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Effects of Dehydration on Cognitive and Physical Performance in Female Golfers: A Randomized Crossover Pilot Study

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Abstract: Athletes' commitments to nutrition practices can set them apart in their field. Few studies have investigated the impact of hydration practices on golfers' performance who compete for up to eight hours a day, and none have studied female golfers. In this pilot, randomized crossover study, female elite golfers (n = 6) completed 4 simulated golf holes in both euhydrated and dehydrated states. Euhydration was attained by following NCAA (National Collegiate Athletic Association) hydration guidelines; dehydration was attained by a 12-h overnight fluid fast. Before any fluid intervention, five out of six participants were dehydrated at baseline using urinary specific gravity (USG) classifications for euhydration (USG < 1.010) and dehydration (USG > 1.010). No significant condition by time interactions were found between hydration conditions. Although not significant, participants in a dehydrated state demonstrated lesser mean 7-iron distance (141.9 ± 10.0 vs 144.2 ± 8.0 m), lower putting accuracy (2.4 ± 1.0 vs 2.7 ± 10.0 putts made out of 4 attempts), and greater perceived effort (10.9 ± 2.1 vs 10.5 ± 1.6) as compared to their euhydrated state. The finding of one participant out of six with significant dehydration (USG = 1.021) during attempted euhydrated state may suggest the need for alternative methods to promote adequate hydration in future studies and possibly in golf practice.

Keywords: golf; hydration; cognitive function; motor function

1. Introduction

Despite its lack of energetic yield, taste, or glamor, water is perhaps the most important nutrient for athletes. To begin with, human bodies are largely fluid: water contributes 55–60% of the average human's body weight and constitutes 70% of muscle tissue composition [1]. Beyond athletes and performance, chronic body water deficit reaches across the general population and seriously affects health [2]. If untreated, mild dehydration may be linked with common public health diseases, such as diabetes and obesity [2]. Therefore, the costs of dehydration intrigue both elite athletes and amateurs in addition to those working to reduce medical costs, morbidity, and mortality across the population. Athletes in water balance or slight positive water balance (i.e., euhydration or slight hyperhydration) demonstrate improved performance as compared to slight negative water balance (i.e., dehydration) [1]. For example, euhydrated athletes have greater body fluid available to supply blood and oxygen to working muscles and to produce sweat to cool the body and prevent heat-related disorders. Some sources report that water loss beginning at 1–2% of body weight leads to an increase in heart rate and a decrease in exercise performance [1,3–5]. In general, dehydration of 1–2% body weight does not appear to impact exercise performance of exercise lasting less than 90 min; however, some evidence supports minimal dehydration can impact performance of fine-motor tasks often used in team sports [3]. Water loss at 3–5% of body weight leads to loss of blood volume, low oxygen delivery to muscles, and faster lactic acid build up, ultimately causing higher rates of perceived exertion, faster onset of fatigue, decreased ability to concentrate, and decreased training and performance overall [1].

While the paramount role fluid consumption plays in athletic performance is apparent, an overwhelming number of the athletic population still compete and train in a dehydrated state [3,6–9]. The literature clearly shows that dehydration reduces skill-based performance by causing detriment to both motor skill and cognitive function, yet research supporting a numerical threshold at which effects are displayed is equivocal [10]. Therefore, the question remains whether decreased physical performance and cognitive performance in mildly dehydrated athletes attenuate overall sport performance. Minimal research has examined the effects of fluid ingestion during golf compared to its endurance counterparts. Although the sport of golf reports low energy expenditure and is non-contact, non-explosive, and generally non-fatiguing, it may still pose threats to homeostasis by 4–8 h of prolonged walking and the high cognitive demands of shot and putting execution during an 18- or 36-hole round [11]. Only two studies have examined golf performance in dehydrated athletes and only male participants were included. The first study observed normal drinking habits and demonstrated that male elite collegiate golfers (n = 15) who were significantly or seriously dehydrated had a four-stroke higher average than golfers who were euhydrated or minimally dehydrated after a competitive 18-hole round [3]. The second study, a repeated measures counterbalanced study design with elite male golfers (n = 7), induced mild dehydration (change in body weight = −1.5 ± 0.5%) [4]. These golfers demonstrated an 11% loss in average iron distance, near doubling of off target iron accuracy, and over a six-fold increase in overestimation of distance from pin compared to their euhydrated condition (change in body weight = −0.3 ± 0.6%) [4]. Thus, research quantifying the detriments of dehydration on performance may increase awareness among coaches and athletes.

