Relationships Between WUT (Body Weight, Urine Color, and Thirst Level) Criteria and Urine Indices of Hydration Status

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Background: A Venn diagram consisting of percentage body mass loss, urine color, and thirst perception (weight, urine, thirst [WUT]) has been suggested as a practical method to assess hydration status. However, no study to date has examined relationships between WUT and urine hydration indices. Thus, the purpose of this study was to investigate relationships between urine specific gravity, urine osmolality, and the WUT criteria.

Hypothesis: Urine specific gravity and urine osmolality indicate hypohydration when the WUT criteria demonstrate hypohydration (≥2 markers).

Study Design: Laboratory cohort study.

Level of Evidence: Level 3.

Methods: A total of 22 women (mean ± SD; age, 20 ± 1 years; mass, 65.4 ± 12.6 kg) and 21 men (age, 21 ± 1 years; body mass, 78.7 ± 14.6 kg) participated in this study. First morning body mass, urine color, urine specific gravity, urine osmolality, and thirst level were collected for 10 consecutive days in a free-living situation. Body mass loss >1%, urine color >5, and thirst level ≥5 were used as the dehydration thresholds. The number of markers that indicated dehydration levels were counted and categorized into either 3, 2, 1, or 0 WUT markers that indicated dehydration. One-way analysis of variance with Tukey pairwise comparisons was used to assess the differences in urine specific gravity and urine osmolality between the different number of WUT markers.

Results: Urine specific gravity in 3 WUT markers (mean ± SD [effect size], 1.021 ± 0.007 [0.57]; $P = 0.025$) and 2 WUT markers (1.019 ± 0.010 [0.31]; $P = 0.026$) was significantly higher than 1 WUT marker (1.016 ± 0.009). Urine mosmolality in 2 WUT markers (705 ± 253 mOsmol [0.43]; $P = 0.018$) was significantly higher than 1 WUT (597 ± 253 mOsmol). Meeting at 3 WUT resulted in specificity of 0.956 and at 0 WUT resulted in sensitivity of 0.937 for urine osmolality>700mOsm.

Conclusion: These results suggest that when 3 WUT markers are met, urine specific gravity and urine osmolality indicated hypohydration and 0 WUT represents a high likelihood of euhydration. 1 and 2 WUT values are indeterminate of hydration status. The WUT criterion is a useful tool to use in field settings to assess hydration status when first morning urine sample was used.

Clinical Relevance: Athletes, coaches, sports scientists, and medical professionals can use WUT criteria to monitor dehydration with reduced cost and time.

Keywords: dehydration; Venn diagram; practical method; field settings

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Dehydration is known to impair health, quality of daily life, and exercise performance.[1,26] Greater than 1.5% to 2% of body mass (BM) loss (BML) decreases aerobic exercise performance and 3% to 4% of BML leads to lower muscular strength and power.[9,18,26] Additionally, progressive 2-4% of BML decreases sports-specific cognitive, motor, and skill execution performance.[8] In addition to the effects of hydration on exercise performance, dehydration increases the likelihood of development of heat illness, including heat exhaustion, exercise-associated muscle cramps, and exertional heat stroke.[7] Therefore, it is important to assess hydration status to optimize exercise performance and safety.

While several methods are utilized to assess fluid balance, there is no gold standard to assess hydration status.[19] Methods to determine fluid balance include plasma osmolality and volume, urine specific gravity (USG), urine color (U_{COL}), urine osmolality (U_{OSM}), BM indices, and thirst level.[3,19] While plasma osmolality with total body water assessment is considered the most precise measure of hydration status, it is not practical for most settings because it must be obtained from a blood sample and requires expensive instruments to analyze.[26] Urinary indices, such as USG, U_{COL}, and U_{OSM} are the most widely used methods to assess hydration status and provide an accurate assessment of hydration during mild dehydration.[19] However, urine indices can be altered independent of hydration status during rapid fluid intake.[13] First morning urine sample is not valid when assessing hydration status of 24 hours; however, it is useful as a spot hydration assessment.[4] BML is also commonly used to track acute changes in hydration status with or without exercise, as well as over several hours.[4,19] Previous research suggests that BM measurements from 3 consecutive mornings provides an accurate baseline BM, which can then be used to track daily BM changes as an indication of hydration.[10] Furthermore, daily BM fluctuation is less than 1% when replacing 100% of sweat losses from a previous day of exercise.[10] However, when using BM change over several hours, it is important to consider that BM can be altered by other factors, such as bowel movement and food or fluid consumption.[19] Thus, considering advantages and disadvantages of each method to assess hydration status, using urine indices along with BM indices can provide useful information in practical and time-efficient ways.[26]

