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SHORT REPORT

Effects of Fluid Intake on Sleep Duration and Quality Among Healthy Adults

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Purpose: Inadequate fluid intake disrupts body homeostasis. The aim of this study is to examine the relationship between fluid intake and sleep quality/duration among healthy adults.

Participants and Methods: This crossover study included 15 healthy adults aged 18–40 years. Participants completed an initial study visit followed by 2 four-day monitoring periods separated by a one-week washout period. The first monitoring period (P1) was used to establish a baseline hydration level. In the second monitoring period (P2), participants reduced fluid intake to induce mild dehydration. Sleep was continuously monitored during P1 and P2 using a wearable sleep sensor (Oura Ring®), while hydration status was assessed via 24-hour urine samples and urine-specific gravity measurements. Data analysis included paired sample *t*-tests, correlation, and mixed model analysis to examine relationships between variables.

Results: There were no significant differences in sleep variables between hydration protocols. In a subset of successfully dehydrated participants (n = 8), sleep length, REM length, and sleep efficiency all associated with quantity of water/fluid intake ($p < 0.05$), with a significantly strong correlation found for REM sleep length ($r = 0.800$, $p < 0.05$, $R^2 = 0.64$). In the linear mixed effects model, a significant interaction was observed between adequate hydration and water intake on REM sleep (B = 37.41, SE = 9.89, unadjusted p = 0.006, adjusted p = 0.028). Similarly, a significant effect of water intake on REM sleep in the dehydration condition was observed, however, after applying the Bonferroni correction the effect was no longer significant (B = 30.04, SE = 12.45, unadjusted p = 0.043, adjusted p = 0.22).

Conclusion: Mild dehydration does not appear to affect sleep measures in healthy adults. However, fluid intake correlates positively with REM sleep length, sleep duration, and sleep efficiency, suggesting that the quantity of water consumed may influence sleep quality. These findings highlight the potential benefits of adequate fluid intake for optimizing REM sleep, which is vital for cognitive and overall brain health.

Keywords: Oura Ring, urine specific gravity, dehydration, rapid eye movement sleep, water intake

Introduction

Humans require air, food, water, and sleep for survival. Adequate sleep supports cognitive function, alertness, and long-term health, while disturbances in sleep are linked to inflammation, metabolic disease, cardiovascular disease, diabetes, and mental health disorders.[1–3] Water constitutes about 60% of the human body and is equally essential. Hydration status profoundly influences physiological responses such as glucose regulation, cardiovascular function, oxidative stress, and cognition.[4]

The potential health implications coupled with few studies on sleep and hydration status prompted our interest in their relationship. For example, Rosinger et al, found an association between inadequate hydration and shorter sleep duration (<6 hours) among adults from the US and China,[3] as indicated by higher urine specific gravity (USG) and osmolality. However, this study did not directly quantify sleep duration, and relied on surveys to obtain data.[3] On the other hand, a 2019 study of healthy young adult males that used a highly controlled biosensor based monitoring approach (polysomnography, PSG), and urine specific gravity, concluded that mild dehydration did not significantly affect sleep quality or duration.[5] Despite the more quantitative approach, these researchers did not include baseline sleep measurements and the participants were only placed into a specific hydration state 24 hours before sleep.[6]

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The paucity of peer reviewed literature on the interaction of hydration and sleep points to a need for additional research using objective measurements. We designed a pilot study to explore the potential relationship between fluid intake and sleep parameters using new technology wearable sleep sensors (Oura Ring®). Photoplethysmography (PPG) generated sleep data, survey data, and measures of urine volume and specific gravity were used to test the hypothesis that adequate hydration leads to sufficient, high-quality sleep.

