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Community Review

Potential nutrition contributions to exercise-associated muscle cramping in four recreational half-marathoners: A case series

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ABSTRACT

Objectives: Nutrition-related practices and outcomes vary dramatically between athletes, and traditional beliefs regarding the role of electrolytes and hydration in exercise-associated muscle cramping (EAMC) may be hindering meaningful prevention strategies. The aim of this study was to characterize the role of carbohydrate (CHO), energy, and exertion level, in conjunction with electrolyte and hydration status to assess the role of these possible predictors of EAMC.

Methods: A case study series approach was used to capture pre-race and on-course food and beverage intake, pre and post-race body weight, relative perceived exertion (RPE), and history of EAMC for four recreational runners prior to and during a half-marathon race.

Results: CHO intake, energy intake, and hydration status varied among the runners with one occurrence of EAMC. Reported pre-race CHO intake for all but one runner fell below 5 g/kg/day. Weight loss during the race was between 1.23-3.03%. Two of the four runners reported a prior history of EAMC, one of which experienced EAMC during the race. The two runners with a prior history of EAMC, also reported the lowest 3-day energy and CHO intakes. The one runner who encountered an EAMC did not experience the greatest net race sodium loss. However, this runner did have the greatest race weight loss, the greatest race sweat loss, the longest duration of activity, the lowest RPE, and suboptimal energy and CHO intakes.

Conclusions: The observed case of EAMC does not appear to be entirely inconsistent with the traditional dehydration/ electrolyte loss theory. However, the in-depth characterization of each runner illustrates the complex interaction of potential predictors and also generates questions regarding the potential contribution of suboptimal energy and CHO intakes.

Keywords: carbohydrate, electrolytes, sodium, muscle cramp, dehydration, running

INTRODUCTION

Exercise-associated muscle cramping (EAMC), a specific classification of debilitating skeletal muscle spasms occurring during or after exercise, is common among all sports, genders, age groups, and environments [1]. While the cause of EAMC remains unknown, dehydration along with electrolyte loss from sweating has historically been viewed as the primary contributing factor [2]. Despite being based on anecdotal evidence or limited research, this widely accepted belief has formed the foundation for EAMC interventions. A survey of certified athletic trainers found that the vast majority (92.1 %) identified either dehydration or electrolyte imbalance as the most common cause of EAMC [3]. A brief snapshot of the historically ubiquitous nature of the dehydration/electrolyte loss theory-based interventions is provided in Table 1 [4-11]. It is therefore not surprising that a recent survey of endurance athletes revealed that the majority (75%) believed sodium intake during endurance activities prevented EAMC [12].

Recent controlled research studies assessing dehydration using plasma volume, blood volume, and body weight changes of participants reporting EAMC do not reflect a strong association between dehydration or electrolyte loss and cramping [13-16]. Studies evaluating the loss of electrolytes and electrolyte serum levels in participants from a variety of sports including football, marathon, and triathlon, have not made a connection between electrolyte levels or electrolyte loss and the occurrence of EAMC [14-17].

Emerging science suggests altered neuromuscular control and the peripheral nervous system are key components in the etiology of EAMC, thereby challenging the electrolyte/dehydration theories that currently drive EAMC intervention strategies [1, 18-19]. One emerging variable for EAMC is the effect fatigued muscles have on neuromuscular control at the alpha motor neurons of the cramping muscle. This fatigue response is associated with the build-up of metabolic byproducts in working muscles (increased CO2, decreased O2, and elevated H+ ions) during repetitive activity and results in the reduction of energy derived from ATPase for free energy which is used for maintenance of the sodium-potassium gradient in the cell membranes as well as down-regulated Ca2+ ATPase activity required to maintain excitation and contraction processes. This hindrance of muscle function results in membrane excitability and possible sustained tetany [20].

