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Countermovement jump, handgrip, and balance performance change during euhydration, mild-dehydration, rehydration, and ad libitum drinking

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Objective: To examine the effects of euhydration, mild-dehydration, rehydration, and ad libitum drinking on countermovement jump (CMJ), handgrip strength, and performance of balance error scoring system test (BESS).

Methods: Eighteen healthy male subjects (mean[M]±standard deviation[SD]; age, 23±3y; body mass, 80.1 ± 9.7 kg; height, 175.8 ± 5.7 cm) participated in this study. Participants reported to the laboratory to perform CMJ, handgrip strength, and BESS with different hydration statuses (euhydrated, EUH; when they initially sensed thirst, THIRST; dehydrated, DEH; following 30 minutes of rehydration, REH; and following 24-h ad libitum drinking, AD).

Results: CMJ at EUH (M±SD; 54.6 ± 3.0 cm) was significantly higher than DEH (52.8 ± 3.0 cm, $p = 0.027$) and REH (52.6 ± 2.8 cm, $p < 0.001$). However, there was no difference between DEH and REH ($p = 0.643$). CMJ at THIRST (54.9 ± 3.0 cm, $p = 0.004$) was higher than REH. Also, AD (53.8 ± 2.8 cm, $p = 0.027$) was higher than REH. In left handgrip strength, THIRST (48.6 ± 9.5 kg) was higher than EUH (46.7 ± 10.1 kg, $p = 0.018$), DEH (45.8 ± 10.0 kg, $p = 0.013$), REH (46.1 ± 9.5 kg, $p = 0.004$), and AD (47.1 ± 9.7 kg, $p = 0.05$). Additionally, in the single-leg stance on a foam pad, more BESS errors were found at THIRST (6 ± 2) compared to EUH (5 ± 2, $p = 0.007$) and AD (5 ± 2, $p = 0.002$).

Conclusion: The findings of this study were: ~2% of mild dehydration induced by 24-h fluid restriction decreased lower body power measured by CMJ, acute rehydration did not restore the loss of lower body power induced by dehydration, and ~0.5–0.9% of dehydration did not decrease lower body power.

1. Introduction

Maintaining appropriate fluid balance is important to optimize physical performance and support health.[1,2] For example, dehydration negatively affects power, strength, and balance, but results among studies with different protocols (e.g., how dehydration is induced) and outcome variables (e.g., selection of representative variables, method of measurement) exhibit mixed results.[3,4] Understanding how hypohydration affects physical performance determinants such as power, strength, and balance is important to consider the practical recommendations for rehydration protocols. Especially, there is limited research examining the effects of hypohydration on performance measurements in daily living situations.

Some previous studies have examined the effects of hydration on performance measurements. A meta-analysis suggests that hypohydration does not significantly ($p > 0.05$) influence vertical jump performance.[3] However, trends ($p = 0.09$) identified in the meta-analysis indicate that 1.0–1.4% body mass loss (BML) decreases vertical jump performance which supports the need for further study to understand the influence of hypohydration on power outcomes.[3,5] For strength measurement, 1.8% BML, induced

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by heat exposure, decreases 4.0% of handgrip strength, but this result is not consistent among the published studies.[5] Balance error scoring system (BESS) is utilized to assess balance performance, which is important since balancing ability is related to task-specific neural adaptations and rate of force development, but could also be related to stability and injury risk.[6] 2.6% BML, induced by exercise in the heat, lowers balance performance measured by BESS.[4]

Studies described in the previous paragraph induced dehydration by heat exposure and/or exercise, which influences performance independent of hydration status and may contribute to varying results. Few studies have examined the effects of dehydration-induced passively (no drinking) without exercise, heat, and/or diuretics on multiple components of performance together (power, strength, and balance).[7,8] Previous study mentioned when hypohydration was induced by exercise and/or heat exposure, the effect of hypohydration cannot be isolated from effects of increased core temperature, therefore, it is critical to induce hypohydration without exercise and/or heat exposure too.[9] Also, there are limited studies examining the effects of different level of hypohydration on performance measurements in non-athletic situations, which is also important situations needing to be examined.[3] Furthermore, the effect of acute rehydration following hypohydration on performance measures remains unclear. Therefore, the purposes of this study were 1) to test the hypothesis that hypohydration induced by passive dehydration without exercise, heat, or diuretic intervention, may negatively affect *power* (vertical jump performance), *strength* (handgrip strength), and *balance* (BESS), and 2) to test acute rehydration following hypohydration impact those performance measurements.

