Attention Control Predicts Operational Errors in Expeditionary Robotics Warfare Operators

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ABSTRACT

Understanding human performance to improve mission outcomes through trait-level and state-dependent individual differences may protect against operational errors. Attention control has received increasing interest as a trait (i.e., relatively stable) and state-dependent (i.e., fluctuating due to fatigue, stress, and sleep deprivation) cognitive ability that predicts performance on technologically demanding operational tasks (Burgoyne et al., 2025). Attention control refers to the domain-general ability to focus on goal-relevant information while resisting distraction from external events (e.g., a loud noise far away) and internal thoughts (e.g., thinking about yesterday) (Burgoyne & Engle, 2020). In the present work, attention control abilities were measured using three-minute “Squared” tasks in 50+ expeditionary robotics warfare specialists conducting multi-day training exercises using Unmanned Underwater Vehicles (UUVs). These training exercises assess a platoon’s ability to perform undersea mine countermeasure missions continuously and in real-time. Instructors assessed each platoon by recording error type and frequency. Error types include mission planning errors, UUV-related errors, safety errors, and Post-Mission Analysis (PMA) errors. Interim analyses revealed that attention control was highly related to PMA errors at the individual level and at the platoon level. Greater attention control was associated with fewer PMA errors, and the proportion of variance explained was substantial (r = -.81). Nevertheless, more sophisticated statistical models (mixed models with operators nested within platoons) lacked adequate power (<80%), necessitating further data collection. As such, we anticipate sampling an additional 30-35 expeditionary robotics warfare specialists within the next 4 months. Greater statistical power will increase the precision of our estimated effects and provide better understanding of the relationship between attention control and operator performance. Collectively, this work will lay the foundation for further explorations involving attention control as both a trait- and state-level variable and its impact on training and human performance in expeditionary robotics warfare specialists.

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INTRODUCTION

In February of 2024, the United States Navy approved their first enlistment rating in over 20 years, the Robotics Warfare Specialist (RWs). Sailors converting to the new rating "…will be the subject matter experts for computer vision, mission autonomy, navigation autonomy, data systems, artificial intelligence and machine learning…" on Naval robotics platforms (NAVADMIN 036/24). Previously, Sailors from a variety of different rates with a variety of knowledge, skills and abilities (KSAs) related to robotics performed these rolls. However, with the official establishment of the rating, concerted efforts are now underway to best identify the most relevant KSAs and how recruitment and training can be configured to optimize operational performance. One ability that has been identified as being particularly relevant to performing complex tasks in human-robotics interactions—especially under expeditionary circumstances where stress and fatigue is common—is the ability to control one's attention (Foroughi et al., 2019).

Attention control refers to the domain-general ability to focus on goal-relevant information while resisting distraction from external (e.g., a loud noise far away) and internal (e.g., fatigue) events (Burgoyne & Engle, 2020; Friedman & Miyake, 2012; Norman & Shallice, 1986). Amidst a maelstrom of visual, auditory, and tactile input, RWs will be tasked with maintaining focus on mission goals and filter out (i.e., inhibit) task-irrelevant information. Furthermore, the expeditionary settings in which RWs will be asked to operate will introduce fatigue, sleep deprivation, and stress, causing challenges to attentional processes.

Previous research has established attention control as a predictor of military-relevant performance in jobs with heavy technology demands. For example, in a sample of naval flight officers, attention control accounted for 11.8% of the unique variance in aviation preflight indoctrination training performance and 4.3% of the unique variance in flight performance above and beyond selection tests that are currently in use by the U.S. Navy (Burgoyne et al., 2024). Based on this empirical evidence and the theoretical role that attention control plays in complex task performance, we reasoned that attention control might also predict the performance of expeditionary robotics warfare operators during training missions.

In the present study, we investigated whether attention control ability is related to RW platoon performance during training missions, specifically the likelihood of mission errors. Mission errors can be extraordinarily costly (e.g., loss of life and/or equipment). Thus, identifying the factors that may lead to optimizing manning and training and personnel for RWs is arguably the first and most important step to reducing avoidable errors.

