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The Effect of Passive Hypohydration on Aviation Relevant Cognitive Performance

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The Florida Institute for Human and Machine Cognition

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Final Report

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14. ABSTRACT

Background: It is well documented that dehydration negatively affects cognitive performance and can lead tactical aviators susceptible to common aeromedical stressors that includes gravitational force induced loss of consciousness (G-LOC), hypoxia, and spatial orientation. Much research in this field suggests cognitive performance to be affected by as little as a 2% loss of body weight. Tactical aviation operators are among a special population vulnerable to various physiological stressors, and dehydration is one that lacks current knowledge to understand its potential influence on military safety and performance. This research seeks to understand if dehydration alone may act as a major contributor to cognitive performance decrements in military aviation. For operational purposes for this evaluation, dehydration is defined as a percentage deficit of body weight resulting from water loss. The current study aims to investigate cognitive performance effects across three levels of dehydration by examining participant loss of body weight at 1%, 2%, and 3% dehydration.
Method: Sixteen active-duty naval aviator students for aviation duty participated in the study. All sixteen participants were male and between the ages of 20-45 years-old (M = 25.5 years, SD = ±3.52 years). Participants performed a series of PAT and SWAY tasks across a six-hour Dehydration protocol on two separate days. Dehydration was induced by the administration of

either a placebo pill or diuretic (Lasix) on one of the two testing days. To ensure fluid loss, participants were instructed not to consume any food or fluids for the duration of the six-hour protocol on each of the data collection days.
Results: PAT performance was analyzed through a series of repeated measures ANOVAS, which revealed no statistically significant interaction between dehydration levels and workload in either of the conditions. Likewise, the three variables associated with the SWAY protocol failed to show evidence of significant effects across dehydration levels.
Conclusion: This study suggests that dehydration is not associated with significant cognitive performance impairment and that heat stress and exercise related fatigue likely moderate the relationship. Results must be interpreted with caution and more investigation is needed to examine the relationship between specific cognitive and perceptual performance domains and hydration across environmental exposures associated with specific military aviation mission sets.

15. SUBJECT TERMS
Dehydration, PAT, tactical aviation, workload, validity, reliability, NASA TLX

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1.0 SUMMARY

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2.0 INTRODUCTION

Dehydration among tactical aviation operators has been found to make personnel significantly more susceptible to common aeromedical stressors such as G-induced loss of consciousness, hypoxia, and spatial disorientation (Nunneley & Stribley, 1979). Relevant to aviation, Lindseth et al. (2013) has reinforced the idea that hypohydration as measured by a 2% depletion in body weight is associated with a significant reduction in flight performance. This finding was relayed to US military aviation in a report from the Naval Safety Center that interpreted Lindseth et al. (2013) as suggesting that dehydration resulting in a 2% reduction in body weight was associated with a 57% reduction in flight performance. This inference was alarming to military operational aviation because dehydration is a widespread problem. It is commonly known that military aviators adhere to a strategy commonly called tactical dehydration which involves avoiding the consumption of liquids for several hours prior to embarking on a mission to prevent them from having to empty their bladder in-flight. When coupled with the layers of required equipment and the reality of sitting for hours at a time in as high as 90-degree temperatures in a cockpit waiting to disembark on a mission, dehydration it thought to pose a significant threat to operator health, safety, and operational readiness.

A thorough review of the Lindseth et al. (2013) puts the veracity of their conclusions into question. The study was designed as a crossover experiment with each participant serving as their own control. Participants were tested dehydrated through a 10-day fluid restriction method. Performance was then compared within individuals to determine whether cognitive and flight simulator performance were significantly affected by dehydration. The study did not find any significant results associated with their planned within-subjects crossover analysis. They shifted to a between group analysis comparing individuals who lost over 2% of their body weight to individuals who lost less than 2% of their body weight. The participants in the study were flight students with differing levels of experience and descriptive statistics show a broad range in performance across participants. Therefore, the results presented as evidence of dehydration related cognitive performance declines could just as likely be associated with group differences that existed prior to fluid restriction. Therefore, despite the hyperbole associated with this particular study, in actuality it shows no significant differences in performance within-participant pre and post hypohydration.

When taken together, the plurality of scientific results associated with the relationship between hypohydration and cognitive performance present an equivocal reality. Sawka et al. (2007) found cognitive performance effects at dehydration levels associated with 2% weight loss and a meta-analysis also concluded that 2% hypohydration significantly degrades attention, executive function, and motor coordination (Wittbrodt & Millard-Stafford, 2018). However, the literature is ubiquitous with studies that did not find evidence of cognitive performance effects at dehydration levels of 2% and 4% (Adam et al., 2008; D'Anci et al., 2009; Ely et al., 2013). The disparity in findings and conclusions across studies has left many of the questions about the relationship between hypohydration and cognitive performance unanswered. A more recent meta-analysis lends insight into the underlying reasons that study results have varied so much across hypohydration and cognitive performance studies. The authors point to varied methodologies used to hypohydrate participants across studies as a large contributor to the observed variation in outcomes (Goodman, Moreland, & Marino, 2019). Studies use passive methods, such as diuretics and fluid restriction, or active methods, like heat stress and exercise. In some cases, studies use a mixture of both. When studies use active methods to hypohydrate their participants or a combination of active and passive methods, they are more likely to find cognitive performance deficits associated with the study's hypohydration manipulation. However, studies have shown that active methods of dehydration, such as thermal stress, may have their own effect on cognitive performance and may mediate the relationship between hypohydration and cognitive performance (Irwin et al., 2018; Tomporowski, Beaseman, & Garrio, 2007). Likewise, studies have shown that fatigue associated with exercise to the degree required for hypohydration can cause cognitive performance declines (Grandjean & Grandjean, 2007). Due to such disparities in methodology, it is still unclear whether there is an effect of hypohydration in isolation on cognitive performance. To clarify this relationship, scholars have suggested that for effects to be successfully replicated experimental manipulations must be matched carefully across studies on the use of thermal stress and exercise. It has also been argued that due to differences between groups and power considerations cross-over designs should always be used (Falcone et al., 2017; Morley, 2012; Tomporowski, Beaseman, & Garrio, 2007).