Materials and Methods

Subjects

This exploratory study design included a limited sample size of fifteen healthy adults recruited from August 2022, until November 2022. The Syracuse University Institutional Review Board approved all aspects of the study (SU-IRB# 22–101). The study complies with the Declaration of Helsinki, participants provided informed consent and were fully educated about the purpose of the study. Participants met the following inclusion criteria: (1) non-smoker, (2) 18–40 years of age, (3) free of chronic disease (ie Type 2 diabetes, heart disease, cancer), (4) not currently or previously diagnosed with a sleep disorder, (5) not currently taking medication or supplements to help with sleep (ie Ambien, melatonin), (6) not currently pregnant or breastfeeding.

Study Protocols

All study visits took place in the Nutrition Assessment, Consultation and Education (ACE) Center at Syracuse University, Syracuse, NY. Participants completed an initial study visit, followed by two sleep and hydration monitoring periods, both lasting four days with at least one week "washout" period between each. Participants returned to the lab on the fifth day after each testing period.

In the first visit, several non-invasive body measurements were taken, including height, weight, and blood pressure. Body composition and total body water were measured by bioimpedance analysis using a SECA medical Body Composition Analyzer (mBCA 514). A urine sample and a blood sample were obtained to measure urine specific gravity and hematocrit, respectively. Participants also completed a health history survey, Pittsburgh Sleep Quality Index (PSQI),[7] a caffeine FFQ,[8] a 24-hour diet recall that included alcohol and caffeine consumption and a food frequency questionnaire. In the first study protocol (P1), participants were instructed to maintain their usual sleep and fluid intake for four consecutive days. Participants completed daily questionnaires, tracked water intake (ounces) and total fluid intake (ounces), tracked sleep using the wearable sleep sensor, and collected urine over 24-hours from the fourth to the fifth day. Participants returned to the ACE center the morning of the fifth day. The 24-hour urine collected was analyzed for volume and urine specific gravity (USG) using an Atago Digital Urine Specific Gravity Refractometer. In visit two, body composition measures and a second 24-hour diet recall were repeated.

Based on the results of the initial lab visit and P1, we determined each participant's baseline fluid intake. After a one-week washout period, participants completed the final protocol (P2) following the same process and visit procedures. The target hydration state for P2 was calculated to be 5% less than baseline fluid intake to achieve a mild dehydration state. This controlled reduction in fluid intake was chosen to represent natural fluctuations in daily fluid consumption individuals may experience. This modest change was selected as a practical estimate, minimizing the risk of adverse health effects. A study that induced mild osmotic challenges found that these changes were enough to significantly impact brain volume and decrease neural cell excitability[9] highlighting the potential of mild dehydration to impact brain functioning. Fluid intake instructions for P2 were in ounces and inclusive of all fluids (eg, coffee, juices, tea, soda, water, etc).

Components of sleep duration, quality, and stages were measured with a wearable sleep sensor that uses PPG technology. Device specifications can be found in Altini & Kinnunen (2021)[10] The output has been shown to be 96% accurate as compared to the gold-standard of PSG recordings.[10] Sleep efficiency was defined as the number of minutes asleep divided by the number of minutes in bed.

Statistical Analysis

Statistical analyses were completed using R statistical software (R version 4.4.1, http://www.r-project.org). Paired samples *t*-tests were used to compare the means of USG, urine volume, and sleep variables (light, REM, deep, length, latency, efficiency) for each protocol. Pearson Correlation analysis was used to determine linear relationships between continuous variables. All sleep and hydration variables were tested for normality using the Shapiro–Wilk test. An exploratory linear mixed effects model with an interaction analysis was used to further examine whether the relationship between water intake and REM sleep length differs by hydration status for the eight participants. To correct for multiple comparisons, we applied the Bonferroni correction. A power analysis was conducted based on the observed effect size, sample size, and standard deviation, with an alpha level of 0.05, the power of the study was calculated to be 96.7%. Statistical significance was set at $p < 0.05$.

Results

Participant Demographics

Fifteen healthy adult volunteers participated in this study. Participants were mostly male and between the ages of 19–22, with an average BMI of 24.88 ± 4.46 (Table 1).