While the primary purpose of this study is to reproduce the aforementioned trial by Smith et al. [4] to determine the impact of mild dehydration on motor function in female golfers, the secondary purpose is to determine its cognitive impact. Dehydration is one of many factors in a complex regulatory system that leads to mental fatigue [12]. A few studies have reported a higher rate of perceived exertion (RPE) for individuals in a dehydrated state than in a euhydrated state and others have shown loss of cognitive function and alertness in mildly dehydrated individuals (body weight loss of 1–2%) [7,12]. Some have proposed that the sensation of thirst increases the athlete's perception of effort, leading to a reduction in physical effort, which could then lead to a reduction in hitting distance for golfers [12]. More research examining cognition as a potential physiological cause of impaired performance in golf is needed, and we believe this study is the first to compare mental fatigue, reasoning capability, and perceptions of effort between euhydrated and dehydrated states of female competitive golfers. Moreover, this randomized crossover study examines the impact of induced mild dehydration on the performance and cognitive function of female elite golfers as compared to performance during a euhydrated state, achieved by following standard NCAA (National Collegiate Athletic Association) hydration recommendations [13]. We tested the hypothesis that female golfers in their dehydrated state would (1) demonstrate worse motor and cognitive performance as compared to their euhydrated state and (2) demonstrate greater decline in performance over time as compared to their euhydrated state.

2. Materials and Methods

Participants included female collegiate golfers from the Virginia Tech Women's Golf Team. The target sample size of n = 7 was chosen based on the sample size in the similarly designed study by Smith et. al [4]. The sample population represented elite golfers participating in high-level, regional, and national competition. A typical week of training would include 15 h of skill practice and/or competitive play and two hours of strength training, with additional training at the discretion of the golfer. The study excluded any person not cleared for exercise by Virginia Tech Sports Medicine staff. The study was approved by the Virginia Tech Institutional Review Board (IRB No. 17-688, 4 January 2018). This research study utilized a randomized (1:1 allocation ratio), controlled, crossover design (Figure 1). Hydration status was measured by urinary specific gravity (USG). The National Athletic Trainers' Association (NATA) considers USG values < 1.010 well hydrated, 1.010–1.020 mild dehydration, 1.021–1.030 significant dehydration, and USG values > 1.030 serious dehydration [14]. Several measures were used to assess motor and cognitive function, including perception of effort, hitting distance and accuracy, putting accuracy, reaction time, and fluid cognitive ability.

