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HYDRATION AND TEAM SPORT COGNITIVE FUNCTION, TECHNICAL SKILL AND PHYSICAL PERFORMANCE

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- Team sport athletes are at risk of training and competing in a hypohydrated state when fluid losses are large and/or there are challenges with fluid availability or opportunity to drink.
- Technical skill and cognitive function are essential to team sport athlete performance and may be impaired with hypohydration, especially when combined with heat stress.
- The mechanism of cognitive impairment with hypohydration is not fully understood. It may be that the symptoms often associated with hypohydration (e.g., thirst, headache, fatigue, negative mood) are a distraction to the individual performing the cognitive tasks.
- Decrements in cognitive function, skill and physical performance in team sports are more likely to occur when hypohydration levels are > 2% body mass loss, but there is significant inter-individual variability in the effect of hypohydration on team sport performance.

INTRODUCTION

Athletes lose body fluid during exercise primarily through sweating. The body fluid balance between sweat losses and fluid intake during exercise may lead to these athletes training and competing in a hypohydrated state. The environmental conditions, body size, protective equipment and exercise demands of team sports vary considerably, leading to a large inter-sport variability in sweat losses. However, even within sports, there can also be large inter-individual variability in sweat losses. The published guidelines on exercise and fluid replacement recommend drinking during exercise to prevent greater than 2% body mass loss (BML), and since sweating rates and sweat electrolyte losses differ greatly between athletes, hydration plans should be individualized (Maughan & Shirreffs, 2010; McDermott et al., 2017; Sawka et al., 2007; Thomas et al., 2016).

Team Sports Terms	Definition of Terms
Team Sports	Team sports depend on the collective effort of individual players performing certain physical and mental skills in efforts to outperform an opposing team. These sports include brief high-intensity physical efforts combined with intermittent physical activity over a prolonged period. They also require the execution of sport-specific skills and the ability to sustain that skill performance throughout the duration of the competition. Team sports also involve varying levels of cognitive demand.
Cognition	Cognition is the processes the mind uses to take in, digest, discern and use information. Cognition includes domains of sensation & perception, motor skills, attention/concentration, memory, executive functioning, processing speed and language skills.
Sport-Specific Technical Skills	Sport-specific skills are performance related activities that rely on an interconnected, complex process of physical and cognitive function. These skills include skills like shooting, passing and dribbling.
Physical Demands	Physical components of team sports include elements important for team sports but not specific to any one sport, such as lateral movements, sprinting, jumping and anaerobic power.

Table 1: Team sport performance terms and definitions (Nuccio et al., 2017).

It is clear that hypohydration of more than 2% BML, especially in hot and humid environments, can impair endurance performance (Cheuvront & Kenefick, 2014; Sawka et al., 2007). This Sports Science Exchange article will focus on the impact of hypohydration on team sport performance, which is less established. Performance in team sport is a combination of both physical and mental domains. The mental domains include sport-specific technical skills that are related to precision and motor control, such as shooting, passing and dribbling, but also cognitive aspects including, but not limited to, motor response and reaction time, visuomotor function, executive function, memory and information processing. The physical demands of team sports include sprinting, lateral movements, jumping and intermittent high intensity running, to name a few. These are defined in Table 1 (Nuccio et al., 2017).

SPORT-SPECIFIC RISK FOR HYPOHYDRATION

Sport-specific risks for hypohydration are based on environmental conditions, exercise intensity and the availability and opportunity for fluid intake, as seen in Figure 1 (Belval et al., 2019; Nuccio et al., 2017). Of the sports reviewed, those with the highest risk for hypohydration were soccer, lacrosse and rugby, followed by American football, Australian rules football, ice hockey and field hockey. Basketball, Gaelic football, cricket, baseball, softball, beach volleyball, court volleyball, futsal, netball, water polo and badminton were classified as lower risk (Belval et al., 2019; Nuccio et al., 2017). However, there can be high variability in the risk for hypohydration within sports due to different environmental conditions across the sport season and locations of play, playing positions (body size, physical demands) and fluid availability/opportunity to drink during training and competition.