Cheuvront and Kenefick[11] suggested the use of 3 intersecting variables (%BML, U_{COL}, and thirst perception) comprising a Venn diagram decision tool (weight, urine, thirst [WUT]) to measure hydration status and fluid needs. This mathematical model is widely used in field settings because of high method practicality. First morning BM, U_{COL}, and thirst level should be measured to use the WUT criteria accurately. When hypohydration is detected by 2 WUT markers, fluid intake is categorized as "*likely* inadequate," and when hypohydration is detected by 3 WUT markers, fluid intake is categorized as "*very likely* inadequate."[11] However, the relationship between the WUT criteria and likelihood of real defects in hydration status has not been validated with urinary hydration biomarkers, which are known to detect hydration state.[4] Thus, the purpose of this study was to investigate the relationship between hypohydration defined by USG or U_{OSM} and resulting diagnosis by the WUT criteria.

METHODS

A total of 22 women (mean [M] ± SD; age, 20 ± 1 years; BM, 65.4 ± 12.6 kg) and 21 men (M ± SD; age, 21 ± 1 years; BM, 78.7 ± 14.6 kg) participated in this study. After an explanation of the study procedures, which was approved by the institutional review board at the University of Connecticut, participants provided written and informed consent to participate.

First morning BM, U_{COL}, USG, U_{OSM}, and thirst level were collected for 10 consecutive days. The first 3 days was a euhydrated baseline period. Participants were recommended to consume additional fluid, such as 500 mL of water, before going to bed to be euhydrated the next day. Also, participants were instructed to arrive to the laboratory before consuming any food and fluid. On arrival to the laboratory, participants provided urine samples to check USG using a handheld refractometer (Model TS400; Reichert Inc). To assess a euhydrated baseline BM (Defender R7000 Xtreme; OHAUS Corp), BM on the first 3 consecutive days was measured when USG was less than 1.020.[26] If USG was ≥1.020, the baseline was repeated for another 3 days until consecutive euhydration was achieved. Then, participants reported their thirst level on a Likert-type scale of 1 to 9, with 1 being "not thirsty at all" and 9 being "very, very thirsty."[12] All measurements were collected at the laboratory for the first 3 days during the baseline period. U_{COL} was assessed by a validated U_{COL} chart[6] and U_{OSM} was assessed with an osmometer (Osmo Pro; Advance Instruments). Five samples of U_{OSM} were missed because of technical issues.

After the 3-day euhydrated baseline period, participants were instructed to perform normal free-living fluid consumption. During the remaining 7 days, participants collected first morning urine sample followed by BM (BalanceFrom LLC) and thirst-level measurements with provided scales at home. Then, participants brought urine samples to the laboratory between 8 AM and 12 PM, depending on their schedules each day, and researchers analyzed U_{COL}, USG, and U_{OSM}.

Percentage BML for each day for each participant was calculated based on the average of the first 3 euhydrated BM measurements: ([BM of each day − Baseline-BM] × Baseline BM^{-1} × 100). Hypohydration level was set as >1% BML and if this criterion was met, it counted as "1" in the WUT criteria.[11] A U_{COL} >5 was chosen to indicate hypohydration and was counted as "1e" in the WUT criteria.[11] A thirst level ≥5 indicated hypohydration and was counted as "1" in the WUT criteria.[11] The number of markers that indicated hypohydration levels were counted. When 2 markers indicated hypohydration levels, hydration status was termed *likely dehydrated*, and when 3 markers indicated hypohydration levels, hydration status was termed *very likely dehydrated*.[11] When 0 or 1 maker indicated a hypohydration level, hydration status was termed *euhydrated*.[11] USG <1.020 and U_{OSM} <700 mOsmol indicate euhydration based on the American College of Sports Medicine (ACSM) standards.[26]

