whole body fatigue, leg fatigue, lightheadedness, and feeling “winded”, all tended to be higher in NF but the differences were not significant. In the Profile of Mood States (POMS) questionnaire, NF players rated their mood states following the trial. NF players had a significantly higher score in the fatigue subsection, with no differences in the confusion or vigour subsections.

Mental fatigue is a major factor in a high-skill, self-paced team sport such as hockey. HFQ total score, which corresponded to players’ feelings of fatigue during the trial, was significantly correlated with increased Tc, total time spent at high effort during the scrimmage, and mean time to complete the post-scrimmage shuttle drill. Peak Tc was also correlated with subjects’ perception of “overheating” during the game. Players appeared to be able to sense small increases in Tc between trials.

Another reason mental fatigue played a large role in this study is that players were not blinded to the treatments. This may have influenced their decisions about effort level in the early part of the game. The correlation between HFQ total score and time at
high effort is only significant for the first 50 min of the scrimmage. Tc was already higher in NF subjects at 5 min into the scrimmage, and so players may have consciously decided to reduce their effort in the first part of the game in order to avoid large increases in Tc and to save energy for the last part. Given the lack of difference in speed and effort over the last 20 min, they may have been successful in this strategy, but it may have come at the cost of poorer performance early in the game.

It seems that CHO intake may be more important than hydration in terms of mental fatigue. A study that examined mental fatigue following a basketball drill exercise found decreased mental fatigue in subjects who ingested CHO, but no difference in fatigue in subjects who dehydrated by 2%, compared to subjects who remained hydrated with water (Dougherty et al. 2006). Welsh et al (2002) found an increased fatigue score in the POMS questionnaire following intermittent exercise when subjects remained hydrated with CES compared to when subjects remained hydrated with water.

However, dehydration can still affect mental fatigue during a game. While RPE was not measured in this study, RPE during a soccer game was higher in players who gradually dehydrated by 2% compared to players who remained hydrated with water (Edwards et al. 2007). However, from other self-paced studies, it appears that RPE does not always provide a clear measure of fatigue. After 2 h of paced intermittent treadmill exercise while dehydrating in the heat, subjects’ RPE was higher than when they remained hydrated (Dougherty et al. 2006). However, during self-paced basketball drills in the same study, RPE was not different between those who were 2% dehydrated and those who remained hydrated.
In summary, mental fatigue was higher in NF subjects compared to CES subjects. This mental fatigue appeared to affect players’ effort levels during the scrimmage as well as their post-scrimmage drill performance.

**Individual analysis**

Player responses in this study were highly variable. Pre-game USG, sweat loss, % BM loss, mental fatigue and motivation are all highly individual. As a result, in the field, it is useful and necessary to examine players individually in order to identify those who may be susceptible to dehydration and/or who may benefit more from CES intake, than others. When examining players based on between-trial differences in peak Tc, mean skating speed, time at high effort, post-scrimmage shuttle drill time, and post-scrimmage mental fatigue, it became apparent that 7 of the 14 subjects were much more affected than others. This group was designated as the “high sensitivity” group (H), while the other group of 7 was labeled the “low sensitivity” group (L).

Indeed, Tc in the H group was much higher during the NF trial than during the CES trial, reaching a difference of 0.6 °C late in exercise. Tc was not different at any time point between trials in the L group. H subjects had a higher mean skating speed and time at high effort throughout the entire 70-min scrimmage. They also spent a higher percentage of their time on ice at a high effort. H subjects had a lower mean skating speed in the last 20 min of the NF trial, and spent a lower percentage of their time on ice at a high effort in the last 50 min of the game. Post-scrimmage shuttle times were significantly higher in NF for H, but not for L. H subjects reported higher fatigue and confusion scores in the POMS questionnaire following NF, and had higher scores in all 6 questions of the HFQ following the NF trial. All 7 of the H subjects had at least a 35%
higher HFQ total score in NF, while 3 L subjects had small 2-12% increases in HFQ total score in NF compared to CES.

Essentially, the H subjects confirmed the initial hypotheses of the study, while the L subjects did not. A major reason for this could be related to their ability to thermoregulate during exercise. Among the 7 H subjects, 6 of them had a BM greater than the mean of 80 kg, with their average BM was 12 kg heavier than the L group. No measurements of body fat percentage or VO$_{2\text{max}}$ were made. Furthermore, players in the H group had a higher sweat rate per kg BM. This suggests the H group had more difficulty with thermoregulation than the L group. The L group had a higher pre-trial BM in NF compared to CES, while the H group did not. This could indicate the L group was better hydrated prior to the NF trial, although USG was not different between trials. Interestingly, %BM loss was not different between groups.