As evidence mounts against old theories behind EAMC there is also a need to reassess nutritionally modifiable causes; specifically (carbohydrate) CHO, because it is well-known that glycogen depletion results in muscle fatigue [20]. Additionally, the importance of CHO on EAMC may be attributed to

Source	Date	Author/Entity	Recommendation
Heat Illness: A Handbook for Medical Officers [4]	1991	U.S. Army Institute of Environmental Medicine	salt supplementation
The Importance of Salt in the Athlete's Diet [5]	2007	Verle Valentine, MD	16 fl oz (473 ml) sports drink with 2.5 ml of additional salt with onset of muscle twitching
National Athletic Trainers' Association Position Statement: Fluid Replacement for Athletes [6]	2000	Casa, D et. al.	0.3-0.7 g/L salt
Muscle Cramping in the Heat [7]	retrieved 3/22/2019	University of Washington - The Sports Institute	consume extra salt in diet, 1/4 tsp (1.2 ml) table salt per 16 oz (473 ml), salt tablets
Muscle Cramps: The Right Ways for the Dog Days; Gatorade Sports Science Institute [8]	3/1/2003	Randy Eichner, MD	1/4 tsp (1.2 ml) table salt per 16-20 oz (473-591 ml)
Curbing Muscle Cramps: More than Oranges and Bananas; Gatorade Sports Science Institute [9]	7/25/2003	Randy Eichner, MD	"The prevention - and the cure - of heat cramping is salt and fluids. The solution is saline."
49ers Fitness Corner: Nutrition [10]	9/28/2005	San Francisco 49ers NFL	"add extra electrolytes (GatorLytes) to their Gatorade and have them drink 20 oz (591 ml) of salted Gatorade before games and practices; and drink Gatorade during the game, at the half, and after the competition."
Workout Tips for Exercise in the Heat [11]	3/15/2005	University of Colorado Sports Medicine	1/4 -1/2 tsp (1.2 -2.5 ml) table salt per liter of fluid

Table 1. Dehydration/Electrolyte Loss Theory-Based Interventions

more than energy availability as research uncovers CHO metabolism as an integral component of cell signaling associated with muscle contraction [20-21].

Nutrition and hydration practices vary dramatically between individual athletes. Individual responses to athletic competition (i.e., sweat rate, sweat sodium concentration) vary dramatically as well [22-24]. In addition, the risk of EAMC increases when a history of cramping is present [15, 19].

As such, prior to assessing the role of possible predictors of EAMC, the nutrition and hydration practices, individual responses, and history of EAMC in endurance athletes must first be better characterized. The purpose of this study is to gain an in-depth understanding of the nutrition-related practices and outcomes of half-marathon racers with a particular emphasis on possible predictors of EAMC.

METHODS

A case study approach was used to capture the nutrition-related practices and outcomes of half-marathon racers competing within age-group categories. All adult runners with a minimum age of 18 years registered to participate in a designated half-marathon scheduled to take place in the fall of 2018 in Colorado were queried for participation in this study. This study was approved by the Institutional Review Boards at the university where the study was housed and conformed to the ethical principles set forth in the Declaration of Helsinki. Runners who volunteered to participate provided written informed consent.

A pre-race questionnaire was used to gather participant information and demographics including age, race/ethnicity, history of cramping, location of cramping, personal record for distance, estimated completion time, and altitude of residence prior to the race. The pre-race questionnaire was provided to the participants electronically after registration through email and was completed 7-14 days prior to race day.

All participants self-reported dietary intake using the MyFitnessPal™ application. Intake of food, beverages, and supplements was collected for three consecutive days leading up to the race, as well as prior to the race on race day. Instructions on how to maintain the food log were provided through email. Video chat and email support were available by researcher on an as needed basis. The application provided reports detailing the total daily energy, fat, protein, carbohydrate, and sodium intake based on each participant's reported intake. A questionnaire administered by researchers immediately after the race was used to document relative perceived exertion (RPE), fluid and nutrition intake during the race, the occurrence of EAMC during the race, and the location of cramp if EAMC occurred. Reported fluid intake was adjusted by subtracting 20% of the volume for spill and fill at aid stations.