All statistical analyses were performed using SPSS Statistics software (Version 25; IBM Corporation). Data are reported as M ± SD. One-way ANOVA with Tukey pairwise comparisons were used to assess the differences in USG, UOSM, %BML, UCOL, and thirst level between the different number of WUT markers that indicated hypohydration as each urine sample was treated individual samples. Effect sizes (ESs) were calculated using Hedges *g* with the resulting effects identified as small (0.2-0.49), medium (0.5-0.79), or large (>0.8).[20] The 95% CIs were also calculated. Receiver operating characteristics (ROC) analysis was performed to calculate the predictive value of 0, 1, 2, or 3 hydration markers (ie, sensitivity and specificity) in detecting a hypohydrated or euhydrated state (defined by either USG or U_{OSM}). Positive and negative predictive values provide additional context for the likelihood that 0, 1, 2, or 3 hydration markers are able to predict hydration state (dehydrated versus euhdyrated) according to USG and U_{OSM}. Significance was set at $P \leq 0.05$.

RESULTS

Accurately Detecting Hypohydration Defined by USG and U_{OSM} Requires Meeting at Least 2 WUT Criteria

USG and U_{OSM} were used to define hydration state as euhydrated or hypohydrated. Defining participants as hypohydrated (*likely dehydrated or very likely dehydrated*) using at least 2 WUT criteria was required to significantly indicate (Table 1) USG >1.020 and U_{OSM} >700 mOsm. The value of diagnosing participants as hypohydrated using 3 WUT criteria was significantly greater than using 1 WUT criterion in the USG-defined hypohydrated group (USG >1.020) but it was not in the U_{OSM} group (U_{OSM} >700 mOsm).

USG and U_{OSM} of participants defined as *not dehydrated*, *likely dehydrated*, or *very likely dehydrated* by WUT criteria are presented in Table 1. Increasing the number of WUT criteria markers used to include participants as diagnosed as *likely or very likely dehydrated* increases both mean USG and U_{OSM} values. Diagnosis of participants as *very likely dehydrated* (3 WUT criteria met) results in USG values corroborating ACSM-recommended hypohydration threshold of USG >1.020 while diagnosis of participants as either *likely or very likely dehydrated* (2 or 3 WUT criteria met) coincides with ACSM recommended hypohydration threshold of U_{OSM} >700 mOsm.

Table 2 presents sensitivity, specificity, positive predictive value, and negative predictive value of 0, 1, 2, or 3 WUT criteria to define hypohydration level of USG >1.020 or U_{OSM} >700 mOsm. Using USG and U_{OSM} to define hypohydrated participants, 91 (USG >1.020) out of 229 samples and 89 (U_{OSM} >700 mOsm) out of 224 samples indicated hypohydration, respectively. Table 2 presents cases identified as *dehydrated* by WUT criteria and of those participants, which satisfied either USG >1.020 or U_{OSM} >700 mOsm. Satisfying 3 WUT criteria resulted in 13 samples diagnosed as *very likely dehydrated*, of which 8 met the USG>1.020 threshold. This resulted in a sensitivity of 0.088 and 0.079, and specificity of 0.964 and 0.956 for USG and UOSM, respectively. These specificity values indicated this test was good at detecting hypohydration when 3 factors are positive. Satisfying 2 WUT criteria diagnosed 106 participants as *likely dehydrated*, and of those, 52 had USG >1.020. In the case of 0 or 1 WUT criteria met, the diagnosis was *euhydrated*. If only 1 WUT criterion was satisfied, 87 participants were defined as *euhydrated* (ie, not *likely dehydrated* or *very likely dehydrated*), and of those, 25 did exhibit USG >1.020 and would have been characterized by USG threshold as hypohydrated. Satisfying 0 WUT criteria, sensitivities were 0.938 and 0.937 for USG and UOSM, respectively, which indicated this test was good at detecting euhydration.