Participant Sleep Data

Most participants slept less than the recommended seven or greater hours per night (Table 2). There were no significant differences in any sleep variables between hydration protocols.

Participants Hydration Status

For the baseline measurements in P1, all subjects were considered euhydrated, with a mean 24-hour USG of 1.012 (0.003 SD) and mean 24-hour urine volume 1849.87 (741.25 SD) on the 4th day of the protocol (Table 3A). The measurement for 24-hour USG on the fourth day of P2 was 1.016 (0.007 SD) and statistically different from the baseline USG measurement ($t(14) = -2.403$, $p = 0.031$). Upon reviewing the data, only eight participants met the USG criteria (>1.020[11]) set for mild dehydration during P2 (Table 3B). Among the eight participants, P2 hydration values were statistically different from baselines for both USG ($t(7)=4.403$, $p = 0.003$) and urine volume, ($t(7) = 2.975$, $p = 0.021$).

Table 1 Participant Characteristics (N = 15)

Participant Characteristic	N = 15
Age, years, mean ± *SD*	22.7 ± 5.7
Sex, male, n (%)	10 (66.7)
Race/Ethnicity, n (%)	
Caucasian	8 (53.3)
Asian	4 (26.7)
Other~	3 (20.0)
BMI (kg/m^2), n (%)	
Normal (22–25)	10 (66.7)
Overweight (25–30)	3 (20.0)
Obese (>30)	2 (13.3)
PSQI*, mean ± *SD*	4.7 ± 1.8
Total Caffeine per day, mg^, mean ± *SD*	83.1 ± 75.9

Notes: *PSQI-Pittsburgh Sleep Quality Index (score range 0–21),[7] ^Total Caffeine per day (mg) from the caffeine specific FFQ, y=years, kg=kilograms, m=meters, relevant variables are underlined, ~Latino and/or Hispanic or unknown.

Table 2 Participant Descriptive Statistics for Sleep Measures (N = 15)

Measurement	Mean ± SD
Sleep Length Average (hrs)	
Protocol 1	6.32 ± 0.89
Protocol 2	6.46 ± 0.79
Significance	p = 0.478
Sleep Length on Collection Day (hrs)	
Protocol 1	6.23 ± 1.01
Protocol 2	5.88 ± 1.03
Significance	p = 0.119
Sleep Efficiency Average (%)	
Protocol 1	85.13 ± 6.31
Protocol 2	85.85 ± 5.70
Significance	p = 0.435
Sleep Efficiency Collection Day (%)	
Protocol 1	84.53 ± 6.14
Protocol 2	86.53 ± 6.41
Significance	p = 0.219
REM Average (min)	
Protocol 1	53.63 ± 7.23
Protocol 2	58.77 ± 8.32
Significance	p = 0.431
REM on Collection Day (min)	
Protocol 1	62.9 ± 25.99
Protocol 2	69.0 ± 29.46
Significance	p = 0.201

Note: Relevant variables are underlined.
Abbreviations: hrs, hours; min, minutes.

Table 3 Descriptive Statistics for Hydration Status

A. Baseline Measurements All Participants (N = 15)	Mean ± *SD*
24-hour Urine Specific Gravity on Day 4	
Protocol 1	1.012 ± 0.003
Protocol 2	1.016 ± 0.007
Significance	p = 0.031*
24-hour Urine Volume (mL) on Day 4	
Protocol 1	1849.87 ± 741.25
Protocol 2	1534.67 ± 878.83
Significance	p = 0.121

(*Continued*)

Table 3 (Continued).

B. Measurements for Dehydrated Participants Only (n = 8)	Mean ± *SD*
24-hour Urine Specific Gravity on Day 4	
Protocol 1	1.012 ± 0.003
Protocol 2	1.021 ± 0.006
Significance	p = 0.003**
24-hour Urine Volume (mL) on Day 4	
Protocol 1	1769.38 ± 860.73
Protocol 2	1055.63 ± 500.72
Significance	p = 0.021*

Note: *p < 0.05, **p < 0.01, relevant variables are underlined.
Abbreviation: mL, milliliters.