While prior research has assessed the impact of dehydration on cognitive performance, an understanding of cognitive deficits at distinct levels of cognitive workload is also of operational interest, as perhaps tactical aviators can perform well one on common, overlearned aviation tasks such as maintaining airspeed and heading. However, aviators may not perform well in high workload multitasking scenarios or while performing novel tasks or responding to unexpected events when dehydrated. To mitigate dehydration in tactical aviation, further research on pilot performance at varying levels of cognitive workload while dehydrated is needed. The performance effects of dehydration have typically been measured through psychometric tests that are not especially relevant to aviation-associated tasks. Researchers present a myriad of effects found using lab tasks that can often leave operators with the impression that the cited effects would pose no operational risk to them. The US Air Force School of Aerospace Medicine (USAFSAM) has recently developed a task called the Performance Assessment Tool (PAT) that closely mimics aviation-associated tasks. The Florida Institute for Human and Machine Cognition (IHMC) has adjusted the PAT to present different cognitive workloads to the user that may better reflect the true cognitive performance cost of operational stressors like dehydration.

To date, there are a multitude of standardized neuropsychological assessments available, offering similar abilities to assess different cognitive domains individually or several simultaneously. A previous review of literature, (Adan, 2012) suggested that subdomains of higher order cognitive processes (i.e., inhibitory control, selective attention, visual processing) in this area of research should be independently analyzed as there is not much of an understanding about how they are individually affected by dehydration. In addition to the PAT, the SWAY cognitive test battery was utilized to measure a selected-set of cognitive functions that have been recognized to be sensitive to the performance effects of dehydration in athletes. Changes and or declines in complex cognitive functions such as vigilance, attention, motor control, reaction time (RT), and memory are of great interest in detecting the performance effects of dehydration while these specific cognitive skills have been investigated in several similar studies (Ganio et al., 2011; Irwin et al., 2018) Utilizing measures of impulse control, RT, and balance through the SWAY tasks will explore how and if these specific skills are affected, across time while being dehydrated.

The current study used a repeated measures crossover design with Student Naval Aviators (SNAs) serving as participants. Participants were hypoydrated through the administration of 80 mg of Furosemide to isolate the cognitive performance effects of hypohydration from the effects of heat stress and exercise induced fatigue. Participants completed cognitive performance assessments, including the Performance Assessment Tool (PAT) which measured cognitive functions like short term memory, visuospatial processing, and time-on-task performance; the assessments completed in the SWAY app measured cognitive functions like impulse control and reaction time. These measures were analyzed to determine if hypohydration in isolation results in a decrement to cognitive performance in healthy young aviation candidates. This study is an important first step in modeling the actual effect of hypohydration on cognitive performance in military aviation. This information will guide efforts to develop a more informed approach to address the issue of tactical dehydration. If dehydration itself does not cause cognitive performance declines strategies that reduce other stressors such as thermal burden may be more successful especially when gravitational stress isn't a comorbid physiological factor.

3.0 METHODS

3.1 Participants

Sixteen active-duty naval aviator students' and/or Naval Medicine Operational Training Command, attached to Naval Air Station Pensacola with a current medical up-chit (Medical Recommendation for Flying or Special Operational Duty, Department of Defense Form 2992) for aviation duty participated in the study. All sixteen participants were male and between the ages of 20-45 years-old (*M* = 25.5 years, SD = ±3.52 years). Participants did not possess a medical waiver and were screened through a medical history questionnaire for verification of having no history of kidney disease, cardiovascular disease, diabetes, gout, urinary retention, or lupus. Additional exclusion criteria included having a salt-restricted diet or if currently taking steroids, laxatives, ACE inhibitors, ARB aminoglycosides, cisplatin, or lithium. After briefing each participant on study procedures and obtaining informed consent, the medical history questionnaire was completed prior to their participation. Medical eligibility for each subject was ensured through an IHMC approved medical monitor, Dr. Bruce Waterman. The present human research protocol was approved by the Naval Medical Research Unit-Dayton (NAMRU-D) International Review Board.

3.2 Instrumentation

Performance Assessment Tool (PAT). The PAT is a cognitive performance assessment tool designed to assess the cognitive and physiological effects of extreme environmental conditions, specific to tactical aviation operators. The PAT is comprised of four different tasks: manual tracking task, mannequin (spatial processing) task, addition task, and a working memory task (as formerly described by Phillips, 2019). The tasks are reliable measurements of higher order cognitive processing within tactical aviation environments. Additionally, the PAT can switch between a low-workload and high-workload setting, meaning it may be conducted with one of the tasks independently (low-workload), or two, three, or all four of the tasks simultaneously (high-workload). For this study, researchers used the PAT to measure the cognitive functioning of participants at induced dehydration levels of 2% and 4% body weight. Participants completed two, one-minute iterations of PAT, one low-workload and one high-workload, every 30 minutes for a duration of six hours.

SWAY. In addition to the PAT, researchers recorded a second measure of cognitive functioning via the SWAY cognitive test battery, which is conducted on a Samsung smart tablet. SWAY is an FDA-approved app which features built-in motion sensors on a mobile device that can assess balance, impulse control, and reaction time. SWAY was utilized in the current study in an attempt to measure signs of dehydration in participants while they performed the series of balance, impulse control, and reaction time tasks. Participants completed a 21-item symptoms checklist presented in a Likert scale format from 1-6, with 6 being the most severe, an impulse control assessment, and a single-leg balance assessment (standing on right leg). Participants were first prompted to fill out the following 21-item symptoms checklist: feeling slowed down, feeling like "in a fog," "don't feel right," difficulty concentrating, difficulty remembering, fatigue or low energy, confusion, drowsiness, more emotional, irritability, sadness, nervous or anxious, headache, "pressure in head," neck pain, nausea or vomiting, dizziness, blurred vision, balance problems, sensitivity to light, and sensitivity to noise. Impulse control was the second assessment prompted. This measured participants' reaction times, attention, inhibitory control, and basic executive function through four 45-second iterations. The third test was the single-leg balance assessment; each participant was instructed to balance on their right leg while holding the tablet to their chest. This measured their static postural stability through four 10-second iterations. The entirety of the SWAY protocol was completed within five minutes and occurred once every 30 minutes for 12 iterations after the participant orally received the Lasix or placebo intervention.

Urine specific gravity. Initial urine samples were needed from the participants upon the start of each visit. The participants were provided with a urine specimen cup and then taken to the bathroom where they were prompted to collect their sample. The participants were instructed to use the clean catch method. They were instructed to wipe their urethra with an alcohol wipe, being urination in the toilet, then collect the middle portion of the stream in the sample cup, fill the cup halfway, (~60 ml) and then complete urination in the toilet. The urine samples were analyzed with the Digital Hand-Held Urine Specific Gravity "Pen" Refractometer PEN-URINE S.G., a hand-held digital refractometer that uses the refractive index method to measure the specific gravity of urine in a 1.000 to 1.0600 range.