A Nokia Body+ Scale (Withings Nokia Health, Cambridge, MA, USA) was used to obtain pre and post-race body weights. Body weights were obtained with runners in race clothing with shoes removed. BMI's were calculated using self-reported heights and pre-race measured weights in the standard mathematical formula: weight (kg) / [height (m)] 2 [25]. Estimated daily energy and macronutrient needs were created using 1.2 g/kg protein, 1 g/kg fat, and 3-7 g/kg CHO [26].

Race weight loss for each participant was determined by subtracting their post-race weight from their pre-race weight. Race sweat was calculated by summing race weight loss and estimated fluid intake during the race. The density of fluid intake was assumed to be 1.0 g/ml [27]. Sweat was also assigned a density of 1.0 g/ml [28].

Total body sodium was approximated using 1030 mg//kg sodium for males and 990 mg/kg sodium for females [29]. Sweat sodium loss was calculated by multiplying race sweat volume by the mean value for whole body sweat sodium concentrations for athletes as reported by Barenes et al [24]. As such, 37.0 mmol/L was used as the value for whole body sweat sodium concentrations. Net race sodium loss was determined by subtracting sodium intake during the race from sweat sodium loss.

RESULTS

Start time temperature and weather conditions were: 11.1° C, 70% humidity, 5.6° C dew point, sunny, with no cloud cover. Six runners initially enrolled in the study; however, only four provided all the necessary information. Of these four, two were male and two were female. Additional participant characteristics are listed in Table 2.

	Participant			
Characteristic	**Runner 1**	**Runner 2**	**Runner 3**	**Runner 4**
Sex/gender	Male	Female	Male	Female
Age	31	25	26	49
Height (cm)	172.7	165.1	182.4	170.2
Pre-race weight (kg)	77.29	60.96	82.28	62.96
BMI	25.9	22.4	24.7	21.7
Altitude of residence (m)	1897	1609	2184	1777
Running experience	4+ years	2-3 years	2-3 years	0-1 year

Table 2. Summary of participant characteristics

Runner 1

Runner 1 was a 31-year old male having four or more years of running experience with a history of completing at least one half or one full marathon prior to participating in the study race. BMI was 25.9 kg/m2. Elevation at his recorded residence was 1897 meters. His half marathon personal best time was 1':47", and he had no history of EAMC within the 12 months preceding the study.

For the three days prior to the race, mean energy and sodium intakes were 18213 kj (4353 kcal) and 3589 mg, respectively. CHO intake averaged 9 g/kg /day (63.1%, of total energy), protein intake averaged 2.0 g/kg/day (14.1% of total energy), while fat intake averaged 1.48 g/kg/ day (22.8% of total energy). In addition, Runner 1 consumed a breakfast meal prior to race. Total energy intake for breakfast was 4803 kj comprised of 49.4% CHO, 35.3% fat, and 15.3% protein. Dietary sodium at this meal was 832 mg.

Runner 1 had a finish time of 1':39":54 with an average pace per kilometer of 4':44. Total race time for Runner 1 was 29% faster than the mean race time of 2':21":36 and 6 minutes faster than his half marathon personal best. EAMC was not experienced during the race with a reported RPE of 8 on a scale from 1-10. Runner 1 did not consume any solid or semi-solid products during the race. Estimated fluid intake during the race included 355 ml of water and 473 ml of hydration formula provided 835.5 kj (199.7 kcals) as CHO in the form of glucose, fructose and dextrose as well as 948 mg of sodium, 111 mg calcium, and 97 mg of both potassium and magnesium.

Runner 2

Runner 2 was a 25-year-old female with two to three years of running experience and a history of completing at least one half or full marathon prior to participating in the study race. BMI was 22.4 kg/m2. Elevation at her recorded residence was 1609 meters. Her half marathon personal best time was 2':30". She had a history of EAMC within the 12 months preceding the study. Location of EAMC was reported as "abdominal".