Sleep Measures for Dehydrated Participants

Table 4 includes sleep measures collected by the wearable sleep sensor for the eight participants determined to be in a mild dehydrated state in the P2 fluid reduction phase of the study. There were no statistically significant differences between means for each protocol for all sleep measures.

Table 4 Paired Samples *t*-Test for Sleep Measures for Dehydrated Participants (n = 8)

	Protocol 1 Mean ± *SD*	Protocol 2 Mean ± *SD*
Sleep Efficiency Collection Day (%)	87.00 ± 5.04	86.50 ± 5.48
Significance	p = 0.668	
Sleep Length Collection Day (hrs)	6.32 ± 1.01	5.75 ± 0.82
Significance	p = 0.057	
Sleep Efficiency AVG (%)	87.06 ± 4.85	86.47 ± 3.84
Significance	p = 0.584	
Sleep Length AVG (hrs)	6.21 ± 1.01	6.60 ± 0.70
Significance	p = 0.149	
REM Length Collection Day (hrs)	0.99 ± 0.57	0.86 ± 0.50
Significance	p = 0.213	
REM Length AVG (hrs)	1.15 ± 0.44	1.23 ± 0.49
Significance	p = 0.520	
Latency Length Collection Day (hrs)	0.17 ± 0.07	0.11 ± 0.09
Significance	p = 0.219	
Latency Length AVG (hrs)	0.17 ± 0.07	0.12 ± 0.05
Significance	p = 0.131	
Light Length Collection Day (hrs)	2.87 ± 0.71	2.65 ± 0.62

(*Continued*)

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Table 4 (Continued).

	Protocol 1 Mean ± *SD*	Protocol 2 Mean ± *SD*
Significance	p = 0.360	
Light Length AVG (hrs)	2.74 ± 0.51	2.84 ± 0.71
Significance	p = 0.706	
Deep Length Collection Day (hrs)	2.44 ± 0.45	2.21 ± 0.47
Significance	p = 0.214	
Deep Length AVG (hrs)	2.38 ± 0.32	2.47 ± 0.34
Significance	p = 0.470	

Abbreviations: hrs, hours; AVG, average.

Table 5 Bivariate Correlation Test Results for Dehydrated Participants (n = 8) in P2

Variable	Pearson Correlation	Significance
REM Length + Water (ozs)	r = 0.800	p = 0.017*
Sleep Length + Water (ozs)	r = 0.804	p = 0.016*
Sleep Efficiency + Total Fluid (ozs)	r = 0.760	p = 0.029*

Note: *p < 0.05, ozs=ounces.

Sleep During Dehydration

Strong positive correlations were found between REM sleep length and water intake, sleep length and water intake, sleep efficiency and total fluid among the 8 participants who experienced dehydration (Table 5). Water intake on the 24-hour urine collection day associated with increased length of sleep ($r = 0.805$, $p < 0.05$), and sleep efficiency was associated with an increase in total fluid intake ($r = -0.760$, $p < 0.05$). REM sleep length and water intake on 24-hour urine collection day also had a positive linear relationship ($r = 0.800$, $p < 0.05$, Table 5; $R^2 = 0.64$, Figure 1). These relationships were non-significant among the non-dehydrated population.

A linear mixed model revealed a significant interaction between centered water intake (ounces) and adequate hydration status on REM sleep (seconds) (B = 37.41, SE = 9.89, unadjusted p = 0.006, adjusted p = 0.028, 95% CI = [20.851, 53.628]; Figures 2 and 3). Similarly, water intake had a significant effect on dehydration status, but this effect was no longer present after Bonferroni correction (B = 30.04, SE = 12.45, unadjusted p = 0.043, adjusted p = 0.22, 95% CI = [9.075, 50.455]; Figures 2 and 3).