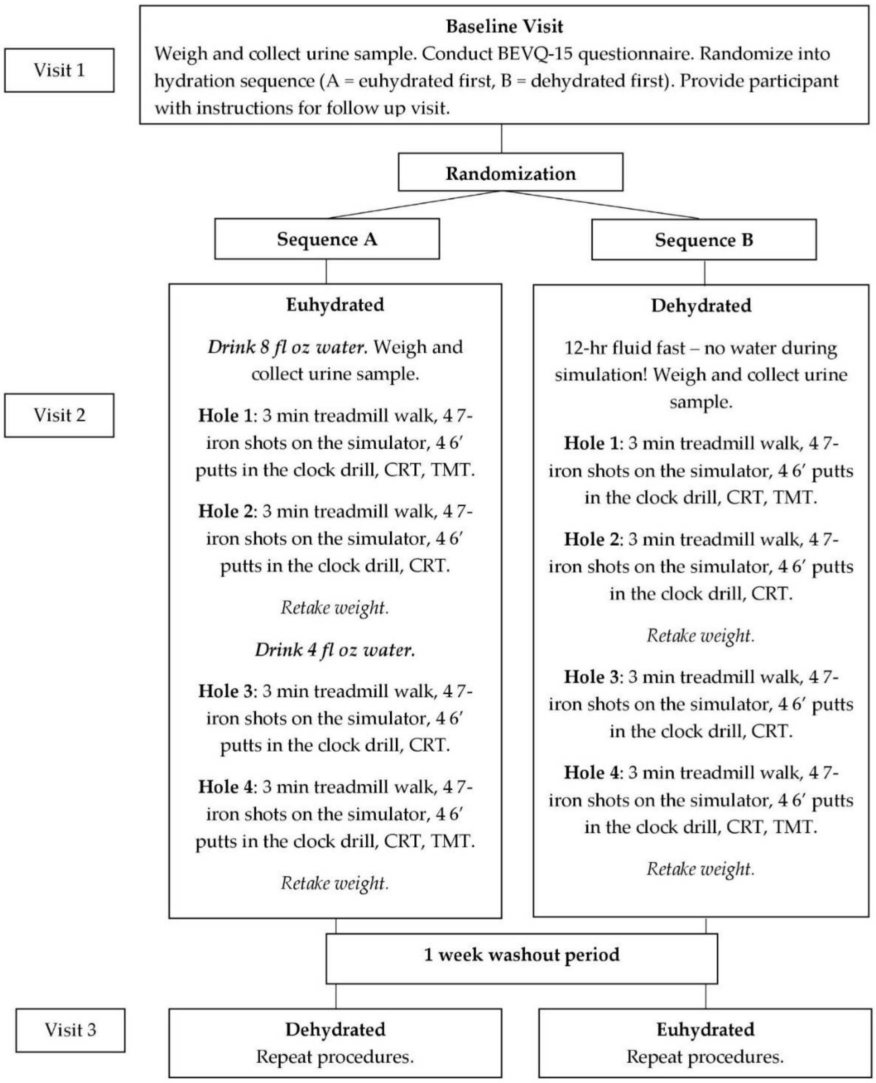

Figure 1. Study design and description of procedures; CRT = Deary–Liewald choice reaction time task, TMT = Trail Making Test B.

The study consisted of 3 visits with baseline measurements taken on visit 1 and underwent the euhydrated and dehydrated conditions on either visit 2 or 3 (order randomly assigned). Visits were scheduled around participants' competitions in order to limit consequences of dehydration on performance. Visits were also scheduled around participants' menstrual cycles to avoid confounding factors on hydration status or performance. Participants were randomized via computer generation into one of two groups, sequence A or sequence B, to control for potential biases in ordering of induced euhydration or mild dehydration on test results. Participants in sequence A performed the tests in the euhydrated condition first (i.e., visit 2), and participants in sequence B performed the tests in the dehydrated condition first. For both conditions, participants were instructed to drink a minimum amount of fluid (40 mL/kg of body weight) to maintain adequate water balance on the day before the visit and keep a record of their fluid intake throughout the day. Euhydration was expected as a result of compliance to NCAA hydration recommendations: drink 16 fl oz water 2–3 h before exercise, 8 fl oz water 15 min before exercise, 4 fl oz water every 15–20 min during exercise, and 16–20 fl oz of fluid after exercise for every pound lost [13]. Dehydration was expected as a result of a 12-h overnight fast, which was previously used by Smith et al., and had previously demonstrated a USG ≥ 1.010 and a 1–2% body weight loss [4]. Additionally, participants in the dehydrated condition were restricted from fluid during exercise. Participants were enrolled and assigned to interventions internally by the secondary investigator.

All sessions were held in the Willis and Mary Blackwood Indoor Golf Facility on site at Virginia Tech. During visit 1 researchers obtained baseline measurements including weight and body composition via bioelectrical impedance analysis (BIA, model 310GS; Tanita, Tokyo, Japan), USG urinalysis via a handheld refractometer (ATAGO 4410 Urinary Specific Gravity Refractometer, Bellevue, WA, USA), and typical beverage intake via a beverage questionnaire (BEVQ-15) [15–17]. Participants were given instructions to meet hydration requirements based on the sequence assigned and were provided with a fluid intake log to fill out before returning for their second visit.

Participants were asked to eat a standardized breakfast of two pieces of toast (with peanut butter and jelly or honey) and a banana. During visit 2, researchers measured participant weight and USG. For the exercise bouts, participants first performed 3 min of walking on a treadmill (5% incline at 3 mph) wearing a 15 pound weighted vest to mimic competition demands of carrying a golf bag. Second, participants began the golf-specific tests in the simulator by performing a typical warm up (~5 min). After the warm up, the golfers hit four full shots with their 7 iron towards the simulator target. Next, the golfers performed a clock drill putting test in which four six-footers were set up on the putting green around the hole. Participants were instructed to putt as many balls in around the hole, and the total number of putts made were recorded. Third, participants underwent two cognitive function tests: the Deary–Liewald choice reaction time task and the Trail Making Test B. This series of tests was repeated four times to simulate four holes with the exception of Trail Making Test B, which was only performed at the beginning and the end (holes 1 and 4). At completion of the second set of tests (hole 2), weight was taken again to ensure weight loss did not exceed 5% of body weight (classification of serious dehydration) for the safety of the participants, and participants in the euhydrated condition were given 4 fl oz of water [18]. At the end of the fourth set of tests (hole 4), weight was retaken and recorded. To aid in proper rehydration post-test, participants were given water or Gatorade and instructed to drink 16–20 fl oz of fluid for every pound lost. A washout period of at least seven days was implemented before participants reported back for the third and final visit to conduct the same tests in the opposite condition. All sessions were scheduled between 8 and 10 a.m., and exercise was conducted at room temperature within the practice facility. The sessions were designed to mimic 90 min of a golf competition; therefore, only four simulated holes were played.