For the three days prior to the race, mean energy and sodium intakes were 5050 kj (1207 kcal) and 2676 mg, respectively. CHO intake averaged 2 g/kg /day (43.3%, of total energy), protein intake averaged 1.1 g/kg/day (22.2% of total energy), while fat intake averaged 0.73 g/kg/ day (33.2% of total energy). On the day of the race, 0 kj (0 kcal) were consumed prior to the race.

Runner 2 completed the race 6% slower than the average participant at the half marathon with a 2'31":00 finish time. Her average pace per kilometer was 7":09. At roughly 1 minute slower than her personal best, her reported RPE was 7-8 on a scale from 1-10. EAMC was not experienced. Runner 2's intake during the race included a "hand-full of Skittles", 828 ml of water, and 118 ml of hydration formula. In all, these items proved 376.2 kj (89.92 kcals) as CHO in the form of glucose, fructose and dextrose, as well as 239 mg of sodium, 28 mg calcium, 26 mg of potassium and 24 mg of magnesium.

Runner 3

Runner 3 was a 26-year-old male with two to three years of running experience and a history of completing at least one half or full marathon prior to participating in the study race. BMI was 24.7 kg/m2. Elevation at his recorded residence was 2184 meters. His half marathon personal best time was 2':07". He had no reported history of EAMC within the 12 months preceding the study. For the three days prior to the race, mean energy and sodium intakes were 10631.5 kj (2541 kcal) and 3636 mg, respectively. CHO intake averaged 3.7 g/kg /day (48.2% of total energy), protein intake averaged 1.5 g/kg/day (20.2% of total energy), while fat intake averaged 1.1 g/kg/ day (31.6% of total energy). On the day of the race, pre-race energy intake was 0 kj (0 kcal).

Runner 3 had a finish time of 2':06":44 with an average pace per kilometer of 5":38. Total race time for Runner 3 was 10% faster than the mean race time and 16 seconds under his reported personal best time. EAMC was not experienced during the race with a RPE of 7 on a scale from 1-10. Runner 3 did not consume any solid or semi-solid products during the race. Estimated fluid intake during the race included 1500 ml water and 237 ml of hydration formula which provided 99.84 kcals as CHO in the form of glucose, fructose and dextrose as well as 474 mg of sodium, 55 mg of calcium, 49 mg of both potassium and magnesium.

Runner 4

Runner 4 was a 49-year-old female with less than one year of running experience and no history of completing a half or full marathon event distance prior to participating in the study race. Elevation at her recorded residence was 1777 meters. BMI was 21.7 kg/m2. Runner 4 reported a history of EAMC within the 12 months preceding study. The location of EAMC was described as "calf".

For the three days prior to the race, mean energy and sodium intakes were 6962 kj (1664 kcal) and 2819 mg, respectively. CHO intake averaged 2.6 g/kg / day (39.3%, of total energy), protein intake averaged 1.2 g/kg/day (19% of total energy), while fat intake averaged 1.3 g/kg/ day (42% of total energy). Total energy intake reported before the race was 1431 kj (342 kcal) consisting of 37.4% CHO, 47.4% fat, 15.2% protein.

Runner 4 had a finish time of 2':39":17 with an average pace per kilometer of 7":33. Total race time for Runner 4 was 10% slower than the mean race time. EAMC was experienced during the race with a RPE of 4-6 on a scale from 1-10. Runner 4 did not consume any solid or semi-solid products during the race. Estimated fluid intake during the race included 828 ml water, 118 ml of cola, and 355 ml of hydration formula. Together the cola and hydration formula provided 820 kj (96 kcal) as CHO in the form of glucose, fructose and dextrose as well as 726 mg of sodium, 83 mg of calcium, and 149 mg of both potassium and magnesium.