METHODOLOGY

Sample

Unmanned Maritime Systems (UMS) platoons primarily utilize unmanned underwater vehicles (UUVs) and robotics to provide expeditionary mine countermeasure support to the Explosive Ordnance Disposal community and to the Fleet. These platoons preceded and largely informed the development of the RW rating and currently include members that have converted to the rating. Platoon size and make-up (i.e., ranks and ratings) varies based on unit. Sixty-five UMS Operators [62 males (95.4%) and 3 females (4.6%)] across 6 platoons (Plt. 3, $n = 9$; Plt. 5, $n = 11$; Plt. 6, $n = 9$; Plt. 7, $n = 18$; Plt. 8, $n = 13$; Plt. 9, $n = 5$) participated in the study (IRB protocol NHRC.2022.0009). Ranks ranged from E-3 to E-8 across a variety of different enlisted ratings (e.g., RWs, Minemen, Aerographers, Boatswain's Mates, Electronic Technicians, Operations Specialists). The average experience in UMS operations for the sample was 25.8 months (minimum = .5, maximum = 120).

Final Assessment Exercise (FAE)

The Final Assessment Exercise (FAE) is a five-day training exercise and evaluation of a platoon's overall competency. Platoons are required to establish a forward operating base and are tasked around the clock with a variety of different expeditionary maritime robotics missions. Each mission consists of receiving tasking, planning and briefing the mission, executing the mission, completing a post-mission analysis (PMA) of data collected by robotics, and debrief of the PMA results. Each platoon is given the same mission sets during the FAE and can complete on their own timelines so long as the mission is successfully executed.

Operational Errors

Platoons are evaluated by instructor staff for errors that are committed by the platoon during each operation. These errors align with the RW functional areas and include (with examples):

- planning errors: entering incorrect waypoints into navigational tools, platoon not checking where potential minefield is within the operating area, platoon going underway at or close to when enemy patrols are present, platoon programming vehicle too close to shoreline not considering tide levels
- UUV mission errors: launching/ recovering vehicles in an untimely fashion causing timelines to shift, platoon entering minefield with UUV while underway
- PMA errors: labeling an object identified in the UUV data incorrectly (e.g., biological, manmade, mine type), giving a confidence value without justification based on mission parameters

Attention Control

We measured operators' attention control using three conflict tests known as the "Squared" tasks: Stroop Squared, Flanker Squared, and Simon Squared (Burgoyne et al., 2023; see Figure 1). These tasks require several cognitive processes supported by the control of attention, including conflict resolution, task switching, and working memory updating. The trio of Squared tasks used in the present study overcome known reliability limitations (Hedge et al., 2018) by increasing the signal-to-noise ratio by doubling the amount of conflict on each trial and circumventing the need for difference scores by using speed and accuracy to generate a points system. As a result, the Squared tasks demonstrate excellent psychometric properties, including very high reliability and convergent validity with other established measures of attention control (Burgoyne et al., 2023). On each of the Squared tasks, participants were given 30s of practice followed by 90s of test trials. Their score was the number of correct responses minus the number of incorrect responses

Stroop Squared. In Stroop Squared, participants must select the response option that states the display color of the word appearing towards the top of the screen. In the example shown in Figure 1, the correct response option is the word "BLUE", because the top word appears in blue color.

Simon Squared. In Simon Squared, participants must select the response option that states the direction the arrow is pointing, while disregarding the side of the screen that the arrow appears on.

Flanker Squared. In Flanker Squared, participants must select the response option that has a central arrow pointing in the same direction as the flanking arrows in the stimulus that appears at the top of the screen. In the example shown in Figure 1, the correct response option is "> > < > >", because the stimulus at the top of the screen has flanking arrows pointing to the left ("< < > < <").