2. Methods

Eighteen healthy male subjects (mean ± standard deviation [M±SD]; age, 23 ± 3 y; body mass, 80.1 ± 9.7 kg; height, 175.8 ± 5.7 cm Body mass index, 26.0 ± 3.5 kg m^{-2}) participated in this study. Following an explanation of study procedures, which was approved by the Institutional Review Board at the «removed for review», participants provided written and informed consent to participate in this study. This research was a part of a large study, and other research questions were examined in other manuscripts.[10,11]

The study design is presented in Fig. 1. On day 1 (familiarization visit) in the morning (7:00–8:00 a.m.), participants were instructed to arrive at the laboratory fasted and without prior fluid intake. Upon arrival, participants provided a urine spot sample, and then, body mass (BM) (model DS44L, Ohaus Inc, Florham Park, NJ) was collected with minimal clothes (such as undergarments). Urine samples were analyzed for urine specific gravity (USG) using a hand-held refractometer (model 300CL, Atago Co, Tokyo, Japan), and urine color with a validated urine color chart.[12] Blood was drawn from an antecubital vein and centrifuged at 3000 rpm for 15 minutes. Plasma osmolality was assessed using the freezing-point depression method (model OsmoPRO, Advanced Instruments, Inc., Norwood, MA). 24-h urine collections were performed from day1-day2 (EUH), day2-day3 (DEH), and day3-day4 (AD), and urine osmolality (model OsmoPRO, Advanced Instruments, Inc., Norwood, MA), USG, and urine color were assessed for each 24-h urine sample.

Following urine, BM, and blood measurements, participants completed countermovement jump (CMJ), handgrip strength, and BESS tests. CMJ is used to assess lower-body power. CMJ performance is translational to sports performance, such as sprint.[13] Participants performed three CMJ with 30 seconds rest between each trial using a jump mat (just jump system, probotics) following two practice jumps. Participants were instructed to squat down until the knees are bent at 90° with swinging both arms, then immediately jump vertically as high as possible. Participants were asked that the take-off was from both feet, with no initial steps or shuffling. During the time spent in the air, participants were told to maintain extension in the hip, knee, and ankle joints to prevent achieving any additional flight time by bending their legs.

Following CMJ, participants conducted two times of handgrip strength tests on each hand using the handgrip dynamometer (Takei Handgrip dynamometer, Japan). Before the trial, the grip was adjusted with the participant's first and second knuckle joints at a 90-degree angle. Following the handgrip strength test, participants completed a BESS test. BESS is used commonly to assess lower balance performance, which is important for neural adaptations.[4] BESS consisted of assessments with 3 different stances and 2 different surfaces (total 6 conditions).[14] First stance was the double leg stance, in which was participant's feet were flat on the floor and both feet were attached with hands on hips and eyes closed.[14] A second stance was the single-leg stance, in which participants stood on the floor on the non-dominant leg with the hip flexed about 20-degree and knee flexed about 45° on the dominant leg.[14] The third stance was the tandem stance, in which participants stood heel to toe on the floor with the non-dominant foot in the back.[14] Participants tried to remain in each stance as still as possible for 20 seconds and the number of errors, including moving hands off hips, opening eyes, stepping, stumbling or falling, abduction of hip flexion beyond 30°, lifting forefoot or heel, and remaining out of the original position for longer than 5 seconds, were counted.[14] The maximum number of errors for a single condition was 10 if the number of errors was more than 10.[14] The numbers of errors were performance outcomes for BESS. Tests for each stance were performed on both the floor (firm surface) and a foam pad.

Following performance testing, participants left the laboratory and conducted normal daily activities but were instructed to consume an additional 500 ml water in the evening, and to arrive at the laboratory on the morning of day 2 in the hydrated state. Participants collected their 24-h urine production in a clean container each day. Upon the arrival on day 2 in the morning, participants provided BM, urine sample, and blood drawn. Then, they performed a battery of performance tests.

Following the morning visit on day 2, participants started consuming no fluid and ate only dry food. Fluid restriction was performed until day 3-morning visit. On day 2, when participants sensed thirst for the first time after starting fluid restriction, they reported to the lab and followed the same protocol (THIRST).

