# The Effects of Dichotic Listening in Unmanned Aircraft Systems (UAS) Pilot Efficiency

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## ABSTRACT

The lack of standardized training for Unmanned Aircraft System (UAS) pilots presents a challenge for the consistent evaluation of pilot proficiency. While the FAA mandates simulation-based standards for manned aircraft (e.g., CFR Part 60), no equivalent guidelines exist for UAS operations. To address this gap, this study investigated how multisensory attention and multitasking demands affect performance in a simulated UAS task by replicating the cognitive load of real-world operations.

Participants completed a computer-based dual-task simulation that required visual monitoring and piloting of an on-screen simulated drone while filtering for relevant auditory instruction. Keyboard controls allowed for the maneuvering of the "drone" within a predetermined continuous flight path. For the listening portion of the task, participants had to filter among two competing streams of auditory input. One stream included relevant altitude directives and a working memory task (letter-span recall), while the other contained UAS-relevant background chatter (e.g., NOTAMs, weather updates) to serve as a distractor. Periodic auditory directives informed participants to redirect attention and respond to commands from the previously unattended stream. Performance was assessed by path-tracking accuracy, working memory recall, and response accuracy to altitude-change commands.

Findings revealed that simultaneous presentation of competing auditory signals during the working memory task disrupted verbal rehearsal, significantly lowering recall accuracy. Asynchronous presentation of auditory commands preserved memory performance, suggesting anticipation of task structure facilitated the strategic allocation of attention. Visual-manual tracking performance declined generally in later task phases but was not sensitive to auditory timing, which indicated the use of distinct resource pools for verbal and visuomotor tasks. These results demonstrate that the timing of auditory directives affects task performance more so than the mere presence of the directives alone, especially under high workloads.

These insights highlight the importance of incorporating realistic cognitive demands into UAS training. Findings can inform training standards that emphasize deliberate attention management, preparing operators for the multitasking challenges inherent to UAS missions and advancing industry-wide training provisions.

## ABOUT THE AUTHORS

**Bailey Miller** is a third-year graduate student in the Clinical Psychology Master's program at Texas A&M University–Corpus Christi. He earned his bachelor's degree in Psychology from the same institution, where he developed a strong foundation in research and human behavior. Bailey currently serves as a graduate research assistant with the Autonomy Research Institute (ARI), where his work focuses on cognitive processes such as working memory, attention, and the role of simulation in pilot training and assessment.

**Andres Castillo** is a second-year graduate student at Texas A&M University–Corpus Christi's Clinical Psychology Master's program. He holds bachelor's degrees in Biomedical Science, Philosophy, and Psychology from Texas A&M University–Corpus Christi. Andres is currently working as a research assistant with the Autonomy Research Institute.

His work focuses on working memory, attention, and the role of simulations in pilot training and assessment. Through this research, he aims to gain insights that may enhance cognitive training protocols and improve pilot performance.

**Dr. Collin Scarince** is an Assistant Professor in the Department of Psychology and Sociology at Texas A&M University–Corpus Christi. His area of expertise is in cognitive psychology, specifically regarding the applications of visual attention and decision-making. He obtained his B.A. in Psychology from University of Wyoming and his M.A. and Ph.D. in Experimental Psychology from New Mexico State University. He has published peer-reviewed articles in the domains of visual search, visual perception, and cognitive demands on uncrewed aircraft system operators. Currently, he is working collaboratively with the Autonomous Research Institute to study the human factors of operating uncrewed aircraft systems, particularly the cognitive demands of training for and carrying out operations in dynamic scenarios (such as search and rescue after a natural disaster or emergency response).

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## INTRODUCTION

Unmanned Aircraft Systems (UAS) have become increasingly integral across commercial, military, and emergency response operations. As of April 2025, the Federal Aviation Administration (FAA) reports over 1,000,000 registered UAS, with approximately 420,800 classified for commercial use, around 9,400 registered digitally for recreational use, and nearly 445,000 registered under legacy paper-based systems (Federal Aviation Administration, 2025).

