Voluntary Urinary Retention Effects on Cognitive Performance

Cheryl A. Griswold; Kaila A. Vento; Kara J. Blacker

INTRODUCTION: Aircrew in-flight bladder relief remains an understudied stressor; specifically the effects of withholding urination on flight-relevant cognitive performance. This quasi-experimental study investigated whether voluntary urinary retention over a 3-h period negatively impacted cognitive performance.

METHODS: We assessed vigilance using the psychomotor vigilance task (PVT) and measured the P3b event-related potential (ERP) in response to PVT stimuli. We also measured working memory (WM) performance using a change detection task and assessed the contralateral delay activity during the WM task using electroencephalography (EEG). Subjects ($N = 29$) completed a baseline test on both tasks, following bladder voiding and immediately after consuming 0.75 L of water. Subjects performed tasks at 1, 2, and 3 h post-void and urgency to void one's bladder was assessed regularly. A total of 17 subjects were able to complete the entire study protocol. Repeated-measures ANOVAs assessed changes in PVT and WM outcomes.

RESULTS: Reaction time (RT) on the PVT was significantly impaired (5% slower) with longer urinary retention time and showed a 2.5-fold increase in the number of lapses (RT > 500 ms) with increased retention time. Together these results indicate that sustained attention was impaired with increased voluntary urine retention. We did not see significant changes in WM performance with our manipulations. Additionally, neural measures acquired with EEG for both tasks did not show any significant effect.

DISCUSSION: As measured with the PVT, sustained attention was impaired during 3 h of voluntary urinary retention, highlighting the need for further development of adequate bladder relief systems in military aviation.

KEYWORDS: urine retention, cognitive performance, bladder relief, hydration.

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Military aircrew are faced with numerous operational stressors during flight and an often overlooked area of concern is the lack of adequate bladder relief options, which leads to extended urinary retention. Suppressing the need to urinate during a flight could compromise safety, resulting in operational errors, task saturation, injuries, and potential for mishaps. Personal health can also be negatively impacted by continued urinary retention, including risk of developing urinary incontinence, bladder over-distension, urinary tract infection (UTI), and kidney damage.[12,17] In fact, over a 14-yr surveillance of the Defense Medical Surveillance System, the occurrence of a UTI reported among U.S. active-duty military pilots and aircrew were 2337 women (56.3%) and 3262 men (4.8%), of which 42% and 10.9% had a recurrence, respectively.[1] While these rates are similar to other occupational communities in the military,[1] the extreme imbalance between men and women among aircrew makes the relationship less clear. Currently, the effects of a UTI or related urinary infections on aviation-relevant tasks are unknown. However, a UTI (or like infection) could disrupt the aviator's service obligations, grounding them and possibly compromising flight safety.

This issue of urinary retention due to insufficient bladder relief options affects both male and female aircrew. Women are

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most affected because current bladder relief systems are ineffectively designed for a woman's anatomy, creating spills.[17,20,23] In addition, some external bladder relief systems require the aviator to remove both their aircraft restraint system and their life support equipment, with an additional health and safety hazard if relieved urine is not completely contained. Given the lack of options for bladder relief in the aircraft, incidents could occur where aviators are forced to urinate on the flight line, in their anti-exposure suits, or on the ejection seat following failed attempts to relieve their bladder in flight. Previous work has demonstrated that being underhydrated can negatively impact flight, cognitive, and aerobic performance metrics.[16,17] For example, pilots who are 3% dehydrated experience a 40% reduction in G tolerance times.[13] However, little is known about the potential adverse effects of withholding urination for an extended period and how that might threaten an aviator's aeromedical readiness. Therefore, the primary purpose of this study was to determine whether voluntary urinary retention, due to being unable to relieve one's bladder, negatively impacts cognitive performance. Employing a quasi-experimental design, we hypothesized longer durations of urinary retention would increase reaction time (RT) on a psychomotor vigilance task (PVT) and decrease accuracy in change detection on a working memory (WM) task. Repeated-measures analysis of variances (ANOVAs) examined PVT and WM over time.