Weight. Weight was measured using a digital scale and recorded in kilograms (kg). All participants were instructed to remove their shirts, socks, and shoes when being weighed.

Vital signs. Participant blood pressure was measured using a mechanical blood pressure cuff, which displayed systolic and diastolic blood pressures in millimeters of mercury (mmHg). Heart rate was measured using a pulse oximeter (bpm). Body temperature was measured with a digital ear thermometer reading in Fahrenheit (ºF). Smartabase was used to record vitals for each participant for each of the 13-iterations (i.e., baseline and 12-controlled iterations). Each participant was provided a de-identified serial number used to create their profile.

Furosemide. Furosemide, an FDA-approved medication, was used for the purpose of manipulating dehydration in each of the 16 subjects. Oral ingestion of either the diuretic medication (Lasix 80mg) or a placebo pill was administered on Days 2 and 3 of the study after researchers randomly assigned the medication. The medication was ingested with water four hours after the participants began a hydration protocol assigned ahead of time by researchers. This was to ensure that all participants were in a euhydrated state (USG of 1.002-1.020). This ensured a safe and stable physiological state for the participants to receive the diuretic medication. Only one active dose was administered on study days. The dehydration protocol resulted in both sodium and body water loss in the participant. When participants received the Lasix, the desired levels of dehydration were 2% and 4%, which resulted in approximately 3L of fluid loss for a 75kg subject. Previous research has indicated rehydration to be achieved when fluid consumption is 150% of fluid loss (Evans et al., 2017; Maughan et al., 1997).

Rehydration protocol. A rehydration protocol was required for each subject on Days 2 and 3 of the study. Upon the completion of the last iteration, the participants were provided with one of two sodium rich food items of their choosing, ramen noodle mix (1800 mg Na/serving) or tomato soup (3300 mg Na/L). The participants also chose one of three sodium rich drinks: Pedialyte Advanced Care Plus (1370 mg Na/L), Gatorade (865 mg Na/L), or chocolate milk (440 mg/L). In addition to the food and drink items, the participants were given two 500 ml bottles of water.

3.3 Procedure

This study took place on three separate days for each of the sixteen participants. The participants were instructed to independently follow a hydration protocol upon arrival of their scheduled study day(s). The hydration protocol was as follows: consume a light meal (400-600 calories) and drink ½ L (~2 cups) of water at four hours prior to arrival (0600), consume another ½ L (~2 cups) three hours prior to arrival (0700), and a final consumption of ½ L (~2 cups) one-two hours prior to arrival (~0830). The hydration protocol was implemented to ensure that participants would be in a euhydrated state before beginning the study. Participants were asked to arrive at 1000. Participants were also instructed to arrive at the study site in their physical training uniforms (Navy-provided shorts and shirt) in order to standardize weight measurements across all participants. Baseline vital measurements of weight, blood pressure, heart rate, temperature, and urine specific gravity (USG) were recorded each day prior to the initial dehydration intervention to ensure safety of drug administration to participants.

On Day 1, participants reported to the lab for an informational session where researchers presented details of the study and provided a medical history questionnaire to review. If the subjects agreed to participate, they obtained informed consent, completed the medical history questionnaire, and began the familiarization protocol. Familiarization on Day 1 acts as a pre-study practice session for the proceeding study sessions when the drug intervention is administered. First, participants were familiarized with the PAT assessments by executing twelve, two-minute iterations on the high workload setting. Participants' baseline vitals were recorded and entered in the investigators Smartabase application. The SWAY assessments were the final familiarization protocol that each subject completed on Day 1.

The following testing days (Days 2 and 3) included the manipulation of dehydration by administering either the diuretic or placebo tablet. After 30-minutes had passed from orally ingesting the medication, a timer prompted the researchers when to begin each iteration. Participants were randomly assigned to a high-low or low-high workload condition on Day 2 of their scheduled data collection. For the high-low condition, participants would first execute each of the tasks simultaneously for one session (high-workload) followed by the single tracking task (low-workload) for one session and vice-versa for the low-high workload condition. Each iteration occurred every 30 minutes and took approximately 15 minutes to complete. Within each iteration, the participant executed 2-sessions of PAT on either the high-low or low-high workload condition, executed SWAY, provided a urine sample (¼-½ of urine sample cup) and had their additional vitals recorded.

On Day 2, investigators recorded whether the participant followed the hydration protocol and asked each subject the food items they consumed. Prior to drug administration, participant baseline vitals were taken, and they re-familiarized on PAT for 2-iterations on the high workload setting. The administration of either the placebo pill or Lasix pill was randomly assigned between each participant on Day 2 of data collection. Therefore, whether the participant received the placebo, or the Lasix first varied depending on the outcome of the randomization. Researchers recorded whether the participant received placebo or Lasix to alternate the pill given on Day 3. Once the subject ingested the pill, the researchers began a 30-minute timer on a hand-held stopwatch. Upon the start of every 30-minute iteration, participants completed two iterations of PAT (one high and one low workload), one iteration of SWAY, and had their vitals taken. This pattern occurred twelve times throughout the 6-hour protocol. After the last iteration, the participants completed a supervised rehydration protocol that involved ingesting the sodium rich food and drink item of their choice, in addition to two (500 ml) bottles of water. Participants were dismissed thirty minutes post-protocol so long as they felt no serious symptoms.

On Day 3, participants completed the same protocol they did on Day 2. Although, the subjects randomly assigned condition on day 3 alternated depending on what pill they ingested on Day 2. Therefore, if the subject already received the Lasix on Day 2, they would have received the placebo on Day 3, and vice versa. High and low workload conditions for PAT also alternated based on the previously assigned setting on Day 2. Participants completed each iteration of PAT, SWAY, and vitals every 30-minutes across a 6-hour time period. After completion of the experiment, each participant completed a supervised rehydration protocol. Participants were debriefed by one of the Investigators of the experiment and were cleared to continue their day.