WUT Decision Tool Has Better Probability of Identifying Euhydrated Participants Based on Predictive Value Calculations in the Current Data Set

Including the prevalence of hypohydrated cases as context, we calculated positive predictive values and negative predictive values. Positive predictive value increased as more the number of WUT (0, 1, 2, or 3) was greater. (Table 2) for USG>1.020 and for UOSM>700mOsm. Negative predictive values for both USG and UOSM were greater than positive predictive values supporting the accuracy of WUT decision tool in identifying euhydrated subjects (negative condition) when WUT criteria indicated 0 or 1. This result is likely influenced by the results from identifying participants as *euhydrated* in the case of 1 or 0 WUT criteria met, as in both of these cases, large numbers of participants were identified as euhydrated (or not hypohydrated) and, of those, USG and U_{OSM} cut-points of 1.020 and 700 mOsm, respectively, coincided with the majority of participants (eg, 62 of 87 and 17 of 23 in 1 and 0 WUT criteria cases for USG measurement; Table 2).

Discrepancies Between Dehydration Identification Using WUT Decision Tool and Other Biomarkers May Be Related to Thirst Component of WUT Criteria

Figure 1 illustrates the relationship between WUT criteria defining *likely dehydrated* participants and corresponding mean USG and U_{OSM} for precise combinations of 2 markers. When 2 markers were %BML and U_{COL} (M ± SD: USG, 1.023 ± 0.005; U_{OSM}, 879 ± 188 mOsmol) or thirst level and U_{COL} (USG, 1.021 ± 0.005; U_{OSM}, 778 ± 234 mOsmol), USG and U_{OSM} were higher than ACSM cut-points for the hypohydration threshold (USG >1.020; U_{OSM} >700 mOsm). However, when %BML and thirst level (USG, 1.010 ± 423; U_{OSM}, 423 ± 212 mOsmol) were the 2 WUT criteria to define *likely dehydrated*, USG and U_{OSM} of those participants did not meet ACSM thresholds. Additionally, both USG and U_{OSM} were significantly lower when %BML and thirst level were used for 2 WUT than when %BML and U_{COL} (ES; USG, [2.26], $P < 0.001$; U_{OSM}, [2.22], $P < 0.001$) or thirst level and U_{COL} (USG, [2.08], $P < 0.001$; U_{OSM}, [1.55], $P < 0.001$) were used.

Table 1. Urine specific gravity and urine osmolality when WUT criteria were used to make a decision regarding hydration state[a]

No. of WUT Markers	M ± SD	Comparisons of WUT Markers			ES	95% CI	*P*
Urine specific gravity							
0	1.014 ± 0.005	0	vs	1	0.24	–0.006 to 0.002	0.515
				2	0.54	–0.009 to –0.001	0.009
				3	1.21	–0.002 to –0.002	0.005
1	1.016 ± 0.009	1	vs	2	0.31	–0.005 to –0.0002	0.026
				3	0.57	–0.010 to –0.001	0.025
2	**1.019 ± 0.010**	2	vs	3	0.21	–0.008 to 0.002	0.448
3	**1.021 ± 0.007**						
Urine osmolality, mOsmol							
0	509 ± 249	0	vs	1	0.35	–240 to –63	0.434
				2	0.78	–346 to –47	0.004
				3	1.01	–477 to –28	0.020
1	597 ± 253	1	vs	2	0.43	–203 to –13	0.018
				3	0.65	–356 to 28	0.125
2	**705 ± 253**	2	vs	3	0.22	–246 to 134	0.871
3	**761 ± 250**						

ES, effect size; WUT, weight, urine, and thirst.

[a]Gray-shaded area indicates mean and SD of urine specific gravity and urine osmolality. Gray-shaded area, boldfaced text, indicates diagnosis as *likely dehydrated* or *very likely dehydrated*. Unshaded area include comparisons of different number of WUT criteria (eg, 0 vs 1 WUT criterion) in urine specific gravity and urine osmolality with ES, and 95% CIs. Blue-shaded area highlights significant differences ($P \leq 0.05$).

Hydration biomarker values based on the WUT criteria are presented in Table 3. The %BML with 3 WUT criteria (M ± SD, 2.8% ± 1.5%) was significantly higher compared with 0 WUT criteria (M ± SD [ES], –0.3% ± 0.8% [2.81]; $P < 0.001$), 1 WUT criterion (0.1% ± 0.8% [2.99]; $P < 0.001$), and 2 WUT criteria (0.7% ± 1.2% [0.74]; $P < 0.001$). Additionally, 2 WUT criteria were significantly higher than 0 WUT criteria (ES, 0.85; $P < 0.001$) and 1 WUT criterion (0.53, $P = 0.002$). However, no difference was found between 0 WUT and 1 WUT criterion (0.55; $P = 0.298$).