*Familiarization		*EUH	*THIRST	*DEH	*REH		*AD
Day 1 Morning	Day 1 during the day Stay hydrated	Day 2 Morning	Day 2 during the day 24-h fluid restriction	Day 3 Morning	Day 3 Morning Rehydration	Day 3 during the day Ad libitum	Day 4 Morning

Fig. 1. Study timeline. Body mass, urine and blood analyses, and performance tests (countermovement jump, handgrip strength, and Balance Error Scoring System were measured at familiarization; euhydrated (EUH); when they initially sensed thirst, THIRST; dehydrated, DEH; following 30 minutes of rehydration, REH; and following 24-h ad libitum drinking, AD.

On day 3 morning, participants arrived at the lab in a dehydrated state due to 24-h fluid restriction (DEH), and participants completed the same protocol. Following these measurements, water or a fluid-electrolyte replacement beverage (~23 °C) was provided to participants, and they consumed fluid as much as they want to rehydrate for 30 minutes (REH). This choice was purposefully given to participants to encourage drinking with ad libitum.[10] Then, the same protocol was performed again. After leaving day 3-morning visit, participants spent in free-living life and were able to drink or eat freely. Then, participants came to the lab for the same protocol on day 4 morning (AD).

Data were reported as M±SD with 95% confidence intervals (95% CI). Repeated measures ANOVA with the least significant difference (LSD) comparisons were used to assess differences in hydration measurements and performance variables between EUH, THIRST, DEH, REH, and AD.[16] Average values of CMJ and handgrip strength were utilized to analyze for each visit. BML was calculated based on BM at EUH as a baseline value for each visit. Effect sizes (ES) were calculated using Cohen's d statistic with the effects identified as either small (0.2–0.49), medium (0.5–0.79), or large (>0.8).[15] All statistical analyses were performed using SPSS software (v.25. IBM Corporation, Armonk, NY). Significance was set *a priori* at $p \leq 0.05$.

3. Results

3.1. Dehydration and rehydration interventions successfully changed hydration status as intended

Table 1 indicates BML, plasma osmolality, USG, and urine color from urine spot samples, and USG, urine osmolality, and urine color from 24-h urine collection. Results from these hydration measurements demonstrate that hydration interventions were successfully achieved. The average amount of fluid consumed during 30 minutes of rehydration was 1.4 ± 0.4 L.

3.2. Countermovement jump height was lower when dehydrated, but acute rehydration did not improve performance

Fig. 2 indicates the average CMJ height at each time point. CMJ at EUH (M±SD; 54.6 ± 3.0 cm) was significantly higher than DEH (M±SD [95%CI]; 52.8 ± 3.0 cm [0.09, 1.29], ES = 0.6, $p = 0.027$) and REH (52.6 ± 2.8 cm [0.44, 1.17], ES = 0.69, $p < 0.001$). However, there was no difference between DEH and REH ($p = 0.643$). THIRST (54.9 ± 3.0 cm [0.34, 1.46], ES = 0.79, $p = 0.004$) was higher than REH. Also, AD (53.8 ± 2.8 cm [0.07, 0.98], ES = 0.43, $p = 0.027$) was higher than REH.

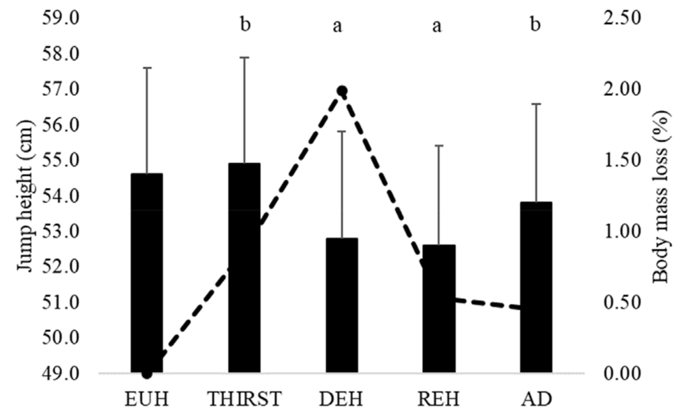

Fig. 2. Changes in countermovement jump height at the euhydration visit on day 2 (EUH), when participants initially sensed thirst on day 2 (THIRST), following 24 hours of fluid restriction on day 3 (DEH), following 30 minutes of acute rehydration on day 3 (REH), and following free-living and 24 hours ad libitum fluid intake on day 4 (AD). a indicates differences from EUH and b differences from REH on CMLK height (left axis), $p \leq 0.05$. The dotted line presents changes in percent body mass loss at each visit (right axis) calculated based on EUH body mass as the baseline values.

