

Physiological and Performance Effects of Glycerol Hyperhydration for World Championship Distance Duathlons in Hot Conditions

John McCullagh, Jaclyn Munge, Nivan Weerakkody, and Kerrie Gamble

Abstract—The aim of this study was to evaluate the effect of pre-exercise glycerol hyperhydration on endurance performance in a heat chamber designed to simulate the World Championship Distance (WCD) duathlon (10km run, 40km ride, 5 km run). Duathlons are often performed in hot and humid conditions and as a result hydration is a major issue. Glycerol enhances the body's capacity for fluid retention by inducing hyperhydration, which is theorized to improve thermoregulatory and cardiovascular responses, and thereby improve performance. Six well-trained athletes completed the testing protocol in a heat chamber at the La Trobe University Exercise Physiology Laboratory. Each testing session was approximately 4.5 hours in duration (2 hours of pre-exercise glycerol hyper-hydration followed by approximately 2.5 hours of exercise). The results showed an increased water retention pre-exercise and an improved overall performance of 2.04% was achieved by subjects ingesting the glycerol solution.

Keywords—Endurance performance, glycerol hyperhydration, heat chamber.

I. INTRODUCTION

ADEQUATE hydration for endurance athletes is important for their performance during prolonged, high intensity exercise. Dehydration causing a decrease in body weight of as little as 2% has proven to be sufficient to reduce endurance performance in warm to hot environments by impairing the functioning of the thermoregulatory and cardiovascular systems [1]-[3]. The resulting physiological consequences that accompany dehydration are an elevation in core temperature due to decreases in sweat rate and blood flow to the skeletal muscle and skin [4]-[6], decreased glycogen utilization and increased perceived exertion rates [3], [7] and an elevation of heart rate and an inability to maintain cardiac output due to a reduction in blood volume and stroke volume [8], [9]. All of these physiological factors result in a decreased endurance performance.

The greater the dehydration (>2% body weight) the further the degradation of aerobic and cognitive/mental performance. The magnitude of performance reduction is likely related to

the environmental temperature, exercise task and individual's unique biological characteristics [10]. In order to prevent a decrease in exercise performance it is important to maintain optimal hydration levels pre, during and post-exercise [7]. Therefore, any strategy that helps an athlete take on extra fluid or "hyperhydrate" to offset the effects of dehydration is likely to enhance performance for endurance events in hot and humid conditions. Over recent years the strategy of ingesting glycerol has grown in popularity, as it has been suggested as an effective hyperhydrating agent producing minimal side effects [11].

Glycerol is a 3-carbon molecule that occurs naturally in the body as a component of stored fats, while small amounts are present in body fluids as free glycerol. It is also a very osmotically active solute, and when ingested is absorbed rapidly and dispersed evenly throughout the body's water compartments [12], [13]. This increases the osmolarity of these compartments, enhancing the retention of fluid with which glycerol is ingested [14]. Several researchers have confirmed that glycerol ingestion decreases or maintains urine excretion and increases fluid retention, causing a period of hyperhydration that can last up to 4 hours [11], [15], [16]. Glycerol hyperhydration can provide an increase in fluid retention within the range of 400-1000ml as compared to ingestion of water alone [2], [13], [15]-[17]. This increased capacity to retain fluid is beneficial to exercise performance as it maintains the body's hydration levels preventing/delaying the deleterious effects of dehydration.

Glycerol hyperhydration results in a total body water increase, thereby increasing plasma volume [18]. The expansion in plasma volumes improves cardiovascular responses to prolonged exercise by reducing heart rate [19]-[23] and increasing stroke volume and cardiac output [2], [19], [22], [24]. Theoretically, this reduction in cardiovascular strain could allow increased oxygen and nutrient delivery to the working muscle [25], thereby improving maximal oxygen uptake (VO₂ Max) and improving performance [26].

Glycerol hyperhydration has also been touted as a method to improve the body's thermoregulation by attenuating core body temperature through an increase in sweat rate [27]. This has been confirmed by several studies [16], [20], [22]. Lyons et al [16] gave subjects 2L of water with and without glycerol over a 2.5 hour period before moderate exercise (60% of VO₂max) in a hot, dry environment. Compared with the water trials

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glycerol ingestion reduced urine production, increased sweat rate and reduced mean rectal temperature during exercise. Improved thermoregulatory function such as increased sweat rate and reduced core temperature have been suggested to improve performance [26].