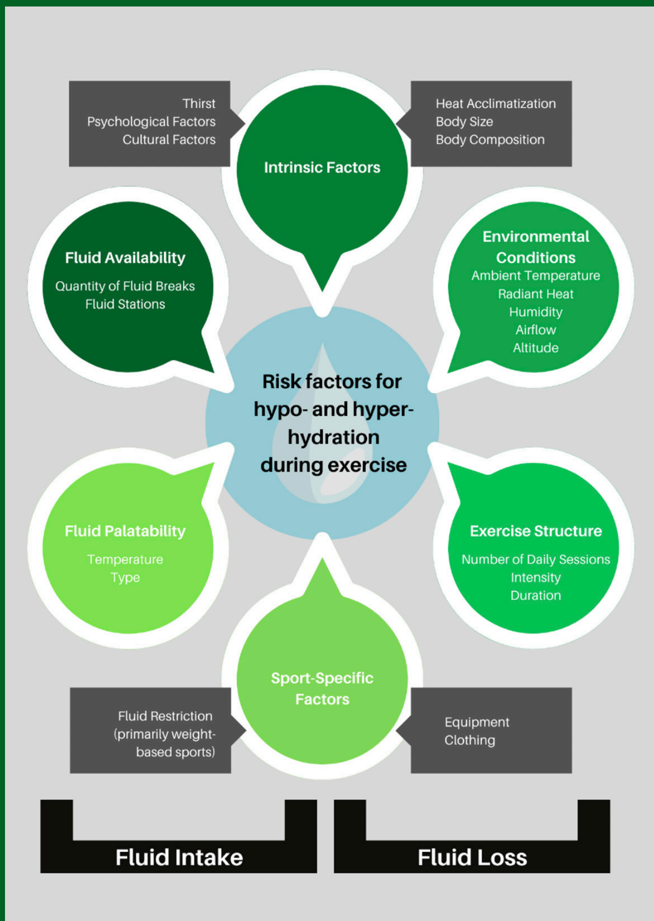

Figure 1: The factors that increase the risk for fluid imbalances (hypohydration or hyperhydration) in team sport athletes.

HYPOHYDRATION AND MENTAL/PHYSICAL DOMAINS OF TEAM SPORTS

The literature is mixed regarding the impact of hypohydration on the mental aspects of team sports. Some have found decrements to certain aspects of cognition and technical skills (Baker et al., 2007a, b; D'Anci et al., 2009; Dougherty et al., 2006; Hoffman et al., 1995; MacLeod & Sunderland, 2012) while others have found no performance impairment (Adam et al., 2008; Edwards et al., 2007; Ely et al., 2013; Grego et al., 2005; McGregor et al., 1999; Serwah & Marino, 2006). Wittbrodt et al. (2018) suggested that there is a potential dose response relationship between body water loss, via fluid restriction, heat stress, exercise or exercise + heat stress, and cognitive-motor deficits, indicating that as the percent BML increases, the cognitive impairment also increases. A study on military personnel found that declines in cognitive performance typically start around 2% BML and increase with greater levels of dehydration (Gopinathan et al., 1988) – similar to the physical performance decrements seen in endurance athletes (Cheuvront & Kenefick, 2014; Gopinathan et al., 1988). However, another group reported that dehydration up to about 3%, without heat stress, is unlikely to impair cognitive or psychomotor function in military personnel

SKILL/COGNITIVE DOMAIN	PERFORMANCE RESULT	PERFORMANCE IMPAIRMENT	NO SIGNIFICANT DIFFERENCE
BASKETBALL			
Shooting	↓ ↔	(Baker et al., 2007b; Brandenburg & Gaetz, 2012; Carvalho et al., 2011; Dougherty et al., 2006) *fewer shots made, lower percentage of shots made*	(Baker et al., 2007b; Hoffman et al., 1995, 2012) *number of shots made, percentage of shots made*
Reaction Speed	↓ ↔	(Baker et al., 2007a; Hoffman et al., 2012) *more errors on tests, slower response time during tests, slower lower body reactive agillity – Quick Board*	(Hoffman et al., 2012) *hand-eye reaction test - Dynavision D2*
Vigilance	↓	(Baker et al., 2007a)	n/a
SOCCER			
Passing	↔	n/a	(Ali et al., 2007; Owen et al., 2013)
Dribbling	↓	(McGregor et al., 1999)	n/a
Shooting	↔	n/a	(Owen et al., 2013)
Concentration	↔	n/a	(Edwards et al., 2007; McGregor et al., 1999) *number identification test*
Reaction Speed	↓	(Bandelow et al., 2010) *Sternberg test*	n/a
Memory	↓ ↔	(Bandelow et al., 2010) *working memory*	(Bandelow et al., 2010) *visuospatial working memory - Corsi block test*
Fine Motor Speed	↔	n/a	(Bandelow et al., 2010) *finger tapping test*
CRICKET			
Bowling	↓ ↔	(Devlin et al., 2001; Gamage et al., 2016) *speed and accuracy*	(Devlin et al., 2001; Gamage et al., 2016) *length and velocity*
TENNIS			
Hitting	↔	n/a	(Burke & Ekblom, 1984) *accuracy*
FIELD HOCKEY			
Field Hockey Skills	↔	n/a	(MacLeod & Sunderland, 2012)
Decision-Making Speed	↓ ↔	(MacLeod & Sunderland, 2012) *during skill test*	(MacLeod & Sunderland, 2012) *after treadmill*
ROWING, LACROSSE, AMERICAN FOOTBALL			
Vigilance	↓	(D'Anci et al., 2009) *continuous performance test*	n/a
Memory	↔	n/a	(D'Anci et al., 2009)
Reaction Time	↔	n/a	(D'Anci et al., 2009)
Visual Perception	↔	n/a	(D'Anci et al., 2009)
Executive Function	↔	n/a	(D'Anci et al., 2009) *mental math, map recognition*