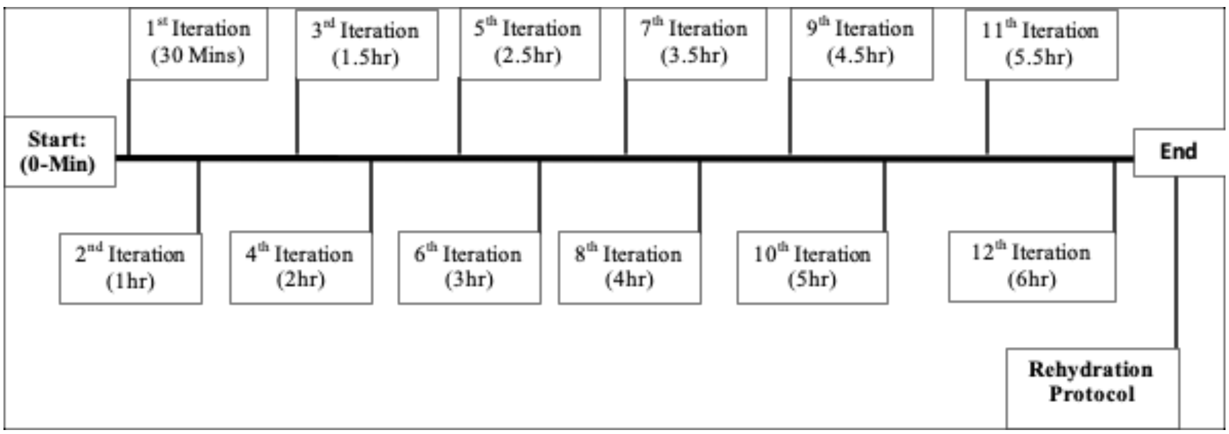

Figure 1. Dehydration Protocol Timeline

3.4 Data Reduction

Each participant completed six hours of testing on each of the two study days. Although we did dose participants with Lasix (80 mg), we had no other direct control over their dehydration level. That made the dehydration variable somewhat quasi-experimental. Participant dehydration status based on body weight was tracked and measured every 30 minutes across the six-hour period (Figure 1).

The participants' performance data were matched based on their individual dehydration level. Thus, there was one performance score, per participant, across each dehydration level reached. For each participant across each dehydration percentage, one through four, performance data was matched with the corresponding session from the placebo condition for comparison. This was done to control fatigue effects that were expected across the six-hour testing block. This process was completed for each dependent variable across PAT and SWAY. For each participant, a total of four out of 12 possible data points was selected for each condition (Lasix and placebo) and was included in the analysis. Based on body weight only four out of 16 participants reached the 4% dehydration level. Considering 14 out of 16 participants did get to the 3% dehydration level, we decided to restructure our analysis to focus on detectible performance effects from a euhydrated state to a 3% dehydration level based on body weight. Table 1 shows the iteration used for each participant for each dehydration level based on individual body weight changes measured in the Lasix condition across the six-hour session depicted in Figure 1.

To do this, we utilized the participants baseline scores as an additional measure of performance for the analysis. Upon arrival on both study days (i.e., Lasix and Placebo), participants executed a refamiliarization session on PAT in the high workload setting which represented their baseline performance score. These scores corresponded to a 0% dehydration percentage. The baseline measure at 0% dehydration was then compared to each of the other three recurring dehydration levels (i.e., 1%, 2% and 3%). Although low and high workload conditions were both measured during the two-day protocol, only high workload was recorded prior to beginning the experiment, which made high workload the only applicable measure for the baseline measure. For this reason, the scores of the low workload at 1% dehydration were used in both baseline and the 1% condition.

Table 1. Dehydration Levels Across Time by Assessment Iteration

Participant	0% Dehydration	1% Dehydration	2% Dehydration	3% Dehydration	4% Dehydration
1	Baseline/ 0-min	2nd Iteration (1hr)	3rd Iteration (1.5hr)	4th Iteration (2hr)	5th Iteration (2.5hr)
2	Baseline/ 0-min	3rd Iteration (1.5hr)	5th Iteration (2.5hr)	10th Iteration (5hr)	N/A
3	Baseline/ 0-min	1st Iteration (30min)	3rd Iteration (1.5hr)	4th Iteration (2hr)	6th Iteration (3hr)
4	Baseline/ 0-min	2nd Iteration (1hr)	3rd Iteration (1.5hr)	8th Iteration (4hr)	N/A
5	Baseline/ 0-min	2nd Iteration (1hr)	4th Iteration (2hr)	7th Iteration (3.5hr)	N/A
6	Baseline/ 0-min	2nd Iteration (1hr)	4th Iteration (2hr)	9th Iteration (4.5hr)	N/A
7	Baseline/ 0-min	3rd Iteration (1.5hr)	5th Iteration (2.5hr)	7th Iteration (3.5hr)	N/A
8	Baseline/ 0-min	3rd Iteration (1.5hr)	5th iteration (2.5hr)	N/A	N/A
9	Baseline/ 0-min	2nd Iteration (1hr)	4th Iteration (2hr)	7th Iteration (3.5hr)	12th Iteration (6hr)
10	Baseline/ 0-min	2nd Iteration (1hr)	3rd Iteration (1.5hr)	5th Iteration (2.5hr)	10th Iteration (5hr)
11	Baseline/ 0-min	2nd Iteration (1hr)	3rd Iteration (1.5hr)	6th Iteration (3hr)	N/A
12	Baseline/ 0-min	2nd Iteration (1hr)	4th Iteration (2hr)	8th Iteration (4hr)	N/A
13	Baseline/ 0-min	2nd Iteration (1hr)	3rd Iteration (1.5hr)	5th Iteration (2.5hr)	7th Iteration (3.5hr)
14	Baseline/ 0-min	1st Iteration (30min)	3rd Iteration (1.5hr)	9th Iteration (4.5hr)	12th Iteration (6hr)

4.0 STATISTICAL ANALYSIS

Dependent variables:

1. PAT Tracking
2. SWAY Balance
3. SWAY Impulsivity Score
4. SWAY Impulsivity Rection Time

PAT Tracking Experimental Design:
Our experimental design was slightly different for the PAT tracking data than for the SWAY data because cognitive workload was also manipulated across PAT sessions. The PAT performance analysis across dehydration conditions was a 2 x 4 x 2 Repeated measures factorial design. And was analyzed in a 2 x 4 x 2 repeated measures ANOVA.

Factor 1: Condition 2 levels Lasix (80mg) versus Placebo
Factor 2: Dehydration Level 4 levels Euhydrated, 1% Dehydrated, 2% Dehydrated, and 3% Dehydrated
Factor 3: Cognitive and Psychomotor Workload 2 levels High Workload (Tracking + Mannequin + Math + Memory) Versus Low Workload (Tracking only)

PAT Tracking Hypotheses:
H01: There are **no effects** of dehydration level on performance
H02: There are **no effects** of Cognitive Workload on performance
H1: There **are effects** of dehydration level on performance
H12: There **are effects** of Cognitive Workload on performance
H0: Operationalized the ANOVA **will not show** a significant interaction effect for Condition x Dehydration.
H1: Operationalized the ANOVA **will show** a significant interaction effect for Condition x Dehydration Level.
H02: Operationalized the ANOVA **will not show** a significant interaction effect for Condition x Dehydration x Workload.
H12: Operationalized the ANOVA **will show** a significant interaction effect for Condition x Dehydration Level x Workload.