The majority of studies that have investigated the impact of glycerol on exercise performance have focused on its effects on pre-exercise hyperhydration rather than performance per se. Despite there being strong evidence that glycerol increases fluid retention, improves cardiovascular and thermoregulatory functions, all of which together have been linked to improved exercise performance [27], [28], the question whether pre-exercise glycerol hyperhydration is beneficial to performance remains equivocal and requires further investigation in order to replicate and explain these performance benefits [27].

The aim of the present study was to evaluate the physiological and performance effects of pre-exercise glycerol hyperhydration on endurance performance in hot conditions using an exercise protocol that simulates the endurance sporting event of a WCD Duathlon.

II. EXPERIMENTAL PROCEDURES

A. Subjects

Six well-trained athletes (5 males and 1 female) volunteered to participate in this study, which was approved by the La Trobe University Ethics Committee (11-063). Participants were in good health, with no medical history, trained on a regular basis and participated regularly in competitive races.

B. Study Design

The trials were conducted in a heat chamber at the La Trobe University Exercise Physiology Laboratory and consisted of a 10km run, a 40km ride and a 5km run. Participants were told to maintain their typical weekly training regime during the course of the study and to refrain from any physical activity 24 hours prior to each trial. They also had to maintain a 24-hour diet record prior to the first testing and were instructed to repeat the same diet for the 24 hours prior to the second testing.

Each participant was required to complete the trial on two separate occasions (glycerol hyperhydration and water hyperhydration). These sessions were separated by at least one week. Participants were required to work at a set load for the first two legs of the trial (run and ride) and to complete the final 5km run at their fastest pace possible, as they would in an actual race. Each testing session lasted for approximately 4.5 hours (2 hours of pre-exercise glycerol hyper-hydration, followed by approximately 2.5 hours of exercise). Following the pre-exercise hyper-hydration phase, participants' heart rate and rate of perceived effort (RPE) were recorded every 5 minutes throughout the duration of the exercise. Heart rate was measured using the Polar heart rate monitor and RPE was measured using the American College of Sports Medicine scale of ratings from 0 to 10 (0 – nothing; 10 – very very hard) [29]. The real time heart rate readings were projected onto a

screen so participants could monitor their own heart rate readings throughout the exercise. A standing electric fan and ceiling fans were activated to circulate air within the laboratory. If participants needed to void their bladder during the exercise their urine output was weighed and recorded.

Participants were also provided with 200ml of Staminade® solution as their carbohydrate fuel, every 20 minutes during the exercise. This solution was pre-mixed according to the manufacturer's instructions (65g for every 1L of water) and kept chilled at approximately 15°C in a cooler box filled with ice. Prior to the exercise trial, participants' blood pressure was measured (OMRON automatic blood pressure monitor with intellisense). Post-exercise, participants' voided their bladder and their mid-stream urine was collected to test for their hydration status post-exercise using urine-specific gravity (USG). Participants were instructed to towel-dry themselves and weigh-in nude using the Seca electronically calibrated scales. Total volume of Staminade® consumed during the exercise was measured and recorded for each participant.

C. Preliminary Testing

Participants completed a familiarization trial a week prior to the trials. This consisted of a 40 minute protocol involving running on a motorized treadmill (H/P/Cosmos, Elite 507) and cycling on a cycle ergometer (MONARK Ergomedic 828E). The cycle ergometer was modified with the participants' own pedal cleats where required. Individual workloads determined during this session are outlined in Table I.

TABLE I
INDIVIDUAL WORKLOADS ON CYCLE ERGOMETER AND TREADMILL

Subject	Workload	
	Cycle(watts)	Treadmill (kph)
1	190	14.5
2	165	14.5
3	165	13.0
4	190	15.0
5	180	13.0
6	170	10.0

D. Pre-Exercise Hydration

A randomized, double-blind crossover design was employed for the pre-exercise glycerol hyper-hydration. The pre-exercise glycerol hyperhydration protocol was adapted from a study by Montner et al [23] and is outlined in Table II. For the placebo solution a zero kilojoule artificial sweetener, Sugarine®, was used in place of glycerol to mask the taste of the glycerol solution. One Sugarine® tablet was diluted in every 100ml of water. The glycerol dose prescribed for each participant was 1.2g/kg of body weight, with an accompanying total fluid volume intake of 26ml/kg of body weight.