Table 2: Summary of the effects of hypohydration on skill and cognitive demands in team sport athletes. (↓ indicates performance decrements with dehydration, and ↔ indicates that there was no significant difference in performance between the dehydration and control trials).

(Adam et al., 2008). Table 2 summarizes the literature on the effects of hypohydration on cognitive domains and team sport technical skills. Of the sports studied (baseball, basketball, cricket, soccer, rowing, football, lacrosse and tennis), there seems to be some performance decrements in shooting/bowling accuracy, decision-making speed, reaction speed, memory, vigilance and fine motor speed, whereas passing and concentration were less affected. A point to note is that most of the cognitive assessments were standard cognitive tests and not sport-specific, with the exception of the cognitive tests done on field hockey athletes (MacLeod & Sunderland, 2012).

Some of the physical components of team sports include elements important for team sports, but not specific to any one sport, such as lateral movements, sprinting, jumping and anaerobic power. The impact hypohydration has on these physical domains has mixed results in the literature. Overall, sprinting speed seems to be slower when hypohydration is mild to moderate vs. euhydration (Baker et al., 2007b; Davis et al., 2015; Devlin et al., 2001; Dougherty et al., 2006; Gamage et al., 2016; McGregor et al., 1999). The other performance measures impaired with hypohydration were lateral movement speed (Baker et al., 2007b; Dougherty et al., 2006) and combination drill speed (Baker et al., 2007b). However, some studies found no differences in sprinting speed (Ali et al., 2011; Ali & Williams, 2013; Carvalho et al., 2011) or combination drill speed (Dougherty et al., 2006). The research on distance covered during a Yo-Yo test is equivocal, with one study in soccer players showing no difference between prescribed water (-0.3% BML), ad libitum water (-1.1% BML) and no fluid (-2.5% BML) intake, and another study showing a decrease in distance covered when no fluid was given (-2.4% BML) or only mouth rinse (-2.1% BML) vs. water intake (-0.7% BML) (Edwards et al., 2007; Owen et al., 2013). Most studies found no significant difference between the no fluid and fluid trials in regards to maximum jump height, peak jump power or anaerobic power (Baker et al., 2007b; Burke & Ekblom, 1984; Dougherty et al., 2006; Hoffman et al., 1995, 2012; Yoshida et al., 2002), yet some showed decreased aerobic power with hypohydration especially during later tests or with higher levels of fluid losses (Hoffman et al., 1995; Yoshida et al., 2002). Figure 2 indicates the percentage of studies showing an effect of hypohydration in each category of team sport performance.

REHYDRATION AFTER EXERCISE-INDUCED DEHYDRATION

An additional area that is less explored is the effect that rehydration after dehydrating exercise has on cognitive/skill sport performance. Cian et al., (2000) found that dehydration via exercise alone and heat stress alone caused performance decrements (increased response times and short-term memory decline), but those decrements disappeared after 3.5 hours when compared to a euhydrated control. During the 3.5 hours after exercise, the perception of fatigue was higher with both methods of dehydration and improved with fluid ingestion. When the subjects were rehydrated after the dehydration period, they were able to maintain long term memory, whereas long term memory declined when dehydrated (Cian et al., 2000). A study with healthy college age individuals also found that when individuals were dehydrated via fluid restriction, Profile of Mood States (POMS) scores (vigor) and cognitive performance (short term memory and attention) were impaired. After rehydrating these individuals, the POMS scores, short term memory, attention and reaction were all improved (Zhang et al., 2019). More work is needed to determine the lasting effects of hypohydration on cognitive and skill domains after athletes rehydrate post-exercise.