SWAY Variables Experimental Design:
For the SWAY performance variables, a series of 2 x 4 repeated measures ANOVAs were conducted to test for differences in SWAY performance across the four hydration levels.

Factor 1: Condition 2 levels Lasix (80mg) versus Placebo
Factor 2: Dehydration Level 4 levels: Euhydrated, 1% Dehydrated, 2% Dehydrated, and 3% Dehydrated

Sway Variables Hypotheses:
H0: There are **no effects** of dehydration level on performance
H1: There **are effects** of dehydration level on performance
H0: Operationalized the ANOVA **will not show** a significant interaction effect for Condition x Dehydration.
H1: Operationalized the ANOVA **will show** a significant interaction effect for Condition x Dehydration Level.

Across the four dependent variables any significant main effect or interaction effect was to be followed up by planned comparisons between each data point in the Lasix condition compared for the same matched timepoint for each participant.

5.0 RESULTS

The results of the series of ANOVA's conducted across all dependent variables are presented in Table 2.

Table 2. RM ANOVA Tests of Within Subjects Effects Across PAT and SWAY Performance Variables

IVs	DF	F	P	$_{P}\eta^2$	Correction
Tracking-Condition	1, 13	0.01	0.910	0.001	None
Tracking-Dehydration	1.54, 19.95	0.80	0.501	0.058	G-G
Tracking-Workload	1, 13	58.05	0.000*	0.817	None
Tracking-Condition x Dehydration	3, 39	0.50	0.684	0.037	None
Tracking-Condition x Dehydration x Workload	3, 39	1.36	0.270	0.094	None
SWAY Balance-Condition	1, 12	1.76	0.209	0.128	None
SWAY Balance-Dehydration	3, 36	0.54	0.658	0.043	None
SWAY Balance-Condition x Dehydration	3, 36	1.99	0.134	0.142	None
SWAY Impulsivity-Condition	1, 12	0.13	0.723	0.011	None
SWAY Impulsivity-Dehydration Level	3, 36	2.38	0.086	0.166	None
SWAY Impulsivity-Condition x Dehydration Level	3, 36	1.22	0.318	0.092	None
SWAY Reaction Time-Condition	1, 12	0.18	0.675	0.015	None
SWAY Reaction Time-Dehydration Level	2.06, 24.73	2.61	0.066	0.179	G-G
SWAY Reaction Time-Condition x Dehydration Level	1.66, 19.97	1.47	0.253	0.109	G-G

5.1 PAT Performance

Tracking Scores: A three-way repeated measures ANOVA was performed to analyze the effects of dehydration levels and PAT workload on tracking performance across the Lasix and placebo conditions. The analysis revealed that there was not a statistically significant interaction between condition, dehydration level and workload in either of the (F (3, 39) = 1.36, p = 0.270, np^2= 0.094; Table 2; Figures 2 and 3)). However, simple main effects analysis showed that workload did yield a statistically significant main effect on tracking performance (F (1, 13) = 58.05, p = 0.000, np^2 = 0.817). Dehydration levels alone did not have a statistically significant main effect on performance in either condition (F (1.54, 19.95) = 0.80, p = 0.501, np^2 = 0.058). Similarly, the condition variable did not have a statistically significant main effect (F (1, 13) = 0.01, p = 0.910, np^2 = 0.001). Descriptive statistics for all PAT tracking measures across all conditions can be found in Table 3.

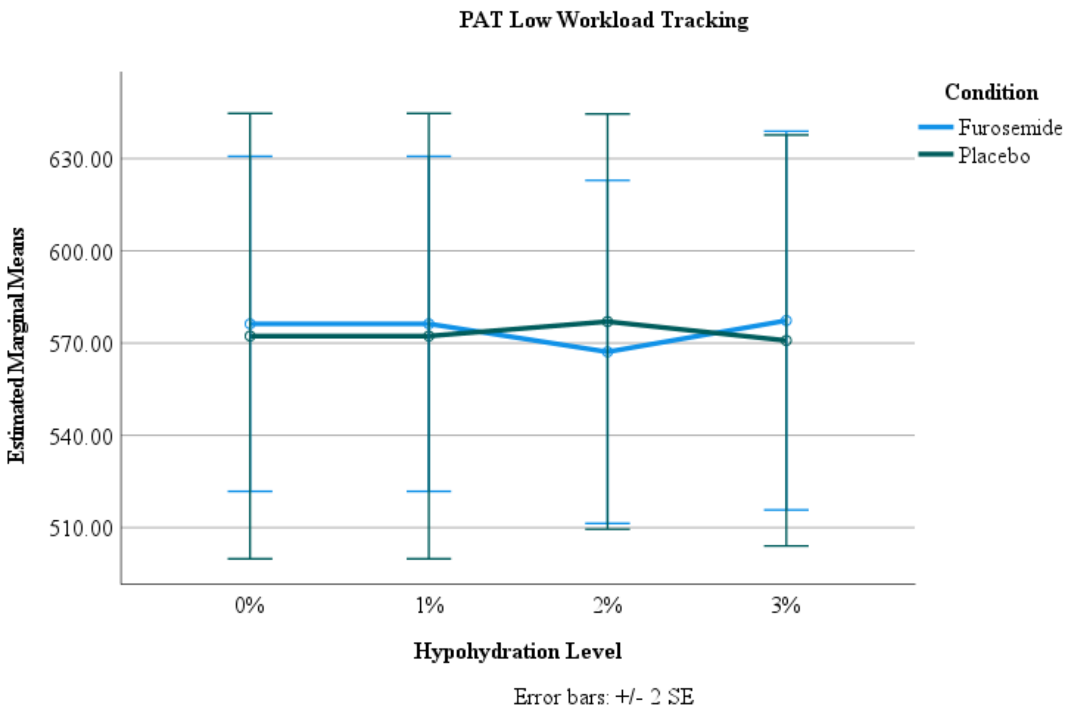

Figure 2. ANOVA Results for PAT Low Workload Tracking Scores Across Dehydration Levels