2.1. Weight and Body Composition

Body weight and total body water was measured to the nearest 0.1 kg using a digital scale (model 310GS; Tanita, Tokyo, Japan).

2.2. Urinary Specific Gravity

For the purpose of this study, NATA values were used to determine hydration status. NATA classifies USG values < 1.010 as well hydrated, 1.010–1.020 as mild dehydration, 1.021–1.030 as significant dehydration, and USG values > 1.030 serious dehydration [14]. USG was determined using a handheld refractometer (ATAGO 4410 Urinary Specific Gravity Refractometer, Bellevue, WA, USA) at the beginning of each visit.

2.3. Heart Rate

Heart rate was measured using a Polar A300 heart rate monitor (Polar Electro Inc., Bethpage, NY, USA) with a chest strap to estimate beats per minute at the end of each three-minute weighted walking exercise test during both hydration conditions.

2.4. Motor Performance

Distance (meters) and off-target accuracy (meters) were measured using a GC quadrascopic launch monitor (Foresight Sports, San Diego, CA, USA). The GC quadrascopic launch monitor uses a combination of infrared object tracking and high-speed cameras to measure ball launch performance. The simulator accounts for environmental factors like temperature and air pressure, meaning the technology provides accurate and precise measurements across study groups. Prior testing by the manufacturer of the GC2 monitor established a distance accuracy of 2–3 m for 140 to 180-meter golf shots. For each simulated golf hole, participants were asked to hit four shots with their 7 iron towards the simulator target to the best of their ability. The simulation target was set to visually represent each golfer's typical full shot distance using a 7 iron. Putting accuracy for each round was determined by the total number of putts made out of four attempts in a clock-drill putting test.

2.5. Cognitive Performance

2.5.1. Perception of Effort

Perception of effort was measured using a Rate of Perceived Exertion (RPE) Scale or the Borg Scale at the end of each three-minute weighted walking exercise test [19]. The Borg scale estimates intensity level during exercise based on how hard the individual perceives he or she is working [19]. The scale numerically represents an individual's perception of intensity ranging from no exertion at all (score of 6) to maximal exertion (score of 20). A rating of 9 on the Borg Scale (RPE) would be considered very light perceived exertion, and a rating of 11 would be considered light. Validation studies have shown strong correlation between perception of effort using the Borg scale and actual heart rate of the individual.

2.5.2. Reaction Time

The choice reaction time task represents mean reaction times of the participants [20]. The choice reaction time task was administered through the Deary–Liewald Reaction Time Tester program downloaded on the investigator's laptop. Procedures for this test simply required the participants to press keys on a computer in response to flashing cues on the screen as fast as they were able. The cues were flashing "X's" in four boxes that corresponded to the four keys the participants rested their middle and pointer fingers on. The participants had a total of 30 cues flash, each within 200 to 1500 ms of each other. The program reported mean response time, the variable of interest, as well as other variables including number of correct responses.

2.5.3. Fluid Cognitive Ability

The Trail Making Test B measured fluid cognitive ability [21]. Fluid cognitive ability, or fluid intelligence, is "the ability to generate, transform, and manipulate different types of novel information in real time" and influences reasoning capabilities of an athlete during training and competition [22]. The Trail Making Test B required the participants to connect the numbers 1 to 13, but also a letter in alphabetical order following each number, i.e., 1-A-2-B, etc. by tracing with a pen.

2.6. Statistical Analysis

Paired samples t-tests of the averages were used to interpret the main effects by comparing the means of dependent variables in euhydrated and dehydrated conditions. Statistical analysis of the euhydrated condition versus the dehydrated condition was assessed using repeated measures analysis of variance (ANOVA) to determine differences within subject conditions over time, i.e., over the course of four holes. Significant values were assessed by the determined significance level ($p \leq 0.05$). All analyses were performed using SPSS Statistical Software (Version 24, International Business Machines Corporation [IBM], Armonk, NY, USA).

3. Results

3.1. Demographic Characteristics

Of the seven female golfers enrolled in the study, and one golfer dropped out from the study due to an unexpectedly high class load. The six golfers were Caucasian between the ages of 19 and 22 (mean age = 20.8 ± 1.1 years). All were golfers participating in elite level, regional, and national competition (i.e., competition on the Virginia Tech Women's Golf Team). Typical total fluid intake via the BEVQ-15 ranged from 26 to 167 fl oz per day (mean intake = 71 ± 50 fl oz). The mean typical total water consumption was 53 ± 34 fl oz per day and ranged from 22 to 120 fl oz per day. Of the USG values at baseline, 1 participant classified as significantly dehydrated (1.021), 4 classified as minimally dehydrated (1.010–1.020), and 1 classified as euhydrated (<1.010). The minimum USG from visit 1 was 1.007 and the maximum was 1.023.