U_{COL} when considering 3 WUT criteria (7 ± 1) was significantly higher than 0 WUT criteria (3 ± 1 [3.2]; $P < 0.001$), 1 WUT criterion (4 ± 2 [1.76]; $P < 0.001$), and 2 WUT criteria (5 ± 1.8 [0.66]; $P = 0.08$). Additionally, 2 WUT criteria was higher than 0 WUT criteria (ES, 1.28; $P < 0.001$) and 1 WUT criteria (ES, 0.84; $P < 0.001$). However, no difference was found between 0 and 1 WUT criteria (ES, 0.53; $P = 0.17$).

Thirst level when considering 3 WUT criteria (5.4 ± 0.7) was significantly higher than 0 WUT criteria (3.8 ± 0.5 [2.8]) ($P = 0.002$); however, it was not different from 1 WUT criterion (5.5 ± 1.5 [0.12]; $P = 0.971$) and 2 WUT criteria (5.8 ± 1.2 [0.34]; $P = 0.71$). Additionally, there was a difference between 0 WUT criteria (ES, 1.8; $P < 0.001$) and 2 WUT criteria while there was no difference between 1 and 2 WUT criteria (ES, 0.17; $P = 0.592$). Thirst level considering 1 WUT criterion was higher than 0 WUT criteria (ES, 1.3; $P < 0.001$).

DISCUSSION

The current study has the following findings: 1) meeting at 3 WUT criteria for defining *very likely dehydrated* significantly indicates hypohydrated state defined by USG (>1.020) or UOSM (>700 mOsm), 2) meeting at 0 WUT criteria indicates euhydrated state, 3) calculation of positive and negative values interpretation of WUT criteria fulfillment as *likely* or *very likely dehydrated* and indicates potential impact in high prevalence (e.g., many dehydrated individuals) field settings, and 4) WUT criterion based on thirst contributes to gaps in accuracy in detecting hypohydration among subjects.

Table 2. Sensitivity, specificity, cutoff determination value (* indicates sensitivity > cutoff determination value, which indicates differentiating hypohydrated vs. euhydrated subjects), positive and negative predictive value, number of total diagnosed using respective WUT criteria, and distribution of subjects based on urine specific gravity (USG)>1.020 and urine osmolality >700 mOsmol. Gray shaded area indicates subjects defined as *likely* or *very dehydrated* (bold-faced text) or *euhydrated* for matching with number of WUT criteria (3, 2, 1, 0) met

Urine specific gravity								
# of WUT markers	Sensitivity	Specificity	Cutoff determination value	Positive predictive value	Negative predictive value	# of total diagnosed using WUT criteria	Distribution of subjects based on USG>1.020 threshold	
							Hypohydration	Euhydration
3	0.088	0.964	0.833	61.5%	38.5%	**13**	8	5
2	0.659	0.572	0.299*	49.1%	50.9%	**106**	52	54
1	0.340	0.428	0.763	28.7%	71.3%	87	25	62
0	0.938	0.123	0.773*	26.1%	73.9%	23	6	17
Total						229	91	138

Urine osmolality (mOsmol)								
# of WUT markers	Sensitivity	Specificity	Cutoff determination value	Positive predictive value	Negative predictive value	# of total diagnosed using WUT criteria	Distribution of subjects based on urine osmolality >700 mOsmol threshold	
							Hypohydration	Euhydration
3	0.079	0.956	0.850	53.8%	46.2%	**13**	7	6
2	0.652	0.570	0.306*	49.5%	50.5%	**103**	51	52
1	0.348	0.430	0.750	29.4%	70.6%	85	25	60
0	0.937	0.126	0.768*	26.1%	73.9%	23	6	17
Total						224	89	135