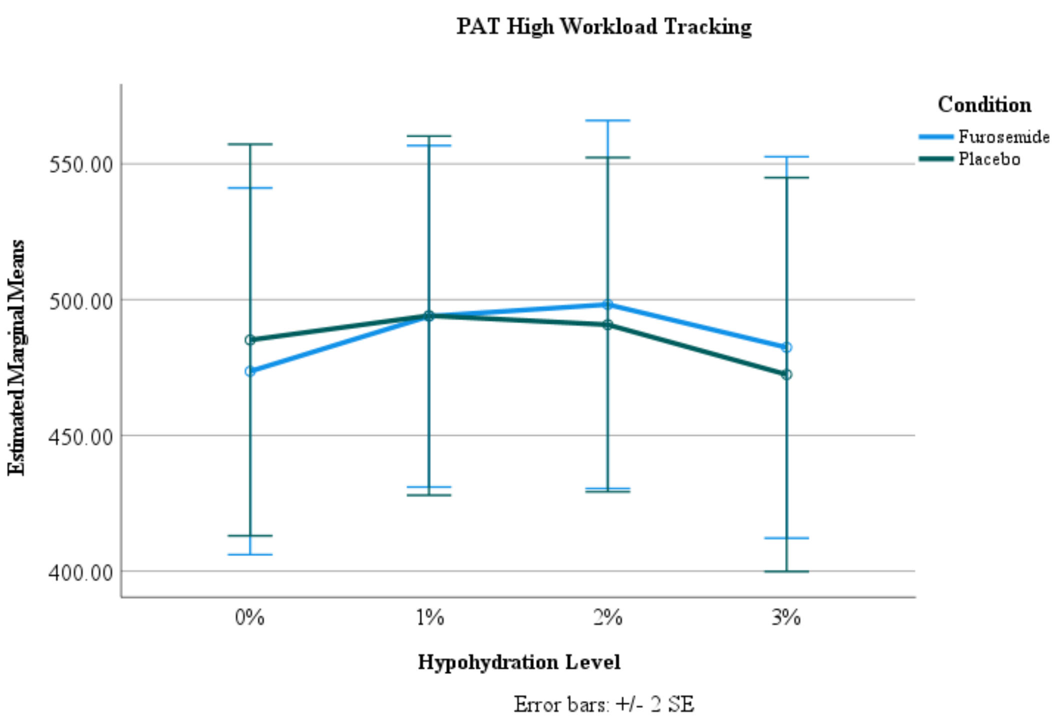

Figure 3. ANOVA Results for PAT High Workload Tracking Scores Across Dehydration Levels

Table 3. Means and Standard Error for PAT Tracking Performance

Condition	Dehydration Level	Workload	*Mean*	*SE*
Lasix	0%	High	473.625	33.763
		Low	576.284	27.239
	1%	High	493.885	31.441
		Low	576.284	27.239
	2%	High	498.224	33.874
		Low	567.164	27.887
	3%	High	482.428	35.118
		Low	577.340	30.804
Placebo	0%	High	485.167	36.047
		Low	572.315	36.218
	1%	High	494.117	33.068
		Low	572.315	36.218
	2%	High	490.795	30.777
		Low	577.012	33.767
	3%	High	472.442	36.267
		Low	570.860	33.421

5.2 SWAY Performance

Balance Scores The results of the two-way repeated measures ANOVA revealed that there was not a statistically significant interaction effect between dehydration level and condition (F (3, 36) = 1.99, p = 0.134, np^2 = 0.142; Table 2; Figure 4; Table 4). However, there were interesting trends that may have yielded a significant difference at higher dehydration levels if more statistical power had been achieved. These trends are further interpreted in the discussion section. The analysis revealed no significant main effect of condition on participants balance scores (F (1, 12) = 1.76, p = 0.209, np^2 = 0.128). There was no significant main effect of dehydration level on participant balance scores (F (3, 36) = 0.54, p = 0.658, np^2 = 0.043). Descriptive statistics for the SWAY Balance scores across conditions can be found in Table 4.

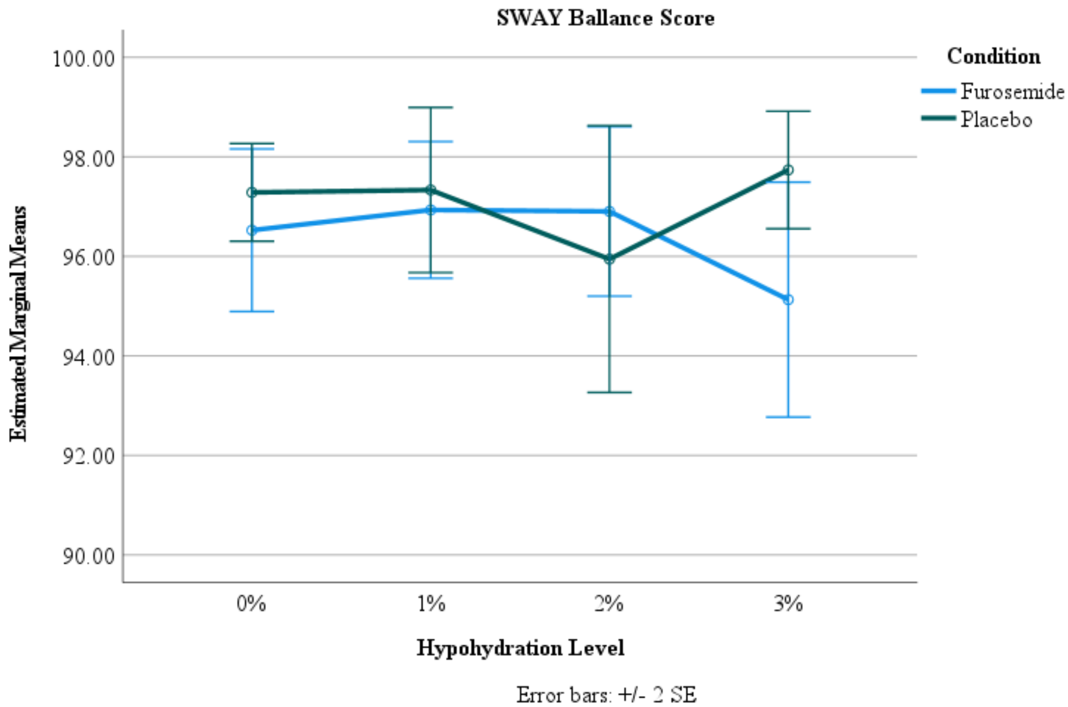

Figure 4. ANOVA Results for SWAY Balance Scores Across Dehydration Levels

Impulsivity Scores There was not a significant interaction effect between dehydration levels and condition on participant impulse control scores (F (3, 36) = 1.22, p > .05, np^2 = 0.092; Table 2; Figure 5). The analysis revealed no significant main effects of condition on participants impulse control scores (F (1, 12) = 0.13, p = 0.723, np^2 = 0.011). There was no significant main effect of dehydration level on participant impulse control scores (F (3, 36) = 2.38, p = 0.086, np^2 = 0.166). Descriptive statistics for the SWAY Impulsivity scores across conditions can be found in Table 5.