Proper thermoregulation involves balancing heat production with heat dissipation. An individual with a higher BM generates more heat at a given intensity (Marino et al. 2000). Two factors that influence heat dissipation during exercise are body surface area and wind speed. Higher surface area allows for more evaporative cooling and more heat dissipation. However, the equipment worn by hockey players drastically decreases the potential for evaporative cooling (Noonan et al. 2007), and so the main factor determining thermoregulation during hockey is BM. The decrease in skin blood flow caused by dehydration may have further exacerbated the problem for H subjects.

Peak Tc in the H group averaged $39.1\, ^\circ\text{C}$ in NF, compared to $38.6\, ^\circ\text{C}$ in CES. In contrast, the L group had no difference in peak Tc between trials, with mean Tc being $38.7\text{-}38.8\, ^\circ\text{C}$. A study comparing NFL linemen to running backs during a pre-season
practice found that linemen had a significantly higher Tc (Godek et al 2006b). This was credited partially to the linemen’s increased BM (135 kg) compared to the backs (96 kg). Mean peak Tc was only 38.65°C in the linemen in this study, but it was a pre-season practice and so intensity was most likely a factor. Also, linemen were less dehydrated than the backs following exercise. If both had dehydrated to a similar level, the linemen may have had a further increase in Tc compared to the backs.

Mental factors were likely involved as well, given the large and consistent differences in fatigue reported between trials in the H group. As mentioned previously, players knew when they were ingesting fluid and when they were not. In particular, larger players were under more pressure to drink to replace sweat losses, and knew how much they would have to drink. The combination of concern for dehydration and having to focus more on drinking, may have caused the larger players to feel more fatigued and exert less effort throughout the scrimmage.

H subjects ingested significantly higher amounts of CHO during the CES trial than the L subjects. It is possible that this helped H subjects avoid fatigue later in the exercise and during the post-scrimmage drills. It may also have improved their mental state throughout the trial.

L subjects actually 7% spent more time at high effort in NF, and spent a higher percentage of their time on the ice at a high effort in the last 20 min. It is probable that the responses of these subjects would be less dependent on the treatment given the fact that thermoregulation ability was not different between trials.

The reduced CHO intake in the L group could have been a factor. L subjects reported more whole body fatigue during CES than during NF. It is possible that the
lower intake of CHO attenuated the positive mental and physical effects of CHO ingestion. A recent study found that ingestion of 60 g·h\(^{-1}\) CHO during 2 h of submaximal cycling resulted in greater improvement in subsequent time trial performance compared with ingestion of 15 or 30 g·h\(^{-1}\) (Smith et al. 2010). However, it should be noted that subjects began exercise after an overnight fast, which may have increased the effect of the CHO (Jeukendrup 2004). In the present study, H subjects had a mean CHO intake of 38 g·h\(^{-1}\) (range: 26-54 g·h\(^{-1}\)), while L subjects had a mean intake of 28 g·h\(^{-1}\) (range: 20-35 g·h\(^{-1}\)), and all subjects began exercise in a fed state, as would be the case before a competitive hockey game. Since maintaining hydration was the primary goal in the CES trial, it was not possible to achieve high amounts of CHO intake with a 5.8% CHO solution. The possibility that L subjects may have started the NF trial in a better hydration state than in CES may have contributed to the differences in performance.

In summary, it appears as though 7 of the 14 subjects in this study were particularly affected by the dehydration and CES intake protocols. A higher BM likely influenced this increased sensitivity. High BM is associated with a decreased ability to thermoregulate during exercise. However, it cannot be discounted that the higher CHO intake in the CES trial for the HS group may have accounted for some of the differences in response.

**Scrimmage characteristics**

This scrimmage was different than a normal competitive hockey game. There were only 8 players per team, compared to the usual 15, and so time on ice was much higher. Also, there were no breaks taken between periods. Players rested between shifts or during brief stoppages in play on the ice. Players spent an average of ~40 min on the
ice. This is much higher than previously reported times of 18-30 min in regular games. However, in this study, more time on ice did not necessarily mean more effort exerted. There was a positive correlation between time spent on the ice and time spent at low effort (i.e., gliding, stopped, skating at a speed <4.2 m·s\(^{-1}\)) \(r = 0.9, p < 0.001\). In other words, if a player stayed out on the ice too long, they would most likely spend that extra time skating at an easier pace. Players spent an average of 25% of their time at high effort (includes high effort skating, fighting for puck, quick turns, etc.), which agrees with data reported in professional players in a normal game (Bracko et al. 1998). Mean on-ice HR was ~176 bpm in both trials (~89% of max HR). This is in agreement with previous measurements in normal hockey games (Green et al. 1976, Montgomery 1988).