Meeting 2 WUT criteria to categorize participants as *likely dehydrated* was statistically better than meeting only 1 WUT criterion when USG or U_{OSM} was used to diagnose participants (euhydrated vs hypohydrated) outside of the WUT decision tool. Meeting only 1 WUT criterion was not comparatively better than meeting 0 WUT criteria ($P > 0.05$). There was a difference between those participants identified as *likely dehydrated* or *very likely dehydrated* on their mean USG versus U_{OSM}; when the WUT criteria indicated *very likely dehydrated*, USG was higher than the ACSM recommended cut-point (1.020) for diagnosing someone as hypohydrated.[26] However, when WUT criteria indicated *likely dehydrated* or *very likely dehydrated*, U_{OSM} met the ACSM recommended cut-point (700 mOsmol). When we probed the combinations of 2 WUT criteria that were satisfied to diagnose participants as *likely dehydrated* (Figure 1), it was evident that the combination of meeting thirst and %BML WUT criteria resulted in lower mean USG (1.010) that likely contributed to the dissociation between participants USGs meeting ACSM standards versus being diagnosed by WUT criteria as *likely dehydrated*. The complicated nature of diagnosis including thirst is further demonstrated by the analysis that indicates that there is no significant difference in how thirsty participants are with 1, 2, or 3 WUT criteria met (Table 3). Although during ultraendurance cycling, for example, USG has been correlated with thirst as participants dehydrate,[21] even in this context the correlation coefficient is based on combined thirst and USG data over the course of an event, including all time points, but was not significantly correlated at the most hypohydrated time point (postride). This indicates a complex nature of relationship between USG and thirst that is demonstrated elsewhere. For example, an athlete hydration spot check of over 300 samples found that U_{OSM} is correlated with

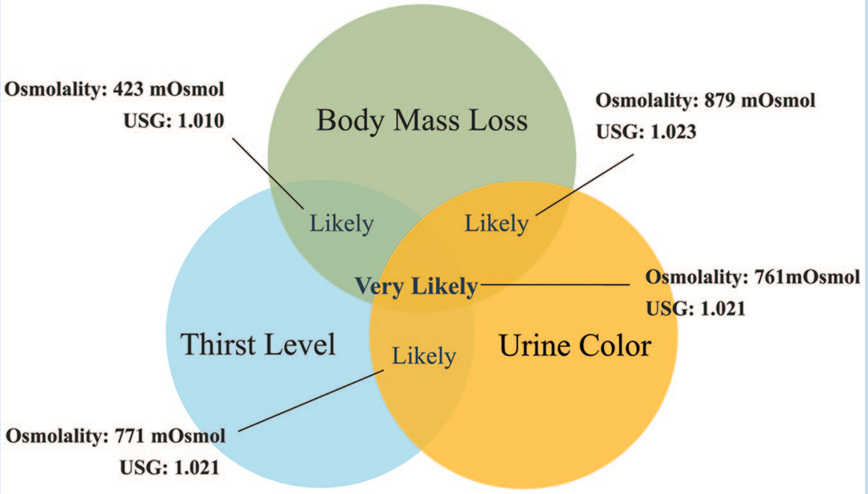

Figure 1. The water, urine, and thirst (WUT) criteria and hydration status. The WUT criteria, which consist of %body mass loss >1%, a urine color >5, and a thirst level ≥5 on a Likert-type scale of 1 to 9, can be used to assess hydration status. Urine osmolality and urine specific gravity (USG) were indicated when body mass loss and thirst level, body mass loss and urine color, and urine color and thirst level were 2 markers.

thirst among dehydrated participants and despite that U_{OSM} and USG were correlated with each other, USG and thirst were not correlated.[17] The contributions of thirst when considering only 2 WUT criteria is limited when using urine hydration markers to define a hypohydrated participant. Our data demonstrate what has been shown already in different ways, but does confirm that satisfying 3 WUT criteria is consistent with identifying hypohydrated participants using USG or U_{OSM}. Specificities were greater than 95% to demonstrate USG >1.020 and UOSM >700 mOsmol (USG, 0.964; UOSM, 0.956) when 3 WUT criteria indicating hypohydration levels. Additionally, WUT criteria identified euhydration as explained by high sensitivities, 0.938 and 0.937 for USG and UOSM, respectively. However, both sensitivities and specificities were not high with 0 and 1 WUT criteria, which indicated they were not good to detect either hypohydration nor euhydration.