METHOD

Subjects

A total of 29 healthy adults (age: mean = 27.07 yr, SD = 5.18; 15 men, 14 women) participated in this study. The study protocol was approved in advance by the Naval Medical Research Unit Dayton's Institutional Review Board. Each subject provided written informed consent before participating. All subjects self-reported normal or corrected-to-normal vision, no history of psychological, neurological, or medical diagnosis, no known conditions that affect the bladder, no use of tobacco in the past 6 months, and no excessive alcohol use. All participants received a gift card for their contribution to the study.

Materials

For two cognitive tasks, subjects were seated approximately 50 cm from a 15.6-in laptop and stimuli were controlled by MATLAB (The MathWorks, Natick, MA, USA) with Psychophysics Toolbox extensions.[5] The order of task completion was counterbalanced across subjects.

For the PVT,[9] subjects were presented with a black uniform background. Periodically, a millisecond counter started to scroll up from zero and subjects had to press the spacebar to stop the counter as quickly as possible. After pressing the spacebar, the counter displayed the achieved RT (in ms) for 1 s, providing the subject with feedback on performance. Interstimulus intervals were distributed randomly from 2 to 10 s and the task lasted for 10 min. The dependent variables of interest for the PVT were median RT and frequency of minor lapses (RT > 500 ms) and major lapses (RT > 1000 ms).

The WM task here was a change detection task modeled after that used by Vogel and colleagues.[25] All stimuli were presented on a uniform gray background. Each trial began with a fixation cross for 500 ms, followed by a left or right arrow cue for 200 ms that indicated which hemifield the subject was to attend to. Subjects were instructed to fixate on the cross throughout the entire task. Next, a memory array appeared for 100 ms. In the cued hemifield, subjects saw one of three set sizes presented: two targets, two targets and two distractors, or four targets. The color of targets and distractors (i.e., red and blue) were counterbalanced across subjects. Following the memory array, a 900-ms delay period occurred, followed by a test array. The 2000-ms test array either showed the targets in the cued hemifield in the same positions and orientations (i.e., no change trials) or one target changed position or orientation (i.e., change trials). Subjects responded change or no change for each trial using counterbalanced response keys. Feedback was presented in the form of a color change to the fixation cross for 200 ms: green signaled correct, red signaled incorrect, and blue signaled that a response was not registered. Subjects completed 360 trials per time point (TP), with 120 trials of each set size. The entire task lasted approximately 22 min. The dependent variable of interest was accuracy for each set size separately.

During the cognitive tasks, electroencephalography (EEG) data were recorded continuously from 32 electrodes covering the whole scalp with approximately uniform density using an elastic electrode cap (LiveAmp, Brain Products, Gilching, Germany) with reference electrode FCz in DC mode at a sampling rate of 500 Hz. Electrode impedances for all channels were kept below 10 kΩ. EEG data were processed using the FieldTrip software package.[21] Details for trial creation, filtering, and averaging are described below for the PVT and WM task data separately. However, artifact rejection procedures for both datasets were identical. Data were rereferenced using a common average reference for the WM data and to electrode Fz for the PVT data. Independent components analysis was performed on epoched data and the eyeblink component was removed. After independent components analysis, EEG waveforms from frontal electrodes (i.e., Fp1, Fp2) were visually inspected to identify voltage fluctuations typical of gross motor movements (amplitude > ±50 μV). Trials containing these types of artifacts were rejected entirely.

EEG data recorded during the PVT task assessed the P3b component. Data were segmented into epochs of 1500-ms time windows ranging from −500 to 1000 ms from stimulus (i.e., counter) onset. After trial epochs were created, data were band-pass filtered between 0.5–20 Hz. After artifact rejection, the P3b was defined as the most positive going waveform between 250–500 ms post-stimulus onset. Mean amplitude centered around the peak was calculated as the average amplitude ± 20 ms around the peak.