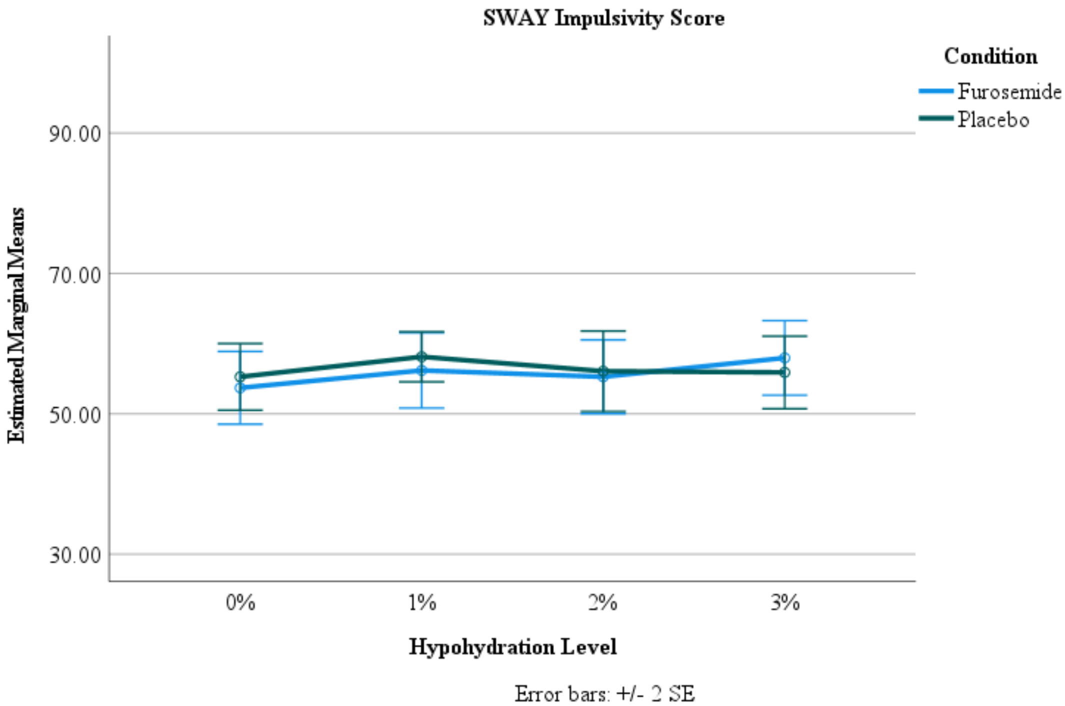

Figure 5. ANOVA Results for SWAY Impulse Control Scores Across Dehydration Levels

Reaction Time (RT) Scores There was not a significant interaction effect between dehydration levels and condition on participant (RT) scores (F (1.66, 19.97) = 1.47, p = 0.253, np^2 = 0.109; Table 2; Figure 6). The analysis revealed no significant main effects of condition on participants (RT) scores (F (1, 12) = 0.18, p = 0.675, np^2 = 0.015). There was no significant main effect of dehydration level on participant (RT) scores (F (2.06, 24.73) = 2.61, p = 0.066, np^2 = 0.179). Descriptive statistics for the SWAY Impulsivity Reaction Time across conditions can be found in Table 6.

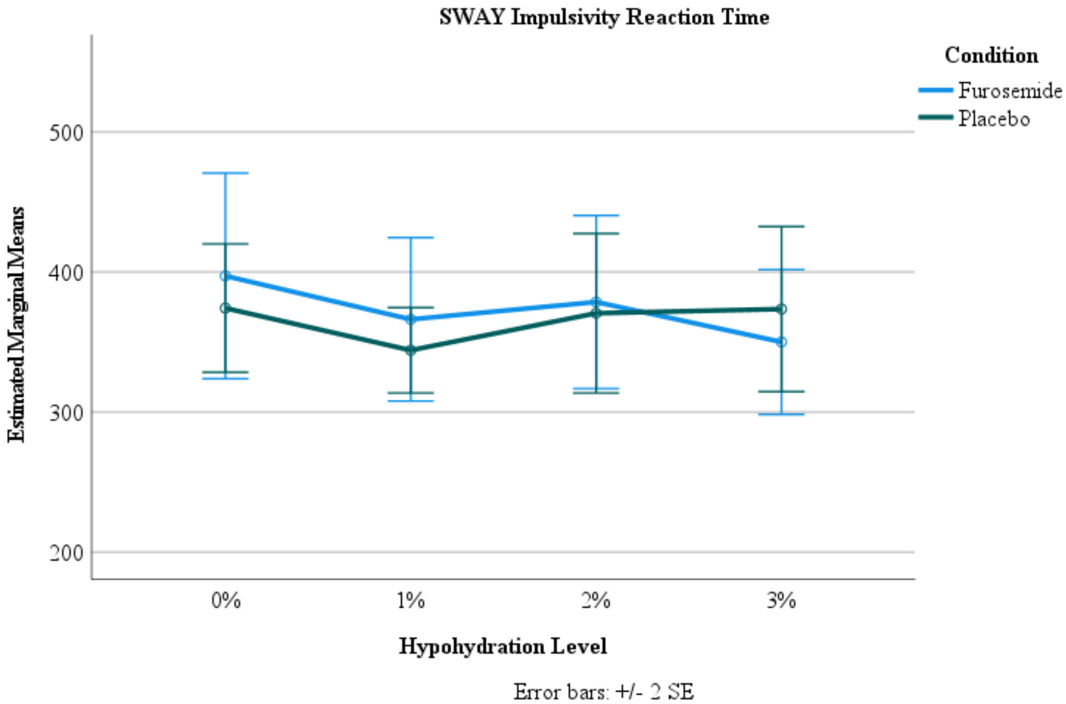

Figure 6. ANOVA Results for SWAY Impulse Control (Reaction Time) Scores Across Dehydration Levels