3.2. Comparison of Body Weight between Hydration Conditions

No significant differences in weight were found across conditions. The weight at the beginning of the euhydrated visit (64.3 ± 9.8 kg) was 1.53 ± 0.73% higher ($p = 0.091$) than baseline weight at visit 1 (63.3 ± 9.0 kg), while the weight at the beginning of the dehydrated visit (63.8 ± 9.9 kg) was only 0.74 ± 0.88% higher than baseline weight at visit 1 ($p = 0.439$). Furthermore, there was no significant difference in the initial euhydrated weight and initial dehydrated weight (mean difference = 0.78 ± 0.52%, $p = 0.194$).

3.3. Comparison of Urinary Specific Gravity (USG) between Hydration Conditions

The USG at the euhydrated visit (1.009 ± 1.007) was significantly lower than the baseline USG (1.019 ± 1.004) at visit 1 (mean difference = 0.010 ± 0.007, $p = 0.034$), and USG at the beginning of the dehydrated visit (1.021 ± 1.003) was significantly higher than the euhydrated USG (mean difference = 0.012 ± 0.004, $p = 0.030$) (Table 1). There was no significant difference in baseline USG and the dehydrated visit USG (mean difference = 0.002, $p = 0.203$). One participant was unable to give a urine sample during the dehydrated visit; thus, only five pairs were used for USG analysis. Otherwise, all analyses reflect the original number of participants and their assigned group.

Table 1. Comparison of body weight and urinary specific gravity across baseline and euhydrated and dehydrated states (n = 5).

Variables	Baseline Mean (SD)	Euhydrated Mean (SD)	Dehydrated Mean (SD)	p-Value [a]
Weight (kilogram)	63.3 (9.0)	64.3 (9.8)	63.8 (9.9)	0.160
USG	1.019 (0.004) [b]	1.009 (0.007) [b,c]	1.021 (0.003) [c]	0.014

[a] Indicates significance of difference between the conditions at different points using repeated measures ANOVA; [b] Indicates significant difference between means at $p = 0.034$ using paired sample t-test; [c] Indicates significant difference between means at $p = 0.030$ using paired sample t-test.

3.4. Comparison of Heart Rate between Hydration Conditions

Mean heart rate was not significantly different between the euhydrated and dehydrated states (120.9 ± 16.9 vs 115.9 ± 14.2 beats per minute, respectively, $p = 0.057$).

3.5. Comparison of Motor Performance between Hydration Conditions

Table 2 reports the overall differences in motor and cognitive performance between conditions. No significant difference were noted when examining mean differences in variables between the euhydrated and dehydrated states. Table 3 reports performance outcome testing over time as the golfer approaches 90 min of exercise. Figure 2 graphically represents the data in Table 3 on an individual level to provide raw data. There was a significant decrease in 7-iron hitting distance over time in both conditions. In the euhydrated condition participants lost 4.7 m ($p = 0.025$) from holes 1 to 4, and in the dehydrated condition 3.2 m ($p = 0.049$) (Figure 2). Additionally, hitting accuracy declined faster over time ($F = 2.796$, $p = 0.155$) for the dehydrated vs euhydrated condition. However, a repeated measures ANOVA reports no significant interaction of condition by time for motor performance variables, i.e., there is no significant difference in the changes of the mean score over the 4 holes.

Table 2. Comparison of mean motor and cognitive performance measures between hydration conditions (n = 6).

Variables	Euhydrated Mean (SD)	Dehydrated Mean (SD)	Difference Mean (SE)	p-Value [a]
Motor Performance Measures		-		
Distance (meters)	144.2 (8.0)	141.9 (10.0)	2.3 (0.9)	0.055
Accuracy (meters)	7.2 (1.4)	7.0 (1.7)	0.2 (0.9)	0.858
Putts made (out of 4)	2.7 (0.6)	2.4 (1.0)	0.3 (0.4)	0.516
Cognitive Performance Measures		-		
RPE [b]	10.5 (2.1)	10.9 (1.6)	0.4 (0.6)	0.544
CRT (milliseconds) [b]	391.4 (22.3)	377.9 (39.9)	13.5 (9.0)	0.194
TMT-B time (seconds) [b]	59.4 (12.8)	58.3 (14.0)	1.1 (6.1)	0.865

[a] Indicates significance of difference between conditions using paired sample t-test; [b] RPE= Rate of Perceived Exertion; CRT=Choice Reaction Time; TMT-B=Trail Making Test B.