EEG data recorded during the WM task assessed contralateral delay activity (CDA).[25] A band-pass filter of 0.1–30 Hz was used. Then data were segmented into epochs of 3900 ms

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ranging from −800 to 3100 ms from delay period onset. Any trials containing lateral eye movements were rejected entirely. Finally, CDA was defined as the mean amplitude from 300 to 900 ms during the delay period for contralateral minus ipsilateral posterior electrode sites (O1/O2, P3/P4, P7/P8). CDA amplitude was calculated separately for two targets, two targets and two distractors, and four targets.

To rate void urgency, the Urgency Perception Score was used.[2] The Urgency Perception Score is a valid and reliable means of grading urgency, ranging from 0 (no urge) to 4 (desperate urge). The scale demonstrates excellent test-retest reliability (intraclass correlation of 0.95) and is validated against clinical interviews.[7] Subjects provided a rating before and after each cognitive task during each TP and were shown the scale upon each rating, as seen in **Fig. 1**.

To ensure urine is free of most germs and blood for result accuracy, subjects used a "mid-stream clean-catch" technique for urine sample collections (i.e., using a disposable sanitary towelette and urinating 2 s before collecting the sample in a sterile container) for the pre- and post-testing. Urine concentration [i.e., urine specific gravity (USG)] examined hydration status while urine glucose and pH (reagent test strips) examined urinary tract health.

Samples were stored in the refrigerator for a maximum of 7 d. After standing 2–3 h in the laboratory following removal from refrigeration, urine samples were measured at 20 ± 2°C (Traceable thermometer, Fischer Scientific, Hampton, NH, USA; ± 0.2°C accuracy) for all hydration assessments.

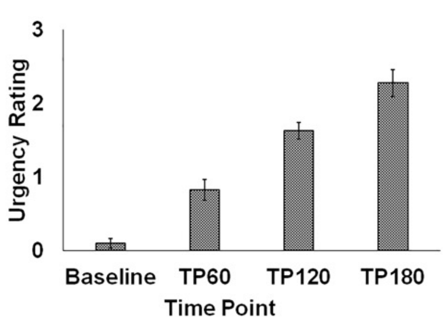
From the collection container, 20 mL of urine was transferred into a 30-mL test tube. A digital handheld refractometer (Pen-Urine S.G. Refractometer, Atago, Tokyo, Japan) measured USG to assess hydration per the manufacturer's instructions. Duplicate measurements were averaged and, if there was a >0.005 variation between the two measurements, a third measurement was performed using the median. The USG cutoff value of ≥1.020 is considered underhydrated, with higher values risking dehydration.[17]

Procedures

In preparation for the visit, subjects were asked not to consume alcohol within 24 h, not to consume caffeine within 12 h, and not to exercise on the morning of the visit. Upon arrival, subjects were asked to void their bladder (void 1), after which baseline anthropometric measurements were taken. Subjects then completed the two cognitive tasks with EEG recording. These initial measurements are henceforth referred to as the baseline TP. After completing baseline measures, the subjects were asked to void their bladder (void 2, baseline) while collecting a urine sample. Next, subjects were asked to drink 0.75 L of water within 15 min. Following the baseline bladder void and water consumption, subjects were regularly assessed via the cognitive tasks and self-report ratings of urgency to void their bladder. Subjects were instructed that when they reached the point where they needed to void their bladder within the next 10 min (i.e., desperate urge) or became too uncomfortable to continue, they would inform the experimenter and the post-protocol completion steps would begin. Cognitive testing with EEG recording and vitals were assessed at 60, 120, and 180 min post-baseline bladder void, hereafter referred to as TP60, TP120, and TP180, respectively. Once the final TP was complete, or if the subject decided to stop, the subject voided their bladder (void 3, post) and provided a urine sample (**Fig. 2**).