MECHANISMS OF HYPOHYDATION RELATED IMPAIRMENTS IN SOME STUDIES

The potential mechanisms for the effects of hypohydration on cognition and team sport skill are not fully understood. It has been suggested that symptoms associated with hypohydration, such as thirst, headache or negative mood may be a distraction to the individual performing the cognitive tasks and contribute to a decline in performance (Cheuvront & Kenefick, 2014). The fatigue and increased perception of exertion that often accompany hypohydration could also explain some of the performance impairments reported (Nuccio et al., 2017). However, perhaps due to genetics or training adaptations, some individuals,

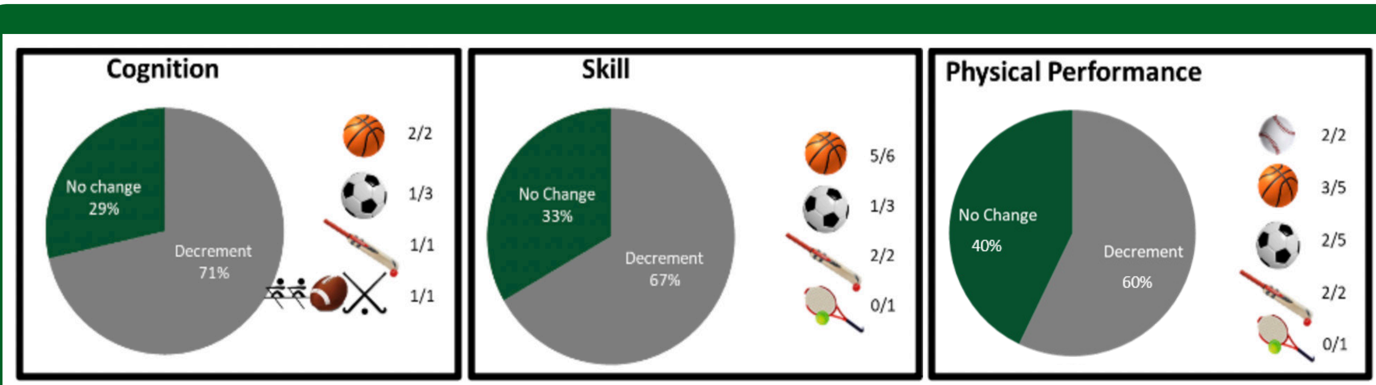

Figure 2: The percentage of studies that reported a decrement or no change with hypohydration during exercise per team sport performance domain. The values next to each team sport equipment indicate the number of studies that found some decrement out of the total number of studies.

though thirsty, exerted and fatigued, may be better than others at increasing concentration to overcome the distractors (Cheuvront & Kenefick, 2014).

Heat stress could exacerbate the symptoms and cognitive performance impairments of hypohydration. Some research suggests that there are separate effects of exercise heat stress and exercise heat stress combined with dehydration on cognition tasks. A moderate increase in body core temperature has the potential to improve cognition (Schmit et al., 2017), potentially due to increased cerebral blood flow (Hocking et al., 2001). However, there may be a threshold in which cognitive performance begins to decline with thermal strain, and this may be based more on subjective feelings of discomfort rather than objective measurements of the environment or body temperature (Gaoua et al., 2017). In a recent study, visuomotor performance declined with exercise heat stress, with additional impairments when dehydration was added (Wittbrodt et al., 2018). Furthermore, brain activation increased with dehydration but not exercise heat stress alone (Wittbrodt & Millard-Stafford, 2018; Wittbrodt et al., 2018), suggesting a greater effort was needed to complete the cognitive tasks.