Summary

Two of the four runners reported a prior history of EAMC while one reported a race occurrence of EAMC. All four runners lost weight during the race. Race weight loss ranged from 0.95-1.91 kg or 1.23-3.03% of pre-race body weight. Estimated net race sodium losses varied between 0.71% and 3.36% of total body sodium. A summary of the exploratory EAMC predictors for all subjects is provided in Table 3.

DISCUSSION

Each runner in this study had different approaches to nutrition and hydration before and during the race. This highlights variability in nutrition practices among athletes and the need to understand their nutritional habits when reviewing EAMC occurrence. Many athletes, especially female athletes, do not meet nutritional guidelines for optimal performance [30]. This study founds similar results. Three subjects reflected suboptimal to poor energy intake ranging from 43%-91% of estimated needs. Fat and protein were less variable between participants and fell within or just outside of recommended intakes. CHO intake for all but one participant fell below the 5-8 g/kg recommendation associated with endurance sports lasting less than three hours per day during race season [26].

Race weight loss ranged from 1.23-3.03 % with two runners not meeting the goal of limiting weight loss to less than 2% of total body weight [31]. Race sweat ranged from 1778- 3211 ml while the sweat sodium loss ranged from 1513-2733 mg. Overall these observations reinforced the need for individual assessment and replacement strategies.

Two of the four runners reported a previous history of EAMC. While the two runners with a prior history of EAMC experienced the greatest net race sodium losses per kg of body weight, they also had the lowest 3-day CHO intakes, the lowest 3-day energy intakes, and had the longest durations of activity. These observations leads one to ask whether there may be an association between EAMC and factors other than hydration status and and sodium loss.

The one runner who encountered an EAMC reported a prior history of EAMC but did not experience the largest net race sodium loss. She did report suboptimal energy and CHO intakes, and she had the greatest race weight loss, the greatest race sweat, the longest duration of activity, and the lowest RPE. While these observations do not appear to be entirely inconsistent with the traditional belief that dehydration and/or electrolyte loss are the main contributors to EAMC, they also generates questions regarding the potential contribution of suboptimal energy and CHO intakes. Additionally, the observation that Runner 4 also had the least running experience and longest completion time is consistent with Schwellnus' notes of muscle fatigue being associated with an athlete experiencing levels of intensity or volume beyond the current level of

		Participant			
		Runner 1	**Runner 2**	**Runner 3**	**Runner 4**
EAMC history	Past Occurrence	no	yes	no	yes
EAMC during race	Occurrence	no	no	no	yes
Mean 3 Day CHO	g/kg/d	9.1	2.1	3.7	2.6
Estimated energy needs	Kj/day	10929-14811	8619-11682	11636-15765	8904-12067
Mean 3 day energy intake	% est. energy needs	123-167	43-59	67-91	58-78
Race time	h:m	1h:39m	2h:31m	2h:06m	2h:39m
RPE	1-10	8	7-8	7	4-6
Race CHO intake	g	52	22	26	52
Race fluid intake	ml	828	946	1736	1301
Race weight loss	g	950	1720	1360	1910
Race weight loss	% pre-race weight	1.23	2.82	1.65	3.03
Race sweat	ml	1778	2666	3096	3211
Total body sodium	mg	79,609	60,350	84,748	62,330
Sweat sodium loss	mg	1513	2269	2635	2733
Race sodium intake	mg	948	239	474	726
*Net race sodium loss**	mg	565	2030	2161	2007

Table 1. Summary of incidence of to exercise-associated muscle cramping and possible predictors
*Net race sodium loss = sweat sodium loss – race sodium intake

fitness [15]. The observations related to activity duration and suboptimal nutrient intakes combined with emerging studies indicating possible muscle fatigue with peripheral nervous system interactions in EAMC provide reason to assess nutritional factors alongside non-nutritional factors as part of a multifactorial process in the EAMC. Figure 1 depicts this possible process.