3.3. The onset of thirst (THIRST) coincided with isolated performance effects in handgrip strength and balance

Table 2 presents handgrip and BESS results. There were no differences in right handgrip strength at any time points ($p = 0.124$). However, THIRST (48.6 ± 9.5 kg) was higher than EUH (46.7 ± 10.1 kg [0.38, 3.56], ES = 0.19, $p = 0.018$), DEH (45.8 ± 10.0 kg [0.69, 5.00]. ES = 0.29, $p = 0.013$), REH (46.1 ± 9.5 kg, [0.93, 4.16], ES = 0.26, $p = 0.004$), and AD (47.1 ± 9.7 kg [−0.01, 3.19], ES = 0.16, $p = 0.05$) in left handgrip strength. No differences were found in BESS with double leg stance on the floor ($p > 0.05$), single leg stance on the floor ($p = 0.614$), tandem stance on the floor ($p = 0.282$), double leg stance on a foam pad ($p = 0.215$), and tandem stance on a foam pad ($p = 0.118$). However, in the single leg stance on a foam pad, more BESS errors were found at THIRST (6 ± 2) compared to EUH (5 ± 2 [0.32, 1.79], ES = 0.5, $p = 0.007$) and AD (5 ± 2 [0.50, 1.83], ES = 0.5, $p = 0.002$).

4. Discussion

The main findings of this study (Fig. 2) were: ~2% BML induced by a 24-h fluid restriction (Fig. 1) decreased lower body power performance measured by CMJ; 30-min acute rehydration did not

Table 1
Percent body mass loss (BML), plasma osmolality (mOsmol), urine specific gravity (USG) and urine color from first morning urine samples, and USG, urine osmolality (mOsmol), and urine color from 24-h urine at day 2 morning (EUH), day 2 when feeling thirsty (THIRST), day 3 morning (DEH), day 3 morning after rehydration (REH), and day 4 morning (AD).

	BML (%)	Plasma osmolality ($mOsmol \cdot kg^{-1}$)	First morning USG	First morning urine color	24-h USG	24-h urine osmolality ($mOsmol \cdot kg^{-1}$)	24-h urine color
EUH	0 ± 0*	$294 \pm 6^{+}$	1.018 ± 0.007	4 ± 1*	1.017 ± 0.007*	583 ± 267*	4 ± 1
THIRST	$0.87 \pm 0.70^{*\&}$	$297 \pm 4^{+}$	$1.023 \pm 0.004^{\&}$	$5 \pm 1^{*+}$	NA	NA	NA
DEH	1.99 ± 0.60	$297 \pm 5^{+}$	$1.030 \pm 0.003^{\&\#}$	6 ± 1	1.025 ± 0.005	901 ± 175	5 ± 1
REH	$0.53 \pm 0.77^{*\&}$	$294 \pm 4^{*\#}$	$1.029 \pm 0.003^{\&\#*+}$	$6 \pm 1^{*\&+\#}$	NA	NA	NA
AD	$0.45 \pm 0.63^{*\&}$	$292 \pm 5^{*\#}$	1.021 ± 0.008	4 ± 1*	1.017 ± 0.007*	613 ± 271*	3 ± 1

* indicates differences from DEH, $p \leq 0.05$.
& differences from EUH, $p \leq 0.05$.
#differences from THIRST, $p \leq 0.05$.
+differences from AD, $p \leq 0.05$.

Table 2
Right and left handgrip strength, and Balance Error Scoring System (BESS) results of each stance and surface at day 2 morning (EUH), day 2 when feeling thirsty (THIRST), day 3 morning (DEH), day 3 morning after rehydration (REH), and day 4 morning (AD). * indicates differences from THIRST, $p \leq 0.05$.

———	Right Handgrip (kg)	Left Handgrip (kg)	Balance Error Scoring System					
			Floor Double	Floor Single	Floor Tandem	Foam Double	Foam Single	Foam Tandem
EUH	49.9 ± 9.7	46.7 ± 10.1*	0 ± 0	2 ± 2	1 ± 1	0 ± 0	5 ± 2*	3 ± 2
THIRST	51.1 ± 10.6	48.6 ± 9.5	0 ± 0	2 ± 2	1 ± 1	0 ± 0	6 ± 2	3 ± 2
DEH	48.4 ± 9.6	45.8 ± 10.0*	0 ± 0	2 ± 3	1 ± 2	0 ± 1	5 ± 2	3 ± 2
REH	49.5 ± 10.4	46.1 ± 9.5*	0 ± 0	2 ± 2	0 ± 1	0 ± 0	5 ± 2	2 ± 2
AD	50.6 ± 9.5	47.1 ± 9.7*	0 ± 0	1 ± 2	0 ± 1	0 ± 0	5 ± 2*	3 ± 2

remedy the effects of a 24-h water restriction period, a ~0.5–0.9% BML did not decrease lower body power performance, and handgrip strength was higher and balance was lowered at the onset of thirst (THIRST).