Table 3. Comparison of motor and cognitive performance measures between and within hydration conditions over time (n = 6).

Variables	Hole 1 Mean (SD)	Hole 4 Mean (SD)	Difference between Hole 1 and Hole 4		Difference between Condition over Time F (p-Value) [a]
			Mean (SE)	p-Value	
Motor Performance Measures			-		
Distance (meters)			-		
Euhydrated	147.6 (8.5)	142.9 (6.9)	4.7 (1.5)	0.025	0.391 (0.559)
Dehydrated	144.0 (10.1)	140.8 (10.1)	3.2 (1.3)	0.049	
Accuracy (meters)			-		
Euhydrated	5.9 (2.8)	6.6 (2.9)	0.6 (1.1)	0.581	2.796 (0.155)
Dehydrated	6.5 (3.0)	9.5 (4.5)	3.0 (2.0)	0.200	
Putts made (out of 4)			-		
Euhydrated	2.7 (1.2)	3.0 (0.9)	0.3 (0.7)	0.661	0.077 (0.793)
Dehydrated	2.2 (1.0)	2.7 (0.8)	0.5 (0.3)	0.203	
Cognitive Performance Measures			-		
RPE [b]			-		
Euhydrated	9.9 (1.8)	10.9 (2.2)	1.0 (0.5)	0.111	0.484 (0.518)
Dehydrated	10.6 (1.6)	11.3 (1.9)	0.8 (0.5)	0.178	
CRT [b] (milliseconds)			-		
Euhydrated	399.8 (25.4)	386.6 (24.3)	13.2 (8.0)	0.159	1.629 (0.258)
Dehydrated	382.8 (33.7)	379.4 (45.5)	3.3 (6.1)	0.610	
TMT-B time [b] (seconds)			-		
Euhydrated	65.7 (20.0)	53.1 (10.7)	12.6 (7.8)	0.168	0.144 (0.720)
Dehydrated	67.6 (24.9)	49.1 (8.3)	18.5 (9.9)	0.121	

[a] Indicates significant difference between euhydrated and dehydrated states over 4 holes using repeated measures ANOVA; [b] RPE = Rate of Perceived Exertion; CRT = Choice Reaction Time; TMT-B = Trail Making Test B.