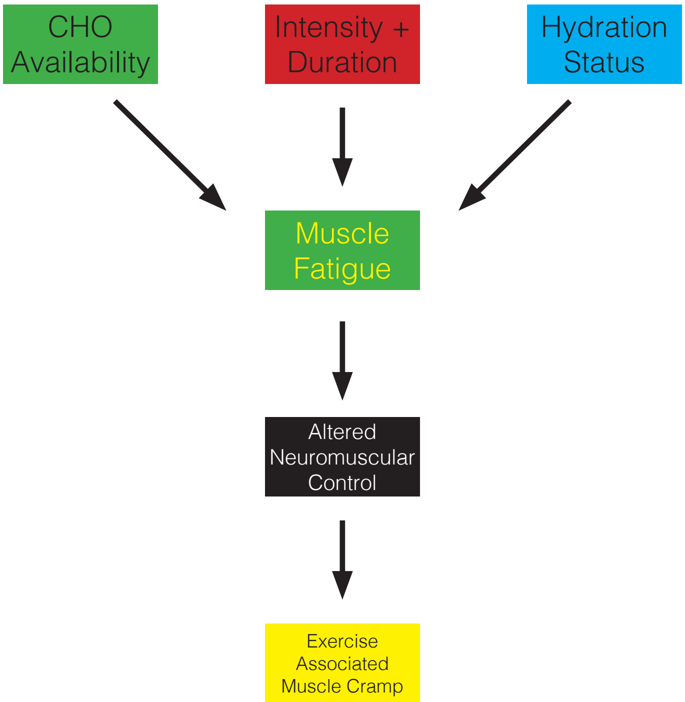

Figure 1. Hypothesized interactions of exercise-associated muscle cramping

As Shirreffs and Maughan and [32] point out in their recent review, the most viable hypotheses suggest EAMC originate in part as an imbalance of water and salt, an abnormal motor discharge, or both. Given the design, it is beyond the scope of this case series to prove or disprove the validity of any proposed predictor of EAMC. The unpredictable nature and complexity of EAMC, makes laboratory studies challenging [32]. As such, this case study series balances the aggregate data of all recent and relevant research on EAMC within the context of real-world outcomes and their impact on decision-making in practice.

As Langford and Bird [33] acknowledge, athletic case-studies are sometimes undervalued when appraised from a scientific viewpoint. Yet, the case study approach is an ideal means for bridging the gap between research and practice. Evidence based practice involves the integration of research, clinical expertise, and client needs [34]. For the strength and conditioning practitioner, case studies can augment experience and provide insight into client perceptions and needs. Case studies can help reconcile the inconsistencies discovered between what is observed in practice and what one might expect to find based solely on research. In all, published case studies can serve as a means to enrich overall professional competence.

For the researcher, case studies and other qualitative methods can provide insight into the needs of practitioners and generate important real-world questions. While not appropriate for hypothesis testing, case studies provide insight and give a voice to complex issues. In this study, we used an in-depth approach to examine factors relevant to research on EAMC. Combined with the suggested challenges to the historic theory of EAMC, the observations of this study reinforce the need for additional research in the area of EAMC.

Limitations of this study included the inability to obtain nude post-race weights to control for soaked clothing resulting in weight loss calculations with an error factor of up to 10%. The inability to control aid station fluid intake for participants prevents accuracy in electrolyte and body weight loss data. Self-reported dietary intake and height reduce the precision of calculations. Lastly, volume and intensity of training was not documented. This would have provided insight into whether energy intakes for the participants were adequate, as well as providing a means of comparison for RPE on race day.

While the observations of this study are not entirely inconsistent with the dehydration/electrolyte loss theory, the in-depth characterization of each runner illustrates the complex interaction of potential predictors and also generates questions regarding the possible contribution of suboptimal energy and CHO intakes. For the practitioner, these observations reaffirm the need to understand the full clinical picture when reviewing EAMC occurrence. For the researcher, several possible avenues for future research present themselves. Such future research undertakings include assessing the occurrence of EAMC and the presence of chronic suboptimal nutrition, quantifying muscle glycogen within cramping muscles, and determining where nutritional and physiological predictors converge and how their confluence exerts pressure on the peripheral nervous system leading to muscle fatigue and ultimately EAMC.