Discussion

This study investigated the relationship between fluid intake, hydration status, and sleep quality, employing objectively measured sleep data (eg, REM sleep, sleep efficiency, and sleep duration) and hydration markers (eg, urine-specific gravity). Among a modest sample, hydration status did not significantly impact sleep measures overall. These results are consistent with outcomes found in Aristotelous et al.[5] However, there were strong positive correlations between water or total fluid intake and sleep quality within a small sub-group of mildly dehydrated individuals. When in a mild state of dehydration, greater total fluid intake was positively associated with improved sleep efficiency. Greater water intake, specifically, was associated with longer sleep duration.

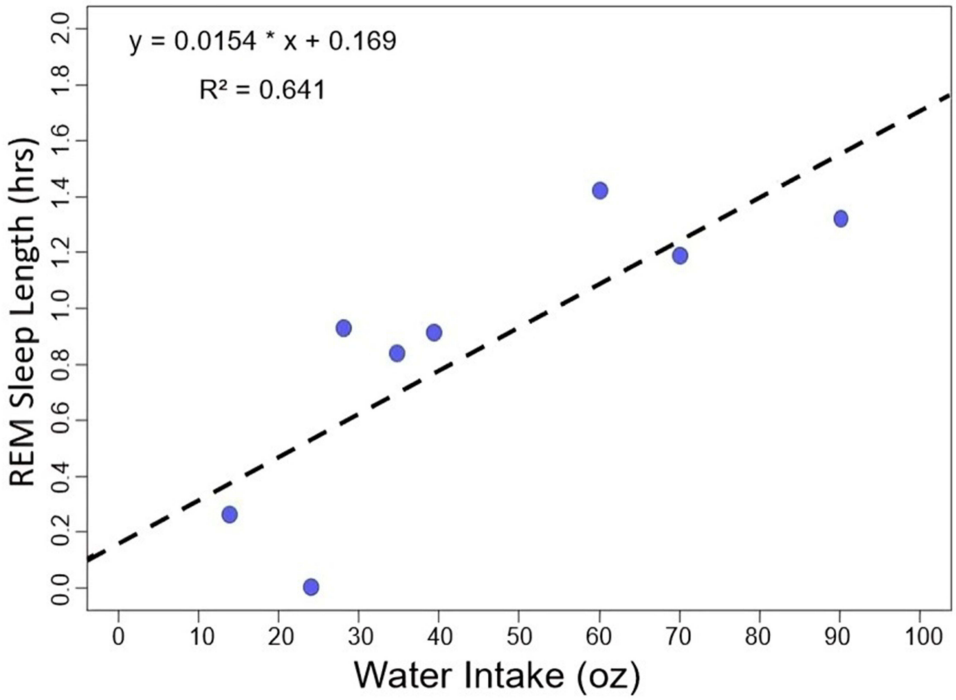

Figure 1 Significant positive association with length of REM sleep and water intake during mild dehydration (P2, n = 8).
Note: oz-ounces.