In the current study, ~2% BML as a result of a 24-h fluid restriction decreased CMJ performance. Previous dehydration studies reported disparate findings regarding the effects of dehydration on jump performance.[3,5,7,16,17] These conflicting findings could be due to multiple factors, including the level of dehydration (static vertical jump vs CMJ), methods that induced dehydration, and subject characteristics/capabilities/skills. For example, Judelson et al. demonstrated that 2.4% and 4.8% of dehydration, induced by exercise heat stress, did not impact vertical jump height in resistance-trained males.[16] However, participants in this previous study were trained individuals, and the effects of hydration might be different between trained individuals and individuals in free-living situations as in the current study. [3,16]The current study induced dehydration without exercise, heat exposure, or diuretic substances, which is the normal case where dehydration occurs before sport/physical activity. Therefore, as this study shows, dehydration occurring in daily living can decrease lower body power, which negatively impacts exercise performance such as sprinting or jumping.[13]

Acute rehydration (30 minutes of ad libitum consumption) on day 3 did not compensate for the decrement in CMJ performance induced by a 24-h fluid restriction while ad libitum drinking throughout the day reversed this performance impairment. It is widely recommended to start physical activities in a euhydrated state, and when an individual is hypohydrated, the fluid should be consumed before the beginning of the exercise.[18] However, the current study reveals that an acute rehydration period did not restore lower body power performance even though hydration status was recovered, evidenced by lower BML and plasma osmolality. These results emphasize the importance of adequate fluid intake in daily living and maintaining euhydration status.

While there are conflicting results related to the effects of hypohydration on power performance, one suggestive mechanism involves a diminished ability of the central nervous system to recruit motor units.[9] A few studies indicate the loss of body water impacts the neuromuscular system.[19,20] Further studies are required, but this negative neuromuscular effect is not recovered immediately after fluid intake.[19,20]

Handgrip strength was greater at THIRST compared to other time points (Fig. 1). This could be because all other time points but THIRST were performed in the morning, and THIRST was during the daytime when subjects initially sensed thirst. No differences were observed between any morning measurements even though a wide range of dehydration levels were achieved. Previous studies indicate that short-duration maximal exercise performance peaks in the afternoon.[21] Therefore, this result could be independent of hydration status, and the time effect might lead to differences. In addition to the time effect, methods to induce hypohydration might contribute to findings. Previous studies demonstrate that 1.8% of dehydration, induced by exercise, decreased handgrip strength.[6] Therefore, dehydration induced by exercise might decrease handgrip strength, while dehydration achieved by fluid restriction in the free-living situation might not.

When thirst was initially sensed (~0.9% dehydration), balance performance was inferior to that measured at a 2% dehydration level. It is known that the time effect is minimal on balance performance.[22] Thus, further study will be required to examine the effect of the onset of thirst on balance performance. Unlike the result of the current study, the previous study shows 2.6% dehydration, induced by exercise heat exposure, and decreased BESS performance. When comparing the results of the previous study and the current study, dehydration induced via fluid restriction in free-living individuals may not negatively impact balance performance to the extent that dehydration occurring as a result of exercise heat exposure does.

This study's limitation includes different levels of dehydration that were induced in the same order for all subjects due to the nature of the study design and research questions. However, to minimize the learning effect of performance testing, familiarization of testing was performed before the first day of testing. Additionally, only male subjects were recruited, and female subjects would need to be tested in the future.

5. Conclusion

In conclusion, mild dehydration (2%) induced by water restriction impaired lower body power performance, but 30-min acute rehydration did not reverse this performance decrement while ad libitum drinking throughout the day reversed this performance impairment. This study emphasizes the importance of maintaining a euhydration state, not only right before the beginning of the exercise. Future study is required to identify optimal rehydration timing that improves a lower body power performance decrement resulting from hypohydration.

Author contribution statement

YS and ECL contributed to all aspects of study, including designing this research. ECL and LEA are the PI. All other authors contributed to data collection and manuscript.

Declaration of competing interest

Authors have no conflict of interests.

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