REFERENCES

1. Schwellnus, MP. Cause of exercise associated muscle cramps (EAMC) - Altered neuromuscular control, dehydration or electrolyte depletion? Br J Sports Med 2009;43:401–408. doi:10.1136/bjsm.2008.050401
2. Edouard, P. Exercise associated muscle cramps: Discussion on causes, prevention and treatment. Sci Sports 2014; 29:299-305. doi:10.1016/j.scispo.2014.06.004
3. Stone MB, Edwards JE, Stemmans CL, Ingersoll CD, Palmieri RM, Krause BA. Certified Athletic trainers' perceptions of exercise-associated muscle cramps. J Sport Rehabil 2003; 12:333–342. doi:org/10.1123/jsr.12.4.333
4. Burr, RE. Heat Ilness: A Handbook for Medical Officers. Army Researach Instituite of Enviromental Medicine, Natick, MA.
5. Valentine V. The importance of salt in the athlete's diet. Curr Sports Med Rep 2007,6:237–240. Retrieved from http://www.fitday.com/fitness-articles/nutrition/healthy-eating/the-importance-of-salt-in-your-diet.html
6. Casa DJ, Lawrence AE, Susan HK, Scott MJ, Ralph RV, Brent RSE et al. National Athletic Trainers' Association position statement: Fludid replacement for athletes. J Athl Train 2000; 35:212–224
7. Muscle Cramping In the Heat. (n.d.). Retrieved March 22, 2019, from https://depts.washington.edu/shsi/article/muscle-cramping-in-the-heat-2/
8. Eichner R. (2003a). Curbing muscle ramps : More than Oranges and Bananas. retrieved March 22, 2019, from https://ihsaa-static.s3.amazonaws.com/Sports_Medicine_Wellness/Injury_Prevention_Treatment/GSSI-Curbing_Muscle_Cramps.pdf
9. Eichner R. (2003b). Muscle Cramps: The Right Ways for the Dog Days. Retrieved March 22, 2019, from https://www.fhsaa.org/sites/default/files/orig_uploads/health/pdf/gatorade_musclecramps.pdf
10. 49ers Fitness Corner: Nutrition. (2005). Retrieved March 22, 2019, from https://www.49ers.com/news/49ers-fitness-corner-nutrition-549320
11. Workout Tips for Exercise in the Heat. (2005). Retrieved March 22, 2019, from http://www.ucdenver.edu/academics/colleges/medicine/sportsmed/cusm_patient_resources/Documents/Workout Tips for Exercise in the Heat.pdf
12. McCubbin AJ, Cox GR, Costa JS. Sodium intake beliefs, information sources, and intended practices of endurance athletes before and during exercise. Int J Sport Nutr Exerc Metab 2019; 29(4):371-381. doi: 10.1123/ijsnem.2018-0270
13. Braulick KW, Miller KC, Albrecht JM, Tucker JM, Deal JE. Significant and serious dehydration does not affect skeletal muscle cramp threshold frequency. Br J Sports Med 2016; 11:710–714. doi:10.1136/bjsports-2012-091501
14. Jung AP, Bishop PA, Al-Nawwas A, Dale RB. Influence of hydration and electrolyte supplementation on incidence and time to onset of exercise-associated muscle cramps. J Athl Train 2005; 40:71–75.
15. Schwellnus, MP, Drew N, Collins M. Increased running speed and previous cramps rather than dehydration or serum sodium changes predict exercise-associated muscle cramping: A prospective cohort study in 210 Ironman triathletes. Br J Sports Med 2011;45:650–656. doi:10.1136/bjsm.2010.078535
16. Sulzer NU, Schwellnus MP, Noakes TD. Serum electrolytes in ironman triathletes with exercise-associated muscle cramping. Med Sci Sports Exerc 2005;37:1081–1085. doi:10.1249/01.mss.0000169723.79558.cf