Statistical Analysis

An a priori power calculation determined a sample size of $N = 26$ (Cohen's $F = 0.27$, an alpha level of 0.05, and 90% power) coming from a previous study showing the degree of performance impairment during a hypoxia exposure as measured by EEG.[4] All statistical analyses were conducted using SPSS (version 27, 2020, IBM Corp). Of the 29 subjects who participated, a subsample of 17 subjects (10 men, 7 women) completed the entire data collection period (i.e., testing 180 min post-void). For those 17 subjects, changes in performance were assessed using repeated-measures ANOVAs with TP as a factor with 4 levels: baseline, TP60, TP120, and TP180. However, we also examined paired-samples *t*-tests for the entire sample of 29, comparing performance measures at baseline compared to the last available time point (i.e., the final measurement before participation was withdrawn to void one's bladder). These analyses yielded the same direction of effect and significance level in every instance and, therefore, we only report the repeated-measures ANOVAs below for brevity. In addition, the Greenhouse-Geisser correction was applied where Mauchly's test showed that the sphericity assumption was violated.



Grade	Definition
0	No urge (Not at all)
1	Mild urge (I can delay urination for over an hour if I have to)
2	Moderate urge (I can delay urination for greater than 10 minutes but less than 60 minutes)
3	Severe urge (I can delay urination for less than 10 minutes)
4	Desperate urge (I must urinate immediately)

Fig. 1. Average urgency to void ratings by time point (TP) and urgency rating scale schematic as shown to subjects. Error bars represent standard error of the mean (SEM).

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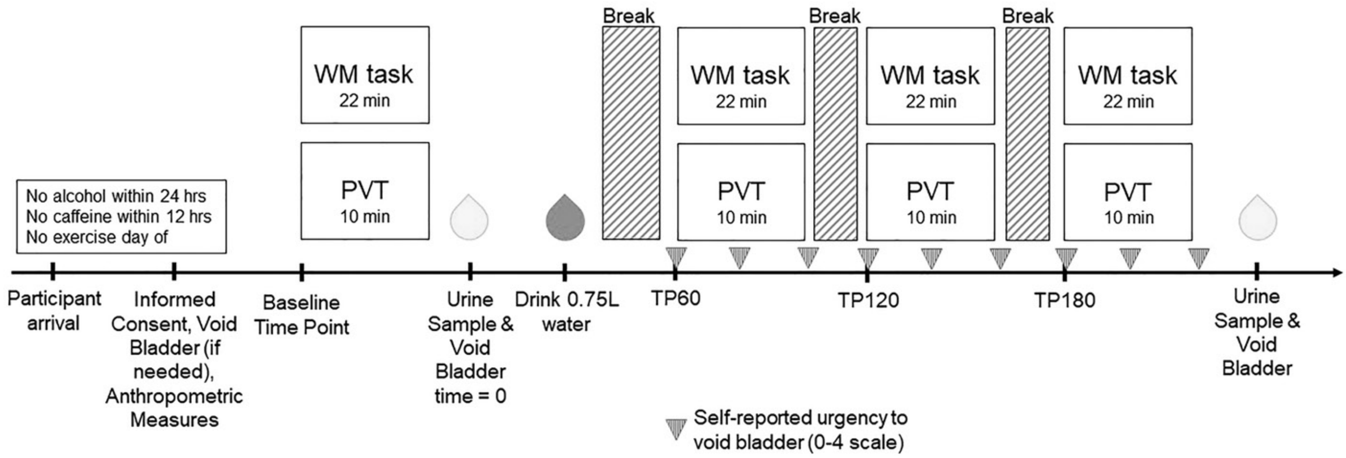

Fig. 2. Study visit procedures. After EEG preparation, participants completed a baseline time point of the two cognitive tasks, the Psychomotor Vigilance Task (PVT) and Working Memory (WM) tasks. EEG was always recorded during cognitive tasks. Urgency to void one's bladder was reported before and after each cognitive task, represented by the arrows.

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RESULTS

To examine changes in subjective urgency ratings across the TPs, we averaged the pre- and post-task ratings for both tasks to create an average urgency rating for each TP. A main effect of TP emerged [$F(2.101,33.620) = 64.992$, $P < 0.001$, $\eta_P^2 = 0.802$]. Pairwise comparisons demonstrated that every TP was significantly different from every other, all Ps < 0.001, with urgency increasing at later TPs (Fig. 1).