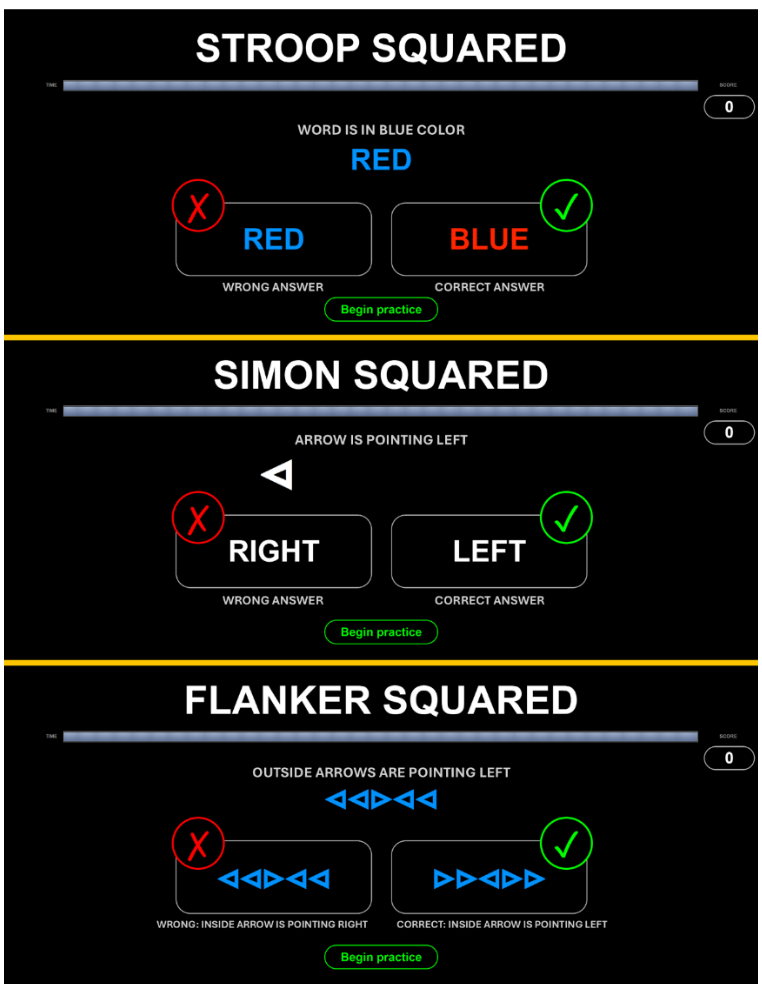

Figure 1. Three Squared tests of attention control, adapted from Burgoyne et al. (2023).

Statistical Analysis

Data Preparation. We removed any scores of zero points or worse, as these scores represent chance-level performance and suggest the participant did not understand the task or was not performing it as intended. There were 10 observations that met this criterion for Stroop Squared, seven for Flanker Squared, and zero for Simon Squared. We then created an attention control composite variable by averaging standardized scores (i.e., *Z* scores) on the three Squared tasks.

We used two different approaches to quantify the operators' performance. At the individual level, we used sleep-wake data to determine which operators were awake at the time that an error occurred. Any errors made by the platoon while an operator was awake were included in that operator's error count. Ideally, we would know which operators made the error, instead of using sleep-wake data to make these inferences, however, this level of specificity was unavailable to us. Additionally, at the platoon level, we counted the frequency of each type of error, and these frequency counts served as the overall measure of each platoon's performance.

Analytical Approach.

The primary goal of the analytical approach was to understand how attention control, at the individual operator level and overall platoon level, contributes to the likelihood of mission errors. To address this goal, we examined descriptive statistics on predictors of performance and compared operators' attention control scores by platoon. Furthermore, we assessed correlations between predictors of performance and mission outcomes, at both the individual-operator level and at the overall platoon level. We also conducted mixed models predicting mission performance at the individual-operator level, specifying a random intercept for platoon membership because operators were nested within platoons and different platoons had different error rates.

Results

Overall Descriptives

The three Squared tests of attention control demonstrated strong internal consistency, ranging from .87 to .94. Scores on Simon Squared (M = 57) were significantly higher than scores on the other two attention control tests (M = 23 and 24, respectively, both ps < .001), consistent with previous studies (Burgoyne et al., 2023). The attention control tests demonstrated acceptable skewness and kurtosis, with values falling between 0 and ±1.5.

The number of errors made by each platoon ranged from 0 (Platoon 8) to 10 (Platoon 3), with an average of 4 (SD = 3.4). At the platoon level, there was a trend such that UUV mission errors (11 errors) and planning errors (10 errors) occurred more frequently than PMA errors (3 errors) and safety errors (1 error) [1]. As shown in Figure 2, scores on the attention control composite differed significantly across platoons ($F(5, 52) = 2.68$, $p = .031$, $\eta_p^2 = .205$); the platoon with the highest attention control scores was platoon 6 (M = 0.45) and the platoon with the lowest scores was platoon 9 (M = -0.56).