17. Maughan RJ. Exercise-induced muscle cramp: a prospective biochemical study in marathon runners. J Sports Sci 1986;4:31–34. doi:10.1080/02640418608732095
18. Miller KC. Rethinking the cause of exercise-associated muscle cramping: Moving beyond dehydration and electrolyte losses. Curr Sports Med Rep 2015; 14: 353–354. doi:10.1249/JSR.0000000000000183
19. Summers KM, Snodgrass SJ, Callister R. Predictors of Calf Cramping in Rugby League. J Strength Cond Res 2014; 774-83. doi:10.1519/JSC.0b013e31829f360c
20. Hearris MA, Hammond KM, Fell JM, Morton JP. Regulation of muscle glycogen metabolism during exercise: Implications for endurance performance and training adaptations. Nutrients 2018; Mar 2;10(3):298. doi:10.3390/nu10030298
21. Ørtenblad N, Westerblad H, Nielsen J. Muscle glycogen stores and fatigue. J Physiol 2013;591:4405–4413. doi:10.1113/jphysiol.2013.251629
22. Bergeron, MF. Heat cramps: Fluid and electrolyte challenges during tennis in the heat. J Sci Med Sport 2003; 6:19–27. doi.org/10.1016/S1440-2440(03)80005-1
23. Lara B, Gallo-Salazar C, Puente C, Areces F, Salinero JJ, Del Coso J. Interindividual variability in sweat electrolyte concentration in marathoners. J Int Soc Sports Nutr. 2016;13:31. doi:10.1186/s12970-016-0141-z
24. Barnes KA, Anderson ML, Stofan JR, et al. Normative data for sweating rate, sweat sodium concentration, and sweat sodium loss in athletes: An update and analysis by sport. J Sports Sci 2019;37(20):2356-2366. doi:10.1080/02640414.2019.1633159 doi.org/10.1152/jappl.1997.82.1.336
25. Centers for Disease Control and Prevention. About adult BMI, healthy weight. (n.d.). retrieved April 9, 2020 from https://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/index.html
26. Burke LM, Hawley JA, Wong SHS, Jeukendrup AE. Carbohydrates for training and competition. J Sports Sci 2011; 29(Suppl 1):S17-27. doi:10.1080/02640414.2011.585473
27. Food and Agricultural Organization of the United Nations and International Network of Food Data Systems. Density Database Version 2.0. 2012; Retrieved April 9, 2020 from http://www.fao.org/3/ap815e/ap815e.pdf
28. Maughan RJ, Shirreffs SM, Leiper JB. Errors in the estimation of hydration status from changes in body mass. J Sports Sci 2007;25(7):797–804. doi:10.1080/02640410600875143
29. Kennedy NS, Eastell R, Smith MA, Tothill P. Normal levels of total body sodium and chlorine by neutron activation analysis. Phys Med Biol 1983 Mar;28(3):215-21. doi: 10.1088/0031-9155/28/3/002. PMID: 6844400
30. Masson G, Lamarche B. Many non-elite multisport endurance athletes do not meet sports nutrition recommendations for carbohydrates. Appl Physiol Nutr Metab 2016; 41:728–734. doi.org/10.1139/apnm-2015-0599
31. Thomas DT, Erdman KA, Burke LM. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. J Acad Nutr Diet 2016;116(3):501–528. doi:10.1016/j.jand.2015.12.006
32. Shirreffs SM, Maughan RJ. Muscle cramping during exercise: Causes, solutions, and questions remaining. Sports Med 2019; 49:115–124. doi.org/10.1007/s40279-

019-01162-1
33. Langford, A. and Bird, S. 2020. Bridging the gap: Why strength and conditioning practitioners and researchers should collaborate. Intern Strength and Cond. doi.org/10.47206/iuscaj.v1i1.13
34. Jeffreys, Ian. Evidence based practice in strength and conditioning—reality or fantasy. Prof Strength Cond 39 (2015): 7-14.