To validate the experimental manipulations, a paired-samples *t*-test on USG demonstrated that subjects were significantly less hydrated (mean = 1.0222 ± 0.0066) at baseline compared to after TP180 (mean = 1.0098 ± 0.0045) [$t(16) = 8.712$, $P < 0.001$, $d = 2.113$]. For PVT median RT, the main effect of TP was significant [$F(3,14) = 2.902$, $P = 0.044$, $\eta_P^2 = 0.154$]. **Fig. 3A** shows that RT increased with longer TPs. Pairwise comparisons specifically demonstrated a significant slowing of RT for TP180 compared to baseline ($P = 0.048$). For minor lapses, the main effect of TP was also significant [$F(3,14) = 3.964$, $P = 0.013$, $\eta_P^2 = 0.199$]. Fig. 3A shows that minor lapses increased in frequency with later TPs. Pairwise comparisons specifically demonstrated that TP60, TP120, and TP180 all had more lapses than baseline, all Ps < 0.05. For major lapses, the main effect of TP did not reach significance [$F(1.958,31.322) = 1.442$, $P = 0.252$] (Fig. 3A). To demonstrate the role of urgency to void one's bladder on changes in PVT performance, as opposed to general time on task effects, we tested nonparametric correlations on urgency rating and median RT, as well as minor lapses. There was a significant positive association between urgency to void and median RT [$\rho(97) = 0.241$, $P = 0.017$] and urgency to void and minor lapses [$\rho(97) = 0.220$, $P = 0.030$]. Additionally, for P3b amplitude, the main effect of TP was not significant [$F(3,14) = 1.110$, $P = 0.354$] (**Fig. 3B**).

For the WM task, each set size was analyzed separately with accuracy as the dependent variable. For two targets, the main effect of TP was not significant [$F(1.938,31.002) = 0.224$, $P = 0.794$]. For two targets and two distractors, the main effect of TP was also not significant [$F(3,14) = 0.731$, $P = 0.539$]. Finally, for four targets, the main effect of TP was not significant [$F(1.949,31.190) = 0.298$, $P = 0.739$]. **Fig. 3C** illustrates these results. For the CDA amplitude, for two targets, the main effect of TP was not significant [$F(3,14) = 1.058$, $P = 0.376$]. For two targets and two distractors, the main effect of TP was not significant [$F(1.965,31.436) = 0.775$, $P = 0.467$]. For four targets, the main effect of TP was also not significant [$F(3,14) = 1.269$, $P = 0.296$]. Results can be seen in **Fig. 3D**.

DISCUSSION

The current study examined the effects of voluntary urinary retention on neurocognitive performance. We found that RT on the PVT was significantly impaired (slower), and subjects also showed a significant increase in the number of minor lapses (RT > 500 ms) with longer urinary retention time. Together these results indicate that sustained attention was impaired with increased voluntary urinary retention. However, we did not see significant changes in WM performance with our manipulations. Additionally, neural measures acquired with EEG for both tasks also did not show any significant effect. The experimental manipulations employed here were mild compared to being unable to void one's bladder during actual extended duration military aviation missions. The RT and attentional lapses in the current study are evidenced in isolation as participants focused on only this one task. However, in an operational environment, multiple tasks and inputs are often co-occurring, which leads to dual- or multitasking. Multitasking has been shown to degrade RT performance, as well.[5,22] Therefore, slowing responses would likely be exacerbated under both urinary retention and dual- or multitask conditions.

To the best of our knowledge, no previous study has examined the effects of urinary retention on cognitive performance. However, we used the PVT[9] as one of our primary measures of performance because it is a gold-standard for assessing