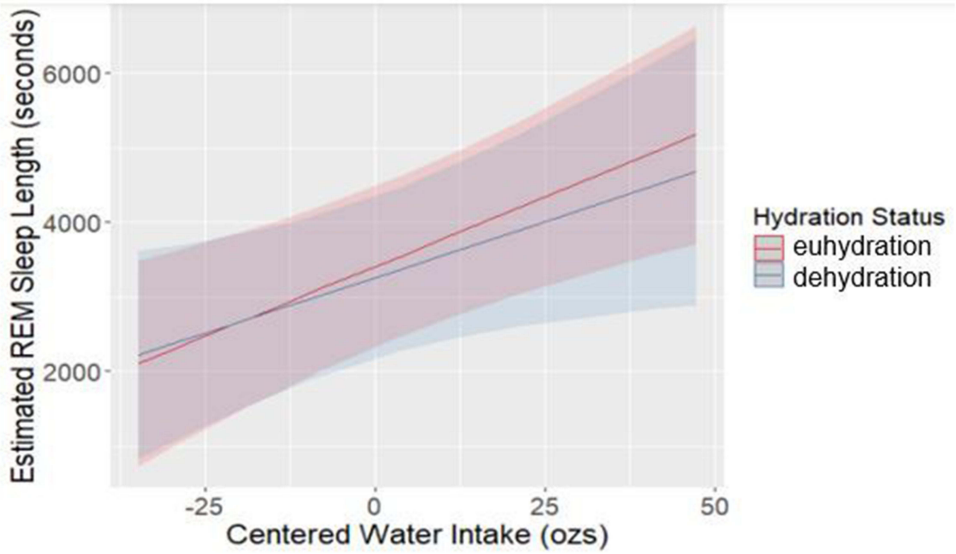

Figure 2 Significant Interaction of water intake and hydration status on length of REM sleep (n = 8) (unadjusted).
Note: ozs-ounces.

A linear mixed model of water intake and REM sleep length based on hydration status suggested a significant interaction between water intake and hydration status. In both hydration states, increased water intake was associated with significantly increased the length of REM, but this interaction was no longer present in the dehydrated state after Bonferroni correction. These preliminary findings suggest dehydration may attenuate the association between fluid intake and REM sleep.

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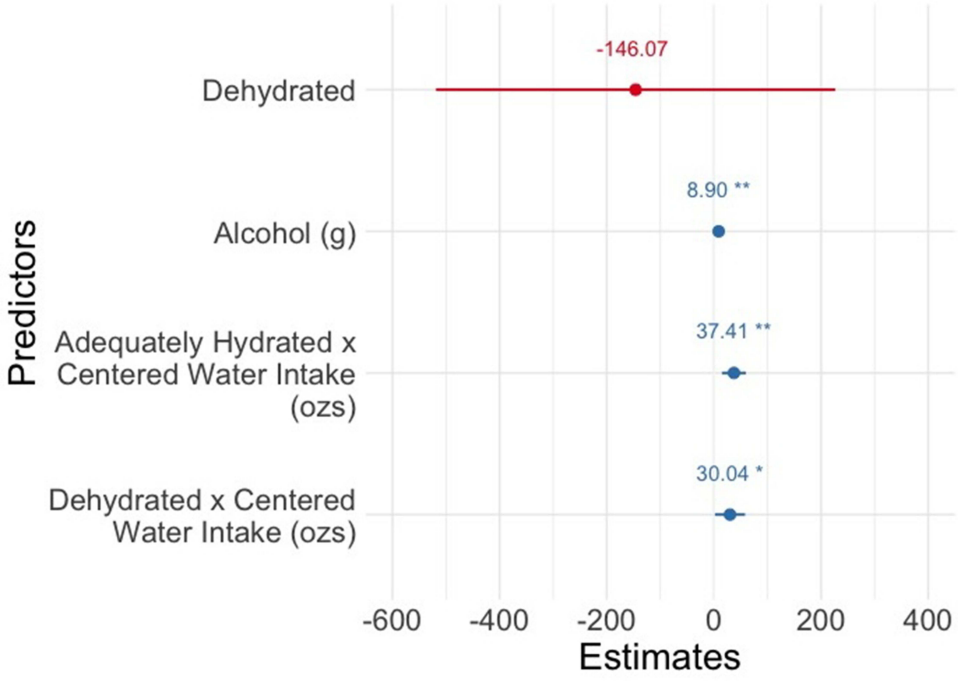

Figure 3 Forest plot of water intake and hydration status on length of REM sleep (n = 8).
Notes: Statistical model exploring the interaction of hydration and water intake on REM Sleep, Model created using fixed effects, horizontal lines indicating the 95% confidence intervals, estimates are in seconds, alcohol consumption as a covariate, dehydrated (coded as 1) compared to the reference group euhydrated (coded as 0), ozs = ounces, g = grams, *p < 0.05, **p < 0.01 (unadjusted).