**Tc measurement accuracy**

Some studies have reported that fluid ingestion, may affect Tc measurements when using ingestible thermistors (Byrne and Lim 2007) if the thermistor is still in the stomach at the time of measurement. In this study, participants ingested Tc pills 6-8 h prior to arrival at the rink in order to ensure that the pill was not still in the stomach. If the pill were in the stomach, Tc would decrease as players began to drink. This was not seen in the present study. Importantly, all Tc readings were taken immediately after a player completed a shift, and before they were permitted to drink. Also, there was no correlation between amount of fluid ingested and Tc increase.

**Conclusions**

Mild dehydration progressing to 1.5-2% throughout a hockey scrimmage and hockey-specific drill session, resulted in increased Tc, reduced hockey-specific skill
performance and post-scrimmage sprint performance, and increased mental perception of fatigue, compared to remaining hydrated with a CES.

It appears that individuals with higher BM are more susceptible to these effects, due to decreased thermoregulation ability. It is also possible that an increased CHO intake contributed to the differences.

**Recommendations for players and coaches**

Players should ingest some form of CES during ice hockey practices and games, in order to prevent sweat losses >1% BM, and to benefit from the positive effects of CHO intake on physical and mental performance.

Some individuals are more affected by dehydration than others. In particular, players with high BM need to be more aware of individual hydration needs, as they seem to be more susceptible to overheating during a game.

Mental fatigue testing is an easy and inexpensive method to identify players at particular risk. In particular, all 7 of the HS subjects in this study had a 35% or higher increase in HFQ total following the NF trial, while the largest increase in HFQ total in NF was 12% for the LS group.

Certain players may have trouble with hydration. Two subjects in this study lost 0.7% BM in the CES trial. Limiting BM losses to 0.5% or lower may not always be possible or practical with some players. Montain and Coyle (1992) recommend that fluid intake should represent ~80% of fluid losses. In the present study, two subjects dehydrated by 0.6-0.7% BM and did not replace 80% of fluid losses. Both subjects were high sweaters and lost 2.25% BM in the NF trial. One subject was tested a second time but was still unable to lose less than 0.7% BM. Both subjects needed to drink ~2 L in
order to maintain BM, and one needed to urinate after the CES trial. Interestingly, of the 4 subjects who had to void following a trial, 3 of them were in the LS group. The small gains resulting from maintenance of BM may be outweighed by feelings of stomach discomfort or fullness from the high fluid intake. Since hydration and nutrition vary between individuals, it is important that players practice with ingesting different amounts of CES in order to be able to limit BM losses but also limit any potential discomfort that may result from overhydrating.

**Limitations of study**

There were only 8 players on each team during the scrimmage, which meant that shift times were longer than during a normal game. However, as mentioned previously, time spent at high effort and mean on-ice HR were similar to values previously reported, and so while the scrimmage setup was not exactly the same as a regular hockey game, the effort level was similar. It is also very difficult even with a coach and 3 lines to keep week-to-week games the same, but it would have provided more representative shift characteristics.

It would have been ideal to study elite junior players in an actual game situation. According to previous research on these groups, sweat rate and %BM loss with no fluid intake would have been higher (Palmer and Spriet 2008, Logan-Sprenger et al. 2011a), which may have produced greater differences between trials. Motivation would have been higher. In the present study, a monetary award for the winning team kept motivation high, but the pressure and competition level of a regular season or playoff hockey game would likely result in higher motivation. Rink temperature was also much cooler in the present study (~4 °C) compared to a rink during a game (10-15 °C).
There was no way to properly blind subjects or experimenters to the treatments. This may have affected the mental fatigue of the players during the scrimmage, although the separation between H and L group fatigue scores provides evidence that players did not just automatically report higher levels of fatigue when they knew they had been dehydrated. One or two additional fluid trials with varying amounts of CHO could have been used in order to blind subjects to differences between hydrated trials.

The distance tracking method was extremely inefficient. However, the repeatability of the measurements was very good.

No muscle or blood samples were taken during the study. Therefore, differences in performance and mental fatigue cannot be related to differences in muscle glycogen content or blood glucose concentration. The ability to measure blood glucose constantly throughout the scrimmage would have been especially useful.

The amount of CHO given to subjects was not standardized. The main goal was to give CES to limit BM losses. During the trial subjects ingested between 51 and 135 g of CHO. There was no correlation between amount of CHO ingested and puck handling performance, sprint skating performance, or mental fatigue scores. There was a correlation between CES intake and time spent at high effort between 30 and 50 min of the scrimmage, but that cannot be separated from the difference in fluid intake. The general recommendation is to take in between 40-75 g·h⁻¹, and the results of studies using varying amounts of CHO do not suggest a graded effect (Jeukendrup 2004). A future study could ensure similar CHO intake between players.
REFERENCES


Palmer MS, Spriet LL. Mild dehydration does not affect glycogen use or exercise performance during a simulated ice hockey protocol. 2011. Unpublished.