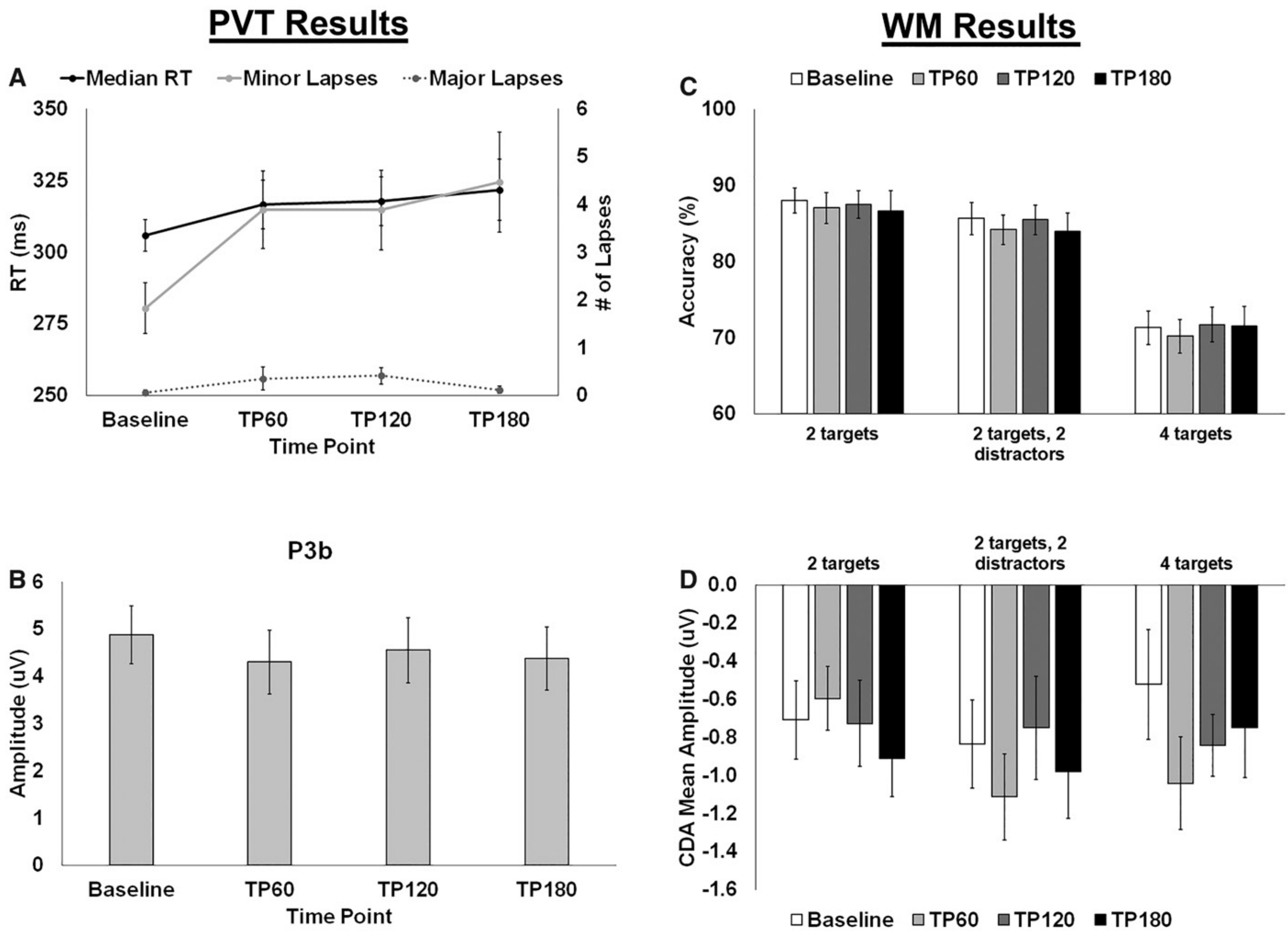

Fig. 3. A) Psychomotor Vigilance Task (PVT) performance results across time points. Group average median reaction time (RT) is displayed with the left y-axis and minor and major lapses are shown with the right y-axis. B) P3b mean amplitude results from the PVT task across time points. C) Working Memory (WM) task accuracy results and D) corresponding CDA mean amplitude results, shown by set size for all time points. Error bars represent SEM.