In our study, using USG and U_{OSM} as external variables to define participants as *dehydrated*, or not to evaluate efficacy of the WUT criteria decision tool, did not yield similar results. This is explained by the physiological difference between USG and U_{OSM} regarding solute influences on these 2 variables. Dehydration increases plasma osmolality and sodium concentration, which increase circulating arginine vasopressin (AVP).[19] AVP increases result in decreased urine output, leading to higher U_{OSM} and USG.[19,24,25] USG and U_{OSM} are normally linearly correlated; however, if there are many high molecular–weight molecules in the urine, USG overestimates the urine solute while U_{OSM} remains accurate.[28] U_{OSM} arguably provides the best accuracy of the kidney's concentrating ability and this may be reflected in our results.[4]

Our results demonstrated that thirst as a WUT criterion contributes to variability in accuracy of detecting hypohydrated participants. Complicating relationships between whole-body dehydration and thirst likely contribute to the variability among our results on the consistency of thirst as a hydration status indicator. Individuals may experience 1% to 2% BML before feeling sensations of thirst.[4] Also, independent of hydration status, tiny amounts of water ingestion can diminish the thirst level.[13] We observed similar thirst levels no matter the number of WUT criteria satisfied among our participants. Even though previous research shows that first morning thirst predicts hypohydrated state,[5] our findings suggest otherwise. Because thirst, even at first morning assessment, is affected by many extraneous variables,[14,15] our findings confirm the understanding that thirst cannot be a sole indicator of hydration state.[12] In fact, no single measurement or gold standard to assess hydration status exists because of the highly contextualized nature of every currently used hydration biomarker or indicator. Our findings support further exploration of decision tools, including multiple variables such as the WUT criteria, particularly with regard to the thirst variable.

Positive predictive values for detecting hypohydration (by USG and UOSM) increased as with zero (26.1 and 26.1%) one (28.7 and 29.4%), two (49.1 and 49.5%), or three (61.5 and 53.8 %). Negative predictive values increased as less markers were included; this indicates better probability of accuracy (70%> with 1 and 0) in detecting true euhydration. In other words, meeting criteria for classification as *euehydrated* with less markers indicated better true negative (detecting euhydration). Using USG and UOSM as the external classifying variable to validate WUT criteria diagnoses on, decreased false negative rates as less markers were satisfied, which means there was less chance to detect euhydration incorrectly. Positive and negative predictive values were calculated using sensitivity, specificity, and prevalence data. Therefore, it is important to consider

Table 3. Percentage body mass loss, thirst level, and urine color when WUT criteria were used to make a decision regarding hydration state[a]

No. of WUT Markers	M ± SD	Comparisons of WUT Markers			ES	95% CI	*P*
Percentage body mass loss							
0	−0.27 ± 0.78	0	vs	1	0.55	−1.04 to 0.20	0.298
				2	0.85	−0.16 to −0.34	0.001
				3	2.81	−3.96 to −2.14	0.001
1	0.14 ± 0.77	1	vs	2	0.53	−0.91 to −0.15	0.002
				3	2.99	−3.41 to 1.85	0.001
2	**0.68 ± 1.17**	2	vs	3	1.74	−2.87 to 1.33	0.001
3	**2.78 ± 1.50**						
Thirst level							
0	3.8 ± 0.5	0	vs	1	1.3	−2.5 to −1.0	0.001
				2	1.8	−2.7 to −1.2	0.001
				3	2.83	−2.7 to −0.5	0.002
1	5.5 ± 1.5	1	vs	2	0.17	−0.7 to 0.2	0.592
				3	0.12	−0.8 to 1.1	0.971
2	**5.8 ± 1.2**	2	vs	3	0.34	−0.5 to 1.3	0.710
3	**5.4 ± 0.7**						
Urine color							
0	3 ± 1	0	vs	1	0.53	−2.5 to −1.0	0.170
				2	1.28	−2.7 to −1.2	0.001
				3	3.20	−2.7 to −0.5	0.002
1	4 ± 2	1	vs	2	0.84	−0.7 to 0.2	0.001
				3	1.76	−0.8 to 1.1	0.001
2	**5 ± 2**	2	vs	3	0.66	−0.5 to 1.3	0.080
3	**7 ± 1**						