Predicting Individual Operator-Level Performance

The attention control composite score was significantly negatively correlated with the frequency of operator PMA errors (r = -.34 [-.55, -.09], p = .009; R^2 = .1156). With respect to the attention control task-level scores, Simon Squared performance was significantly negatively correlated with PMA errors (r = -.44 [-.63, -.20], p < .001; R^2 = .1936), like what was found for

[1] Only one safety error occurred across all the platoons so is left out of analyses due to issues with estimating models.

the attention control composite. Of note, all three of the Squared tasks were negatively correlated with PMA errors, but only the correlations with Simon Squared and the attention control composite were statistically significant. Simon Squared was also positively correlated with planning errors (r = .30 [.05, .52], p = .022) (see Table 1).

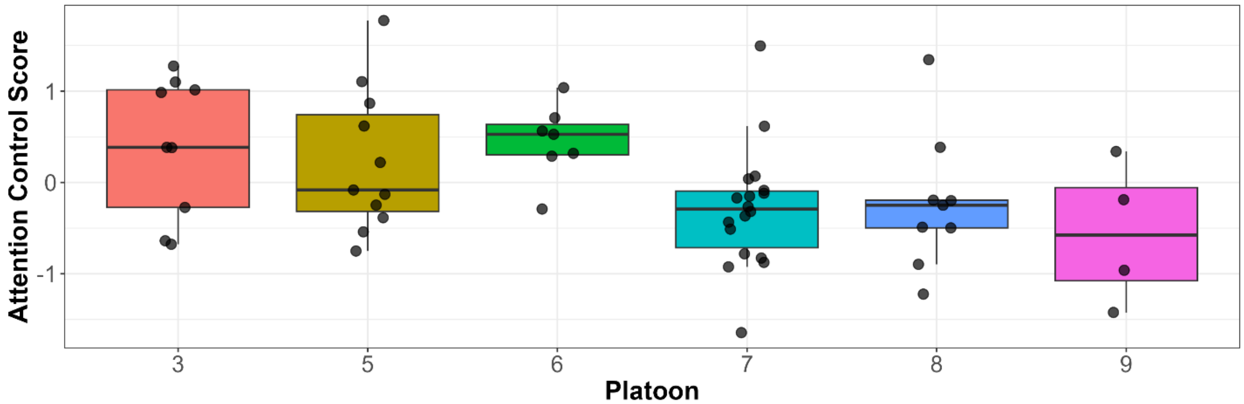

Figure 2. Boxplots of the Attention control composite scores by platoon.

Table 1. *Correlations among the individual-level variables*

Measure	1.	2.	3.	4.	5.	6.	7.	8.
1. Stroop Squared								
2. Flanker Squared	**.45**	---						
3. Simon Squared	**.36**	.26	---					
4. Attention Control Composite	**.80**	**.76**	**.73**	---				
5. Individual Total Errors	.15	.15	.18	.20	---			
6. Individual UUV Mission Errors	.11	.27	.07	.19	**.69**	---		
7. Individual PMA Errors	-.23	-.11	**-.44**	**-.34**	.09	.01	---	
8. Individual Planning Errors	.19	.06	**.30**	.24	**.85**	**.28**	-.18	---

Note. Pairwise n ranges from 46 to 65. Bold, statistically significant at $p < .05$. The red box highlights the specific correlations between attention control and operational errors.

Next, we conducted mixed models with the attention control composite specified as a predictor of mission performance. We allowed a random intercept for platoon membership because operators were nested within platoons and different platoons had different error rates. We ran separate analyses for each of the four measures of mission performance: (1) total errors, (2) UUV mission errors, (3) PMA errors and (4) planning errors. The models revealed an intercept that was greater than zero for total errors and UUV mission errors (ps < .02), but not for PMA errors or planning errors (ps ranged from .15 to .17), likely because these latter two error types occurred at a low frequency. The effect of attention control was negative for total errors, PMA errors, and planning errors, which was the predicted direction (i.e., greater attention control was associated with fewer errors), but positive for UUV mission errors. However, the effect of attention control was not statistically significant. Compared to the correlational analyses reported previously, these results account for platoon membership, which had a large effect on individual operators' error rates (i.e., mission performance) and possibly reduced the relative contribution of attention control in these models.