E. Statistics

Inferential statistics involving the paired t-test were used to analyse the data in this research. Statistical significance was set at $p \leq 0.05$. Results and spread are shown as means and standard deviations (SDs).

TABLE II
PRE-EXERCISE GLYCEROL HYPERHYDRATION PROTOCOL

Time (min)	Solution
0 min	5ml/kg of body weight of 20% glycerol solution
30 min	5ml/kg of body weight of water
45 min	5ml/kg of body weight of water
60 min	5ml/kg of body weight of water + 1ml/kg of body weight of 20% glycerol solution
90 min	5ml/kg of body weight of water
30 min post hyperhydration	Rest

III.RESULTS

Six subjects completed the glycerol hyperhydration (GH) and water hyperhydration (WH) trials without any nausea or other side effects. The environmental conditions were held constant across trials with a temperature of 30°C±1°C. Blood pressure readings taken post hyperhydration demonstrated slightly elevated diastolic blood pressure for subjects in the GH trials (Systolic BP(mmHg), GH: 130.5, SD: 7.1; WH: 131.3, SD: 5.4; Diastolic BP(mm Hg), GH:82.8, SD:6.3; WH:76.8, SD:8.1).

Fig. 1 demonstrates that there was a significant increase in weight gain achieved pre-exercise by subjects in the GH trials (GH: 1.21 ± 0.42kg, WH: 0.75 ± 0.33kg, p = 0.01). Pre and post exercise body weight changes are presented in Table III. The average body weight loss pre to post exercise was 2.63 kg for the GH trials and 2.85kg for the WH trials. The average body weight loss pre hyperhydration to post exercise was 1.40 kg for the GH trials and 2.12kg for the WH trials.

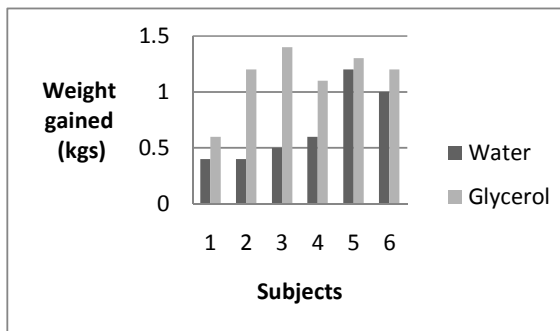


Fig. 1 Weight gained pre exercise for GH and WH trials

TABLE III
AVERAGE BODY WEIGHT RECORDED PRE HYPERHYDRATION, POST HYPERHYDRATION AND PRE-EXERCISE AND POST-EXERCISE

	GH		WH	
	Mean	SD	Mean	SD
Pre hyperhydration	69.61	8.30	69.81	7.90
Post hyperhydration	70.80	8.54	70.52	8.28
Post exercise	68.23	8.12	67.73	8.05

Table IV displays the results from the 10km run and 40 km ride which were conducted at sub maximal workloads. Subjects used the same pre-determined speed and workload for both the WH and GH trials.

TABLE IV
MEAN HR AND RPE FROM THE 10KM RUN AND 40 KM RIDE

	10 km run				40 km ride			
	WH		GH		WH		GH	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Heart Rate	157.19	6.53	155.75	6.11	141.22	1.94	141.67	2.64
RPE	4.66	0.71	4.33	0.67	4.32	0.22	4.06	0.28

The 5km run involved subjects exercising maximally to simulate the final stage of a race. Figs. 2 and 3 demonstrate the results for the heart rate and RPE. The average heart rate and RPE were similar for subjects in both the GH and WH trials. The times taken by subjects for this leg demonstrated a 2.04% increase in performance was achieved by subjects using the GH trials as compared to the WH trials; however, this did not reach significance.