ES, effect size; WUT, weight, urine, and thirst.
[a]Gray-shaded area indicates mean and SD of percentage body mass loss, thirst level, and urine color when 0, 1, 2, or 3 WUT criteria were used to make a decision regarding hydration state (gray-shaded area, boldfaced text, indicates diagnosis as *likely* or *very likely dehydrated*). Unshaded area includes comparison of different number of WUT criteria (eg, 0 vs 1 WUT criterion) in percentage body mass loss, thirst level, and urine color with effect size, 95% CIs, and *P* value demonstrated in white area of the table. Blue-shaded area indicates $P \le 0.05$.

context in discussing the accuracy of markers to detect hypohydration. The positive and negative predictive values are used readily in clinical diagnostic test validation and rely on prevalence data to determine the rate of false positives and negatives, and this may be relevant and impactful in practical application. One application that this is relevant to is in the case in which the WUT criteria or similar multimarker criteria decision tools may be effectively used to maximize the accurate identification of at least *likely dehydrated* individuals in a large group of individuals experiencing a situation (eg, exercise, hot and humid environment, low availability of fluid rehydration) in which hypohydration prevalence is likely to be high. This would be, for example, a case of field study with large numbers of athletes in which invasive hydration biomarkers cannot be readily assessed. This supports the practical applicability of our findings to large field, occupational, sport, or military settings.

The WUT is a practical and time-efficient method. Monitoring BM is a simple, noninvasive, and valid method to assess hydration status.[22] Additionally, U_{COL} assessment requires only a U_{COL} chart and is an inexpensive method.[6] Also, with appropriate education and training, self-monitoring by athletes is easily achievable.[22] This is also applicable to monitoring thirst level, which requires only the thirst scale. However, measuring osmolality needs a trained technician and an expensive osmometer, and it is time-consuming and difficult to get feedback in real time.[4] USG is measured with a refractometer, which is a relatively easy and inexpensive method. However, if there are a large number of athletes on a team, time may become a restrictive factor. While urine volume is often used to assess hydration status, this quantitative measurement method requires good athlete compliance and it is not practical to complete a daily measurement.[22] The WUT is recommended to use with first morning measurements.[11] One of the reasons for this is that urine indices can be altered independent of hydration status during rapid fluid intake,[13] and BM can be altered by other factors, such as bowel movement and food or fluid consumption.[19] Thus, results of this study can be applicable to only first morning measurements.

Limitations are present in this study in that we used USG and U_{OSM} to test a tool that includes a urine compartment biomarker (U_{COL}). Plasma osmolality by itself does not always reflect hydration status,[3] but it is a limiting context of this study that we did not use plasma osmolality as an external validating factor of the WUT criteria. Future study including blood biomarkers of hydration status such as plasma osmolality or increasing concentrations of AVP or copeptin may be informative in further contextualizing the use of a WUT or similar multimarker decision tool. Another limitation of this study is that our results are contextualized to this specific study population (ie, college-aged, healthy adults). Variables of WUT decision tool and any external validating criteria will vary by age, sex, and many other aspects of participant groups. Future study with diverse participant groups will add to our understanding of the useful application of WUT and other similar tools. Uncontrolled aspects of a free-living study are also a limiting factor, despite our efforts to control these. The %BML might be influenced by other factors, such as bowel movement and food consumption from the previous night.[19] To reduce the risk of confounding variables, measurements were collected first in the morning. Behavior during the first 3 days of baseline may have affected the rest of the 7-day free-living phase; however, participants were clearly instructed to perform normal living after baseline days.

CONCLUSION

The WUT criteria with 3 and 0 can be used to identify hypohydration and euhdyration, respectively. However, the WUT criteria with 2 and 1 might not be good at distinguishing hydpodration and euhydration. Especially, when two markers were BML and thirst, the WUT 2 did not detect hypohydration. Thirst has been identified because of its complex physiological nature, is a variable that contributes to lack of precision in identifying level of hypohydration. Considering the trends in positive and negative predictive values, the WUT criteria–based decision tool may have greater impact among large populations with high prevalence of hypohydration, such as in our target field, athletics, military, and occupational settings in which invasive measures of hydration state are not feasible.

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