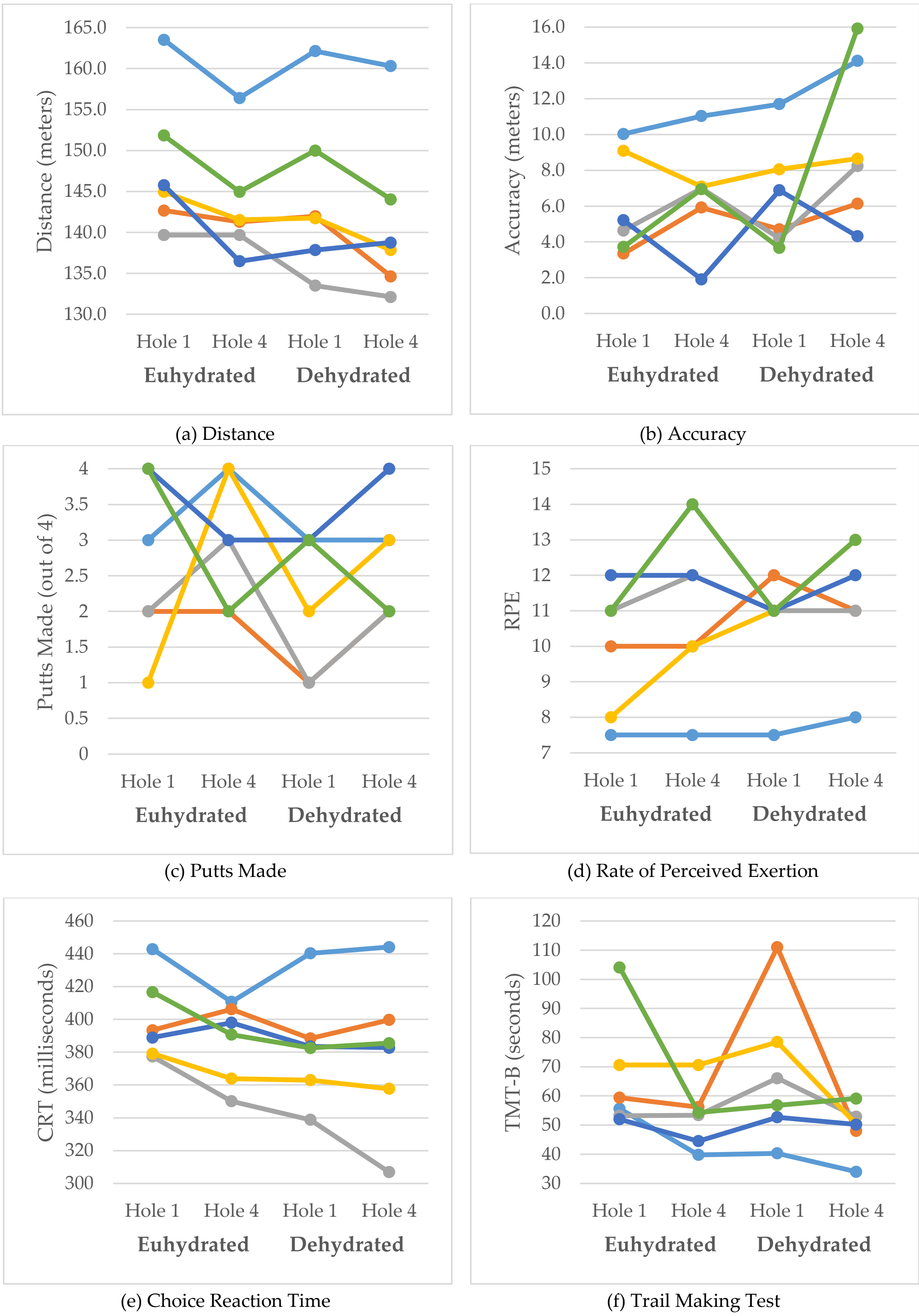

Figure 2. A comparison of (**a**) distance; (**b**) accuracy; (**c**) putts made; (**d**) RPE = Rate of Perceived Exertion: (**e**) CRT = Choice Reaction Time; and (**f**) TMT-B = Trail Making Test B between euhydrated and dehydrated conditions for each participant.

3.6. Comparison of Cognitive Performance between Hydration Conditions

When averaging means from all four holes, no significant mean differences in cognitive performance variables were found between the euhydrated and dehydrated states (Table 2). Furthermore, no significant differences between conditions over time were found for the cognitive variables, i.e., there is no significant difference in the changes of the mean score over the four holes (Table 3). When examining the raw cognitive data (Figure 2, Table 4), an increase in RPE was the only cognitive performace measure that demonstrated an overall decline for most participants (four out of six golfers) when exercising in a dehydrated state.

Table 4. Urinary specific gravity (USG) Measures for Participants (n = 6) Corresponding with Figure 2.

Participant Legend	Participant ID	Euhydrated USG	Dehydrated USG
	Participant 1	1.008	1.018
	Participant 2	1.005	Unknown
	Participant 3	1.007	1.02
	Participant 4	1.003	1.021
	Participant 5	1.008	1.026
	Participant 6	1.021	1.02

4. Discussion

Even though the null hypothesis was sustained, several points from the preliminary results offer researchers valuable data for future investigation. First, the sample population was consistent with the current literature's estimates that the majority of athletes trains and competes in a dehydrated state [3,6–9]. The study found that five out of six participants at baseline demonstrated dehydration based on the NATA classifications for hydration (USG < 1.010) and dehydration (USG ≥ 1.010) [14]. In addition, the average euhydrated hydration status (USG = 1.009) was significantly more hydrated than baseline (USG = 1.019; p = 0.014), further corroborating the high prevalence of dehydration among the sample population. These results indicate that further research should be conducted to elicit the potential impact of hydration status, given the current literature which suggests that golfers who were dehydrated demonstrated a four-stroke higher scoring average than golfers who were euhydrated [3]. Another study showed that golfers who were dehydrated demonstrated an 11% loss in average iron distance, and a near doubling of off-target iron accuracy compared to golfers who were euhydrated [4]. Other literature suggests golfers who are properly hydrated may demonstrate improved reaction time, and thus have delayed mental fatigue and greater ability to sustain effort throughout prolonged competitions [23].