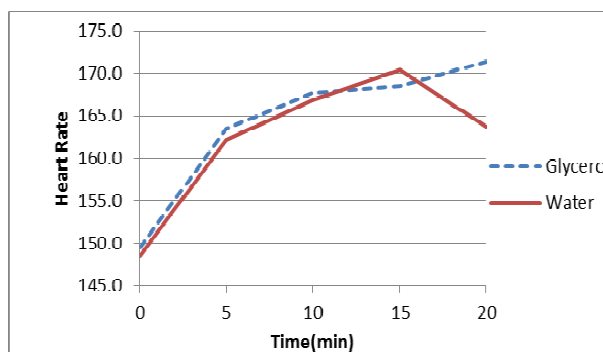


Fig. 2 Mean Heart Rate during the 5km run

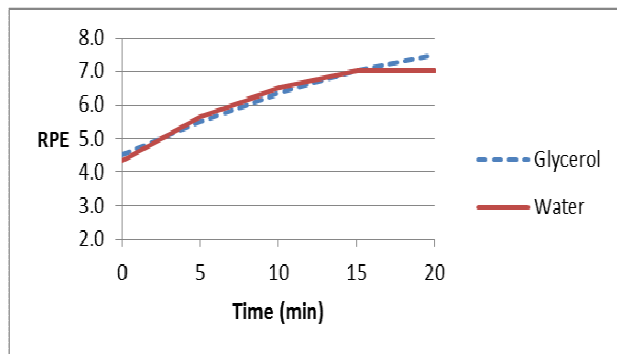


Fig. 3 Mean RPE during the 5km run

Fig. 4 shows the volume of sweat produced by each subject during the testing. The volume of sweat (mls) is calculated by multiplying the weight loss (kg) by 1000, adding the volume of fluid ingested and subtracting the volume urinated. The mean sweat volumes for the GH and WH trials were $3471\text{ml} \pm 1235\text{ml}$ and $3455\text{ml} \pm 1327\text{ml}$ respectively.

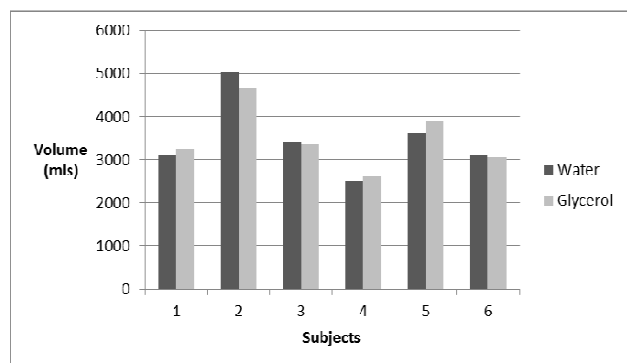


Fig. 4 Volume of sweat produced

IV. DISCUSSION

The goal of this study was to determine whether a pre-exercise glycerol induced hyperhydration had the potential to improve physiological and performance measures in the WCD duathlon in hot conditions. The results demonstrated that some positive physiological and performance benefits were gained by the use of a glycerol hyperhydration pre-exercise protocol, however the results were equivocal.

During the pre-exercise hyperhydration stage, an increased weight gain of $1.2 \pm 0.4\text{kg}$ was achieved for subjects in the GH trials as compared to $0.7 \pm 0.3\text{kg}$ in the WH trials. This was due to a decreased urine excretion in the GH trials resulting in an increase in total body water. The average urine production for subjects was 457.1ml in the GH trials and 798.5ml in the WH trials. Athletes struggle to maintain their fluid levels during high intensity aerobic exercise in hot conditions, so an increase in total body water can be a significant factor in improving their bodies' thermo regulatory control during the exercise. The average increase in fluid retention achieved by subjects in the GH trials was 495ml which is within the range

of $400\text{-}1000\text{ml}$ reported in numerous studies [22], [24], [30]. The increased capacity to hold body water has the potential to prevent/delay the effects of dehydration and therefore benefit an athlete's performance for endurance events in hot and humid conditions.

The results presented in Table IV for the 10km run and 40 km ride showed minimal deviation between heart rate and RPE values for the GH and WH trials. All subjects were sweating quite heavily during these stages and it was expected that subjects in the GH trials may demonstrate some physiological advantage. Subjects were working at a sub maximal load during these two phases and reported that they felt quite comfortable during the cycling leg with the assigned loads. Previous studies have demonstrated minimal effects for glycerol hyperhydration conducted at a sub maximal workrate [24], [31].

The final leg consisted of a 5km run at race pace. This leg was very demanding for the subjects in these conditions. The results for the heart rate and PRE indicated minimal difference between trials for these variables. The reported sweat volumes showed a slight increase in mean sweat volume for the GH trials. These results are supported by other studies which demonstrate an increase in sweat volume for subjects in the GH trials [7], [16]. It is expected that the increased total body water held during the final leg (495ml) would result in an increased plasma volume, cardiac output, thermoregulatory control and athletic performance. An increase in athletic performance was achieved by subjects in the GH trials as indicated by a reduction in overall time taken of 2.04% .