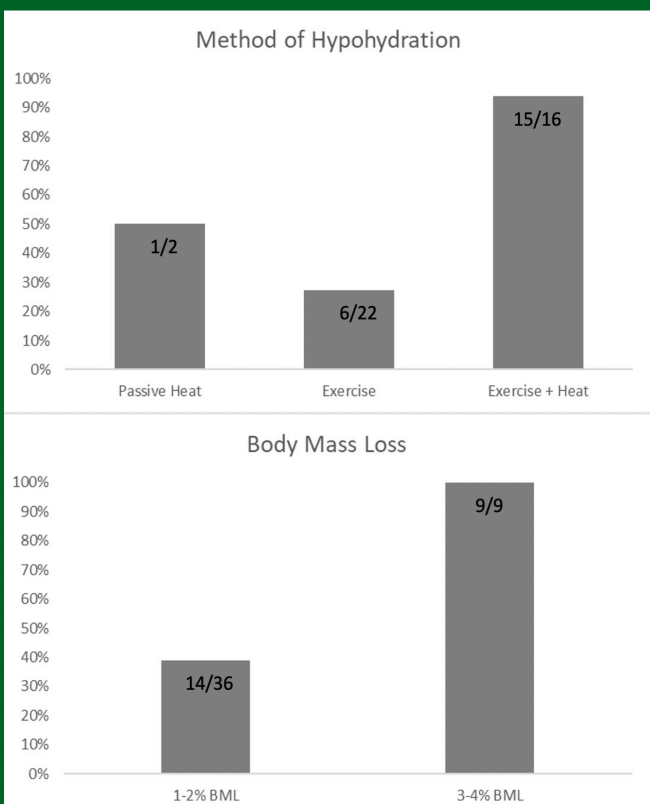

Figure 3: The percentage of studies that reported impaired performance by type and level of hypohydration. BML, body mass loss; values in each bar indicate the number of studies that found some decrement out of the total number of studies.

LIMITATIONS

Summarizing the effect of hypohydration on team sport performance can be challenging. For example, acute exercise has a small, positive, short-lived effect on cognitive performance (Chang et al., 2012). Elevated body core temperature, concomitant with exercise and hypohydration, can also affect cognitive function (Bandelow et al., 2010). Additionally, the technical skill, cognitive and physical performance tests being administered must be sensitive enough to detect true changes due to nutritional interventions (Lieberman, 2007). Taken together, the effect of hydration status on team sport performance has been mixed. However, it seems that hypohydration is more likely to impair cognition, technical skill and physical performance at higher levels of BML (> 2%) and when the method of dehydration involves heat stress (Figure 3).

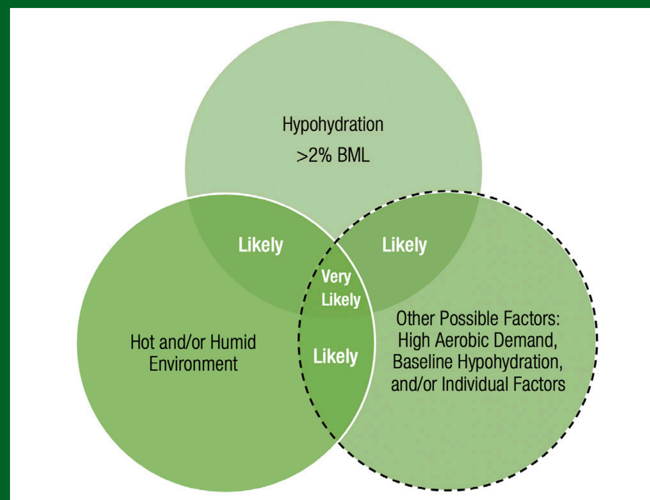

Figure 4: Venn diagram showing the likelihood of performance impairment with hypohydration (Nuccio et al., 2017). BML, body mass loss.

PRACTICAL APPLICATIONS

- The factors that are most associated with an increased risk of hypohydration in team sports are summarized in Figure 4. When at least two of these risk factors are met, it is likely that there will be skill/cognitive implications for team sport performance. If all three are met, then it is highly likely that team sport performance will suffer (Nuccio et al., 2017).
- Athletes and practitioners should strive to understand individual fluid losses during team sport play and provide customized hydration plans accordingly.
- When cognitive, skill and physical domains are critical, athletes should keep BML under about 2%, especially when environmental conditions are hot and humid. To do this, athletes should be given access to fluid and adequate opportunities to drink.

SUMMARY

There is large intra- and inter-sport variability in athletes' sweat losses. Access to fluid and the opportunity to rehydrate during training and competition is also varied between sports. This can result in some team sport athletes performing in a hypohydrated state. The effect of hypohydration on team sport performance has been mixed. However, it seems that hypohydration is more likely to impair cognition, technical skill and physical performance when the body mass deficit is > 2% and combined with heat stress. The mechanism underlying these decrements is not completely understood but may be based in both perception and physiology. To mitigate the risk of performance decrements, athletes should strive to replace individual losses to stay within 2% BML when possible.

Kelly A. Barnes and Lindsay B. Baker are employed by the Gatorade Sports Science Institute, a division of PepsiCo, Inc. The views expressed are those of the authors and do not necessarily reflect the position or policy of PepsiCo, Inc.

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