vigilance in the field and has been studied extensively with sleep deprivation,[6,15,18,26] hypoxia,[4,11] and other aeromedically relevant performance metrics.[3,19] As a comparison, our results here showed a 16-ms slowing of RT after 3 h of urinary retention, which is in line with the effects of a blood alcohol level of 0.06%[10] or breathing 10% oxygen.[4,10] The number of lapses here increased by 2.7 lapses, which exceeds the increase seen after four nights of partial sleep deprivation, a blood alcohol level of 0.08%, or a 10% oxygen hypoxia exposure.[10] Finally, the effects seen here represent a 5% increase in RT, which is comparable to that seen under dual-task conditions, such as walking and performing a cognitive task.[22] Therefore, the adverse effects on cognitive performance in an operational setting might be more severe and widespread than witnessed in this controlled environment, though comparable to that of fatigue, alcohol intoxication, and hypoxia. This highlights the degree to which urinary retention could impact operational performance and the need for additional research on the topic.

Here we focused on the effects of urinary retention on cognitive performance, but additional health sequalae of continued urinary retention are also possible, including development of urinary incontinence, bladder over-distension, UTI, and kidney damage.[12,17] UTIs are the most prevalent diagnoses among active-duty women and are highly recurrent for pilots and aircrew.[1] To the best of our knowledge, there is no research on the effects of a UTI on cognitive ability. However, more extreme insults to the urinary system, such as kidney failure, has been associated with decreased cognitive function in adults of all ages.[14] Cognitive performance has even been shown to rebound following dialysis or transplantation.[8] It is known that a UTI (or like infection) disrupts an aviator's service obligations, grounding them and possibly compromising flight safety if flying. For example, the average UTI symptoms for females last 6.1 d, restricting 2.4 d of physical activity, contributing to 1.2 d of absences and 0.4 d in bed.[24] Within the military, between 2000–2013, UTIs accounted for a yearly average of 2240 hospital bed days and 4981 d of lost work time.[1]

The current study also elucidates both the implications of insufficient bladder relief systems for aircrew and provides a better understanding of the performance repercussions of voluntary urinary retention. However, it was not without its

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limitations. The study's enrolled sample size of 29 was based on a priori power analysis using EEG measures. However, only 17 participants completed the full 3-h intervention, which suggests that our study was likely underpowered. This lack of power may have contributed to our null effects on WM performance and EEG measures of interest. A follow-on effort accounting for attrition is warranted, especially given the understudied nature of the topic. Additionally, a comparable group experiencing acute under hydration is missing. This is important because "tactical dehydration" is used by aviators to circumvent the issue of bladder relief in the aircraft and there are known negative repercussions of dehydration on performance. Instead, this study emphasized urinary retention, rather than hydration status on cognitive performance.[16] Thus, interpretation of results is cautioned. Additionally, sex differences were not examined given the small sample, and we recommend larger powered studies to evaluate cognitive performance and urinary urgency outcomes. Similarly, the effects on sustained attention had no comparison group.

Nevertheless, the current study provides a foundation for future experimental designs that might test the effectiveness of relief systems with a more realistic simulation. For example, prospective studies could conduct a similar intervention examining cognitive performance over 3 h among aviators in full gear in a simulated cockpit, comparing two groups against urinary retention, having 1) refrain from fluids for 12 h (USG > 1.020), unable to consume additional fluids, and 2) well-hydrated (USG < 1.020), able to consume fluids and both able to take bladder relief breaks. Furthermore, future research should examine the additive effects of multiple stressors and how urgency to void one's bladder might interact with operational stressors such as hypoxia, spatial disorientation, fatigue, increased workload, or G forces. To mitigate in-flight bladder relief concerns, we recommend small frequent fluid consumption sips and avoidance of diuretics or foods that stimulate the urge to urinate (such as highly caffeinated or energy drinks).

In conclusion, aircrew in-flight bladder relief systems have not kept pace with increases in mission duration and aviator diversity.[20,23] We demonstrated that sustained attention was impaired during 3 h of voluntary urinary retention as measured with the PVT. The knowledge gained will help educate aviators on the negative impact of voluntary urinary retention. These data should promote advances in bladder relief systems suitable for all aircrew.

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