Table 4. Means and Standard Error Scores for SWAY Balance Assessments

Condition	Dehydration Level	*Mean*	*SE*
Lasix	0%	96.527	0.817
	1%	96.934	0.687
	2%	96.905	0.851
	3%	95.132	1.180
Placebo	0%	97.286	0.491
	1%	97.335	0.830
	2%	95.946	1.340
	3%	97.738	0.590

Table 5. Means and Standard Error Scores for SWAY Impulse Control Assessments

Condition	Dehydration Level	*Mean*	*SE*
Lasix	0%	53.710	2.588
	1%	56.192	2.683
	2%	55.284	2.632
	3%	57.973	2.656
Placebo	0%	55.280	2.374
	1%	58.139	1.784
	2%	56.084	2.864
	3%	55.908	2.586

Table 6. Means and Standard Error Scores for SWAY Impulse Control in Reaction Time Measures

Condition	Dehydration Level	*Mean*	*SE*
Lasix	0%	397.231	36.700
	1%	366.31	29.173
	2%	378.615	30.881
	3%	350.083	25.847
Placebo	0%	374.250	22.906
	1%	344.154	15.247
	2%	370.615	28.461
	3%	373.583	29.466

6.0 DISCUSSION

Studies that have examined the effect of dehydration on cognitive performance have argued that evidence of significant results have been found at body weight differences as low as 2% (Wittbrodt & Millard-Stafford, 2018; Sawka et al., 2007). In contrast there are a multitude of studies that have taken participants to a body weight difference of up to 4% and have found no evidence of a cognitive performance effect (Adan, 2012; Lieberman, 2007; Irwin et al., 2018). Therefore, contrary to popular opinion the actual relationship between dehydration and cognitive performance is equivocal. The confusion associated with the relationship between dehydration and cognitive performance is thought to be associated with dramatic inconsistencies across studies examining the relationship between dehydration and cognitive performance. For example, studies use varying methods to dehydrate study participants prior to testing for cognitive performance effects. Some studies use fluid restriction or diuretics whereas others use exercise or thermal stress. When simple diuretics or fluid restriction is used, cognitive performance effects are less likely to be seen. Cognitive effects appear to be much more repeatable when thermal stress or physical exertion is used as opposed to or in conjunction with passive methods. Given the inconsistency among studies it is unclear whether dehydration alone negatively affects cognitive performance or interacts with thermal stress or fatigue associated with active dehydration methods (Goodman, Moreland & Marino, 2019). With these knowledge gaps in mind, the current study used a combination of the administration of a strong diuretic (furosemide 80mg) and a six-hour fluid restriction regimen so that the cognitive effects of fatigue and thermal stress could be isolated from the effects of dehydration alone. As reported, there was no evidence of a significant effect of hypohydration up to 3% body weight loss so hypohydration alone does not appear to negatively affect cognitive performance in a young healthy sample of military aviation students. Trends were present in the Condition by dehydration level interaction of the SWAY balance scores although mean differences were less than 3% (Figure 4, Table 4). It is likely that if the sample size were increased or if adequate numbers of participants had reached the 4% hypohydration level, the ANOVA examining changes in balance between the two conditions would have yielded significant results suggesting better performance in the placebo condition when compared to the experimental condition at higher levels of hypohydration. It is difficult to say if this finding is operationally relevant but these results warrant further investigation. There is some evidence that hypohydration may increase endolymphatic fluid viscosity in the semicircular canals of the inner ear and may disrupt vestibular function, however this effect could also be associated with the relatively large dose of furosemide used in the experimental manipulation (Altin & Aksoy, 2022). If balance is negatively affected by hypohydration, it would represent a significant perceptual impact relevant to aviation and may facilitate the experience of common spatial disorientation illusions. Currently, threats to optimal vestibular function and spatial orientation are not emphasized in operational guidance that is provided to dissuade the practice of tactical dehydration.

7.0 CONCLUSION

The current study did not find any significant differences in cognitive performance among Student Naval Aviators in association with hypohydration across both the PAT and SWAY performance metrics. The hypohydration stress used in this study was not associated with a decline in cognitive performance capability in this sample. These results suggest that in some cases management of thermal stress and physical exertion could offset some of the negative effects of issues related to the practice of tactical dehydration. This would be especially true in situations where significant G-stress is not present. These results must be interpreted with extreme caution. Hypohydration is associated with decreases in blood volume which has been shown to reduce an individual's resting G-tolerance thereby increasing the risk of gravitational stress related loss of consciousness (Nunneley & Stribley, 1979). Operators of tactical aviation mission sets who will be exposed to significant G-stress should never take the risk of hypohydration lightly. More studies should be conducted using the same or other relevant populations that combine passive hypohydration methods with relatively brief periods of heat stress (60-90min) to match experimental manipulations more closely with what operators encounter in real-world situations. Studies should also examine cognitive performance declines associated with interactions between hypohydration, heat stress, and G-stress. In addition to cognitive performance tests, metrics of balance and vestibular function should be encouraged to determine the effect of hypohydration on vestibular function and associated spatial awareness and perceptual illusions. A more robust and systematic program of research is necessary to comprehensively understand the role of hydration on all aspects of flight performance. This program of research would supply vital information to provide a more tailored approach to managing hydration and urine output across military aviation mission sets.

The more comprehensive understanding that scientist, engineers and mission planners have of the true nature of the relationship between hypohydration and the different aspects of cognitive and perceptual performance germane to aviation, the more precisely mitigation strategies will balance safety and performance with practicality when juxtaposed against real world operational scenarios. A hydration instruction will not serve the needs of the operator or the mission if it cannot be applied in every day operational scenarios. If this balance is not accomplished, policies will not resonate with common sense across the military aviation community and will not be taken seriously. To win compliance in an educated and informed population like military aviation the message must be based in good and objective science, logical and concrete, and without unnecessary hyperbole that makes the message unbelievable or impractical.

The results of this study show the relationship between hydration and aviation relevant cognitive performance to be more nuanced than the popular narrative presented in science and official communications. It remains unclear whether hydration is a moderator that exacerbates the effects of other specific stressors such as thermal stress, physical fatigue and G-stress or if the relationship between cognitive performance and hydration is mediated by heat stress and physical fatigue which is commonly associated with active techniques used to dehydrate research participants. A focused program of scientific research is warranted to elucidate this relationship across specific cognitive and perceptual domains germane to aviation.

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