The relationship between REM and fluid intake in humans has rarely been studied. In recent paper, using an animal model, restricting water intake disrupted REM sleep patterns.[11] However, the mechanisms underlying this relationship remain speculative, involving possible roles for thermoregulation, autonomic function, or osmoregulation. In an animal model, thermoregulation was impaired while osmoregulation was not impacted during REM sleep, suggesting that these hypothalamic functions are dissociated during REM sleep.[12] Water deprived rats showed reduced REM sleep episodes; sustained activity of the osmoregulatory network may therefore cause the brain to shift towards non-REM sleep.[12]

REM sleep involves an increase in blood flow that initiates water exchange (conducted by the brain's glymphatic system), flushing out toxins from the functional tissue of the brain to the venous system.[13] Aquaporin 4 (AQP4) plays a mediating allow for the transport of water between blood vessels and the brain interstitial space.[14] Dehydration may impact AQP4 functioning interfering with the glymphatic system's activity and thus influencing sleep and circadian rhythm. Given REM sleep's critical importance for brain health, specifically memory and learning,[15,16] the relationship we observed between fluid intake and REM duration warrants further investigation.

The mixed model analysis was conducted as part of an exploratory analysis to examine whether the observed correlation between REM sleep and water intake varied by hydration state. The small size of our study limits the broader application of our results, but provides preliminary insights into relationships between these variables. The within-subject experimental design did control for most extraneous participant effects. However, sleep is affected by a wide array of external variables, including race, gender, and socioeconomic status (SES)[17] which were not controlled for. Specifically, minority ethnic/racial groups, females, and those with low SES are more likely to exhibit sleep disturbances.[18] Additionally, individual stress, exercise, diet, temperature, caffeine, and alcohol consumption may have influenced the hydration and sleep variables we measured. Higher temperatures, higher activity levels, and/or low water content diet may increase water needs.[19] Greater levels of stress and/or increased consumption of caffeine and alcohol may disturb sleep.[20–22] Unlike PSG, PPG technology cannot assess brain waves to record sleep stages. Finally, a moderate decrease in fluid intake (eg, 5% less) may not be enough to place some participants in a significantly dehydrated state. This may be due to variations in baseline hydration state, activity levels, and environmental conditions.

Despite these limitations, the significant effects we observed for REM and sleep efficiency in a small sample of mildly dehydrated individuals suggest it would be useful to further explore how fluid intake impacts REM sleep. Future studies should include larger sample sizes and increasing levels of dehydration.

Conclusion

In this pilot study including a small sample of healthy adults, hydration status, as defined by urine-specific gravity, does not appear to directly affect sleep measures. However, fluid intake was positively associated with REM sleep length, sleep duration, and sleep efficiency. These exploratory findings highlight the potential benefits of adequate fluid intake for optimizing REM sleep, which is vital for cognitive and overall brain health. Future studies, with larger, more diverse samples, are needed to validate these preliminary findings and explore the mechanisms linking fluid intake and REM sleep.

Data Sharing Statement

The data that support the findings of this study are available from the corresponding author, TF, upon reasonable request.

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Author Contributions

T.F.-Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Visualization, Writing-original draft.

J.G.-Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing-review and editing.

M.A.V.-Conceptualization, Resources, Supervision, Validation, Writing-review and editing.

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; have drafted or written, or substantially revised or critically reviewed the article; have agreed on the journal to which the article will be submitted; reviewed and agreed on all versions of the article before submission, during revision, the final version accepted for publication, and any significant changes introduced at the proofing stage; and agree to take responsibility and be accountable for the contents of the article.

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Disclosure

The authors report no conflicts of interest in this work.

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