Additionally, the mean distance proved to be one of the most promising outcome measures for future research. Figure 2a reflects the clearest trends of all the measures, illustrating that distance decreased in the dehydrated state for all six participants. The participants' mean 7-iron distance demonstrated a 2.3-meter decrease (p = 0.055) from 144.2 ± 8.0 m in their euhydrated state to 141.9 ± 10.0 m in their dehydrated state. Using Cohen's classification for effect size, the magnitude of the effect of dehydration is small but not trivial (d = 0.25). Such minor improvements in iron play have a profound role in golf, given that two to three meters of distance gained can impact the confidence and the demeanor of the player. Given the small sample size, researchers must consider the increased risk of type II error when interpreting the effect size and p-value. Therefore, similarly designed future studies with greater sample sizes are likely to see a significant difference in ball striking distance.

This study is not without limitations. By nature of a sports science study, one limitation is weak statistical power due to a small sample size (n = 6) working with elite athletes. Future studies may consider conducting the same study in multiple labs or find other ways to increase sample size in order to grow the data set and ultimately increase power. Although the golf simulator used is state-of-the-art, the error associated with accuracy may not be sensitive enough to detect differences between the euhydrated and dehydrated conditions; again, additional larger-scale studies may demonstrate larger, detectable differences. Another limitation included failure to achieve euhydration of one participant despite reported compliance to the written guidelines on her fluid intake log. In fact, the participant was significantly dehydrated for the euhydrated visit (euhydrated USG = 1.021; baseline USG = 1.023; dehydrated USG = 1.020). It is possible that a food dye, such as blackberries or beets, a drug, or the presence of hemoglobin or myoglobin could have changed the color of the urine causing a false USG measurement [24]. Urine sample collected via first void as compared to spot urine sample may reduce confounding variables on USG measurements overall [25]. Thus, future investigations should consider the use of morning void urine sample rather than a spot urine sample and the collection of several days' worth of weights rather than attaining a single weight to evaluate hydration status and baseline weight, respectively. In addition, other organizations, including the American College of Sports Medicine (ACSM) define dehydration at USG > 1.020 [8,26]. This provokes the use of a higher cutoff value (USG > 1.020) to define dehydration to further increase statistical power. Strengthening the evidence of mild dehydration in the dehydration group can help future investigations determine its effects on competitive female golfers. Finally, although the present study was designed to simulate four holes of golf, generalizability to live rounds is questionable, and true performance results should be measured on the golf course in a competitive round.

Despite the limitations, this study still holds many strengths. It is one of the first to study dehydration in female golfers who may have interactions of menstruation on fluid regulation as compared to males. The study is relevant to the athletic population who often train and compete in a dehydrated state, as established in previous studies [3,6–9]. In addition, the study is generalizable to both amateurs and professionals who train and play golf competitively. While golfers may not start a tournament after a 12-h fluid fast, they might involuntarily start in a similar state of negative water balance as the fast. To illustrate, a 65 kg player only has to lose 1 kg of sweat over a four-hour round, i.e., less than 250 mL of sweat per hour, in order to lose 1.5% body weight. Sweat rates of golfers playing a round in temperate conditions are estimated at 400 mL/h [4]. In addition, voluntary dehydration is a concern among golfers. Professional golfers reported that worry of increased frequency of urination and feeling uncomfortable and less athletic prevents them from drinking lots of fluid during the round [27]. Other reported reasons for inadequate fluid intake include decreased sensation of thirst, underestimation of perspiration, and unpreparedness of carrying fluids [27]. The high prevalence of dehydration in this sample of female collegiate golfers and the potential of dehydration to impair performance, therefore, may highlight the need for competitive golfers to plan and follow through with nutrition practices. Sports dietitians and coaches may encourage competitive golfers to implement good hydration practices, such as weighing before and after a round to calculate sweat rates. Recommendations to golfers may include initially following NCAA hydration guidelines, evaluating hydration status, and increasing fluid consumption recommendations as needed to reach and maintain euhydration during competition. The finding of abnormally high USG in this study may suggest current hydration guidelines, particularly those administered by a fluid intake log, may not ensure euhydration of all athletes. Thus, more research should be done on effective hydration education methods and hydration planning practices.

In conclusion, no significant differences between euhydrated and dehydrated states were found in this pilot study (n = 6); however, the preliminary results warrant future research. The validity and feasibility of the study design and procedures respectively support the reproducibility of the study. The trends in this study (particularly in distance, accuracy, and RPE), along with the findings of other studies, suggest that similar research, addressing the small sample size and the other limitations, should be done to draw conclusions about the decline in motor or cognitive performance due to dehydration in female golfers. Furthermore, based on USG levels, NCAA hydration recommendations may not be adequate to induce a euhydrated state for all athletes, and future research should examine the validity of these recommendations. The potential of dehydration to impair performance and the revealed prevalence of dehydration in this golf team highlight the need for more proactive hydration initiatives among competitive golfers.

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