V. CONCLUSION

Our results suggest that improvements in performance and physiological factors can be associated with pre-exercise glycerol hyperhydration, however no definitive conclusions can be made. Knight et al [32] state that there is a lack of studies using controlled environments, cross-over design and exercise protocols of greater than 2 hours and also that events lasting longer than 4 hours could potentially benefit most from glycerol hyperhydration. Further research on pre-exercise glycerol hyperhydration is warranted in endurance events lasting longer than 2 hours to fine-tune methodology issues such as time duration between pre-hydration and commencement of exercise, glycerol dose for continued use during exercise, initial glycerol dose and volume and prehydration duration time.

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REFERENCES

- [1] Chevront, S.N., R. Carter 3rd, and M.N. Sawka, *Fluid balance and endurance exercise performance*. Current sports medicine reports, 2003. 2(4): p. 202-208.

- [2] Coutts, A., P. Reaburn, K. Mummery, and M. Holmes, *The Effect of Glycerol Hyperhydration on Olympic Distance Triathlon Performance in High Ambient Temperatures*. International Journal of Sport Nutrition and Exercise Metabolism, 2002. 12(1): p. 105-119.
- [3] Walsh, R., T. Noakes, J. Hawley, and S. Dennis, *Impaired high-intensity cycling performance time at low levels of dehydration*. International Journal of Sports Medicine, 1994. 15(7): p. 392-398.
- [4] González-Alonso, J., J.A.L. Calbet, and B. Nielsen, *Muscle blood flow is reduced with dehydration during prolonged exercise in humans*. The Journal of Physiology, 1998. 513(3): p. 895-905.
- [5] Sawka, M.N., S.J. Montain, and W.A. Latzka, *Hydration effects on thermoregulation and performance in the heat*. Comparative Biochemistry and Physiology-Part A: Molecular & Integrative Physiology, 2001. 128(4): p. 679-690.
- [6] Sawna, M.N. and E.F. Coyle, *Influence of Body Water and Blood Volume on Thermoregulation and Exercise Performance in the Heat*. Exercise and Sport Sciences Reviews, 1999. 27(1): p. 167-218.
- [7] Robergs, R., *Glycerol hyperhydration to beat the heat*. Sports Science Training Techniques, 1998.
- [8] Gonzalez-Alonso, J., R. Mora-Rodriguez, P. Below, and E. Coyle, *Dehydration reduces cardiac output and increases systemic and cutaneous vascular resistance during exercise*. Journal of Applied Physiology, 1995. 79(5): p. 1487-1496.
- [9] Nadel, E.R., S.M. Fortney, and C.B. Wenger, *Effect of hydration state of circulatory and thermal regulations*. Journal of Applied Physiology, 1980. 49(4): p. 715-721.
- [10] Sawka, M.N., L.M. Burke, E.R. Eichner, R.J. Maughan, S.J. Montain, and N.S. Stachenfeld, *Exercise and fluid replacement*. Medicine and Science in Sports and Exercise, 2007. 39(2): p. 377-390.
- [11] Hitchins, S., D.T. Martin, L. Burke, K. Yates, K. Fallon, A. Hahn, and G.P. Dobson, *Glycerol hyperhydration improves cycle time trial performance in hot humid conditions*. European Journal of Applied Physiology, 1999. 80(5): p. 494-501.
- [12] Lyons, T. and M. Riedesel, *Glycerol-induced hyperhydration: its effects on fluid compartments in the rat*. Life Sciences, 1993. 53(23): p. 1779-1787.
- [13] Robergs, R.A. and S.E. Griffin, *Glycerol - Biochemistry, pharmacokinetics and clinical and practical applications*. Sports Medicine, 1998. 26(3): p. 145-167.
- [14] van Rosendal, S.P., M.A. Osborne, R.G. Fassett, and J.S. Coombes, *Physiological and performance effects of glycerol hyperhydration and rehydration*. Nutrition Reviews, 2009. 67(12): p. 690-705.
- [15] Goulet, E.D.B., R.A. Robergs, S. Labrecque, D. Royer, and I.J. Dionne, *Effect of glycerol-induced hyperhydration on thermoregulatory and cardiovascular functions and endurance performance during prolonged cycling in a 25 degrees C environment*. Applied Physiology Nutrition and Metabolism-Physiologie Appliquee Nutrition Et Metabolisme, 2006. 31(2): p. 101-109.