Predicting Platoon-Level Performance

For all six platoons, we computed the platoon's mean score on each attention control measure.[2] We summarized platoons' operational performance by counting the number of errors of each type. Correlations among the platoon-level variables are presented in Table 4. Due to the small sample (n = 6 platoons), these correlations have large standard errors; thus, only the strongest correlations will be statistically significant, and the more importantly, these results should be interpreted with caution. Three results are particularly interesting. First, the platoon's average attention control composite score was significantly negatively related to the number of PMA errors that platoon made (r = -.81 [-.98, -.002], p = .049). This indicates that across platoons, the ability of the operators to control their attention explained 65.61% of the variance in platoon PMA errors. This was corroborated by the relationship between the platoon mean on Simon Squared and PMA error rate (r = -.83 [-.98, -.07], p = .040, R^2 = .6889)

Table 2. *Correlations among the platoon-level variables*

Measure	1.	2.	3.	4.	5.	6.	7.	8.
1. Plt. Stroop Squared	---							
2. Plt. Flanker Squared	.63	---						
3. Plt. Simon Squared	**.95**	.73	---					
4. Plt. Attention Control Composite	**.93**	**.85**	**.98**	---				
5. Plt. Total Errors	.43	.28	.35	.36	---			
6. Plt. UUV Mission Errors	.22	.68	.23	.39	.66	---		
7. Plt. PMA Errors	-.73	-.65	**-.83**	**-.81**	.07	.07	---	
8. Plt. Planning Errors	.64	.15	.56	.47	**.84**	.21	-.26	---

Note. Plt. = Platoon. N = 6 platoons. Bold, statistically significant at $p < .05$. The red box highlights the specific correlations between attention control and operational errors.

Discussion

This study investigated the relationship between attention control and operational performance in UMS platoons. The study was situated within a final assessment exercise designed to assess operational readiness for deployment. The primary findings revealed a significant negative correlation between aggregate attention control performance and PMA error rates at the individual and platoon level. Furthermore, scores specifically on the Simon Squared task negatively correlated with PMA errors at the individual and platoon level. Last, attention control positively correlated with planning errors though only at the individual level.

PMA requires high levels of vigilance to detect threats amongst, even in ideal conditions. Indeed, the association between higher attention control ability and better PMA performance in a laboratory setting has been demonstrated previously (Dunn et al., 2023) and the findings here extend this finding to a field training setting under high operational tempo. Interestingly, the specific Simon Squared task embedded in the attention control battery correlated strongly with PMA performance at the individual and platoon levels. One possible explanation for this relationship is that Simon Squared is the fastest paced of the three Squared tasks, with subjects

[2] We also computed Best Linear Unbiased Prediction (BLUP; Robinson, 1991) estimates of each platoon's performance on the predictors, but because some random effects converged on 0, the resulting BLUP estimates were identical across platoons. Thus, we decided to use the platoons' mean performance, rather than the BLUP estimates, because this allowed us to differentiate between the platoons.

completing more trials at a faster rate (see Burgoyne et al., 2023). Thus, it is possible that this task places greater demands on perceptual speed and are thus more sensitive to the prediction of PMA performance, which often demands efficient, vigilant, and rapid information processing. Critically, PMA is a core functional area of the new RW rating across multiple ranks. For example, all Petty Officer RWs must be able to process, validate, and archive robotics data, and will likely be required under stressful and fatiguing expeditionary settings. Assessing attention control in tandem with Armed Services Vocational Aptitude Battery (ASVAB) entry standards may provide better selection fidelity and attention training protocols (e.g., Peng & Miller, 2016) embedded in schoolhouses may aid in optimizing this aspect of the RW mission.

We additionally observed an unintuitive positive correlation between attention control and planning errors at the individual level, though it is not immediately clear why. It is possible that high attention control individuals were associated with the group that made and error at random. Additionally, external factors such as stress and fatigue may have interacted with attention control in a way that was not measured by our current methods. More data is needed to replicate this finding and drive a more focused experiment to understand potential causes.

There were some limitations to this study, with the major limitation being that the study was conducted in a field setting that was controlled by an entity other than the research team. The FAE was proctored by the training unit instructor staff. While tasking for the FAE remained roughly the same across each platoon, there are slight variations in tasking depending on multiple variables such as weather, time, and platoon performance. Though this also serves as somewhat of a strength, as the research did not impact the operational environment. This is an organic view of how sailors perform during their training and evaluation. Another limitation to the study is that the attention control battery was conducted in the platoon's boat house during their preparation week prior to the FAE. This was due to the training unit's schedule and the research team minimizing the burden of collecting data during training. This resulted in operators conducting their attention battery in an open setting with some distractions present. While not ideal, this minimized the research team's footprint during the training pipeline and allowed for the collection of attention battery scores on all platoon personnel under the same conditions.

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