- [16] Lyons, T., M. Riedesel, L. Meuli, and T. Chick, *Effects of glycerol-induced hyperhydration prior to exercise in the heat on sweating and core temperature*. Medicine and Science in Sports and Exercise, 1990. 22(4): p. 477-483.
- [17] Riedesel, M., D. Allen, G. Peake, and K. Al-Qattan, *Hyperhydration with glycerol solutions*. Journal of Applied Physiology, 1987. 63(6): p. 2262-2268.
- [18] Freund, B., S. Montain, A. Young, M. Sawka, J. DeLuca, K. Pandolf, and C. Valeri, *Glycerol hyperhydration: hormonal, renal, and vascular fluid responses*. Journal of Applied Physiology, 1995. 79(6): p. 2069-2077.
- [19] Anderson, M.J., J.D. Cotter, A.P. Garnham, D.J. Casley, and M.A. Febbraio, *Effect of glycerol-induced hyperhydration on thermoregulation and metabolism during exercise in the heat*. International Journal of Sport Nutrition and Exercise Metabolism, 2001. 11(3): p. 315-333.
- [20] Easton, C., S. Turner, and Y.P. Pitsiladis, *Creatine and glycerol hyperhydration in trained subjects before exercise in the heat*. International Journal of Sport Nutrition and Exercise Metabolism, 2007. 17(1): p. 70-91.
- [21] Goulet, E.D.B., S.F. Rousseau, C.R.H. Lamboley, G.E. Plante, and I.J. Dionne, *Pre-exercise hyperhydration delays dehydration and improves endurance capacity during 2 h of cycling in a temperate climate*. Journal of Physiological Anthropology, 2008. 27(5): p. 263-271.
- [22] Marino, F.E., D. Kay, and J. Cannon, *Glycerol hyperhydration fails to improve endurance performance and thermoregulation in humans in a warm humid environment*. Pflugers Archiv-European Journal of Physiology, 2003. 446(4): p. 455-462.
- [23] Monter, P., Y. Zou, R.A. Robergs, G. Murata, D. Stark, W.S. Quirm, D. Lium, and E. Greene, *Glycerol hyperhydration alters cardiovascular and renal function*. Journal of Exercise Physiology, 1999.
- [24] Magal, M., M.J. Webster, L.E. Sistrunk, M.T. Whitehead, R.K. Evans, and J.C. Boyd, *Comparison of glycerol and water hydration regimens on tennis-related performance*. Medicine and Science in Sports and Exercise, 2003. 35(1): p. 150-156.
- [25] Green, H.J., L.L. Jones, and D.C. Painter, *Effects of short-term training on cardiac function during prolonged exercise*. Medicine & Science in Sports & Exercise, 1990. 22(4): p. 488-493.
- [26] Watt, M.J., A.P. Garnham, M.A. Febbraio, and M. Hargreaves, *Effect of acute plasma volume expansion on thermoregulation and exercise performance in the heat*. Medicine & Science in Sports & Exercise, 2000. 32(5): p. 958-962.
- [27] Nelson, J.L. and R.A. Robergs, *Exploring the potential ergogenic effects of glycerol hyperhydration*. Sports Medicine, 2007. 37(11): p. 981-1000.
- [28] Burke, L., M. Cort, G. Cox, R. Crawford, B. Desbrow, L. Farthing, M. Minehan, N. Shaw, and O. Warnes, *Supplements and sports foods*. Clinical Sports Nutrition. Sydney, Australia: McGraw-Hill, 2006: p. 485-579.
- [29] Medicine, A.C.o.S., *Guidelines for graded exercise testing and exercise prescription*. 1980: Lea & Febiger.
- [30] Wingo, J.E., D.J. Casa, E.M. Berger, W.O. Dellis, J.C. Knight, and J.M. McClung, *Influence of a pre-exercise glycerol hydration beverage on performance and physiologic function during mountain-bike races in the heat*. Journal of Athletic Training, 2004. 39(2): p. 169-175.
- [31] Latzka, W.A., M.N. Sawka, S.J. Montain, G.S. Skrinar, R.A. Fielding, R.P. Matott, and K.B. Pandolf, *Hyperhydration: tolerance and cardiovascular effects during uncompensable exercise-heat stress*. Journal of Applied Physiology, 1998. 84(6): p. 1858-1864.
- [32] Knight, C., A. Braakhuis, and C. Paton, *The Effect of Glycerol Ingestion on Performance During Simulated Multisport Activity*. Research Quarterly for Exercise and Sport, 2010. 81(2): p. 233-238.