Despite this prevalence, UAS operations present unique challenges that significantly differentiate them from traditional manned aviation. Operators must overcome narrowed fields of view, lack of direct sensory feedback, and complex operations such as Beyond Visual Line of Sight navigation (Qi et al., 2018). These factors critically impact situational awareness and decision-making. However, current UAS pilot training standards have not evolved proportionately to address these unique cognitive and operational demands. Building on prior work (Clausen et al., 2024, Scarince et al., 2024), this study explores the integration of multitasking stressors, including multisensory input, and use of simulation environments to enhance pilot readiness.

## ISSUES IN UAS PILOT TRAINING

The FAA defines small UAS (sUAS) as unmanned aircraft weighing less than 55 pounds (Small Unmanned Aircraft Systems, 2018). Correspondingly, sUAS pilot certification requirements are minimal, emphasizing general aviation safety rather than operational complexity (Dees & Burgett, 2022; Szabolcsi, 2016). While such knowledge-based licensing addresses public safety, it does little to prepare pilots for sophisticated cognitive and procedural competencies required for effective mission operations (Wallace, 2016).

Historically, UAS training has been fragmented, developed independently by organizations or military branches without a shared framework (McCain & Reed, 2015; Herrington et al., 2021). Even within formal military contexts, protocols vary substantially across service branches, affecting cross-organization coordination and effectiveness. The absence of training standardization has already demonstrated tangible consequences. A case study of UAV operations during Hurricanes Harvey and Irma (Greenwood et al., 2020) revealed that disparate training approaches hindered effective interagency communication and operational efficiency. Moreover, the Government Accountability Office (GAO) and the Senate Armed Services Committee have raised repeated concerns about UAS mishap rates, particularly emphasizing that Army UAS units experienced higher accident rates than their manned counterparts (McBride, 2017). Despite a growing reliance on UAS, the training ecosystem remains insufficiently equipped to handle the cognitive complexity these systems demand.

### Cognitive Demands Unique to UAS Operations

Operating a UAS imposes distinct cognitive demands that differentiate it from manned aviation. As UAS technology advances and platforms are deployed in increasingly complex mission profiles, the cognitive workload placed on pilots has grown substantially (Qi et al., 2018). Successful UAS operation requires a dynamic interplay of attention management, situational awareness, decision-making, and memory utilization. Pilots must manage a narrowed attentional focus while simultaneously monitoring multiple data streams, such as telemetry, video feeds, and auditory mission updates. Mental workload in UAS pilots has been shown to increase in demanding operational conditions, which is often reflected in both subjective self-assessments and physiological indicators. Duval et al. (2023) directly measured heart rate variability and pupil diameter during cognitively demanding UAS tasks, which supports these as reliable physiological metrics of UAS pilot stress and workload. These findings underscore the importance of designing training environments that prepare pilots to manage elevated cognitive strain effectively.

Attention management is particularly critical in UAS operations. Pilots must rapidly distribute attention across competing sensory channels while maintaining control of the aircraft (Lercel & Andrews, 2021). This ability is supported by working memory—a cognitive system used to process and act on immediate information—and long-term memory—used to retrieve procedures, mission objectives, and operational knowledge (Clausen et al., 2024). Optimizing timely verbal and motor responses requires effective processing and integration of continuous visual, verbal, and haptic inputs, all of which are crucial for mission success.

Effective decision-making further differentiates proficient UAS pilots. However, the perception of reduced personal risk in unmanned operations may foster complacency among less experienced pilots, leading to poor judgment and errors (Herrington et al., 2021). Conversely, minimal training can also lead to hesitancy, undermining effective problem-solving (Wheatcroft et al., 2017). Wheatcroft et al.'s (2017) findings demonstrated that professionally trained pilots outperformed private pilots in simulated decision-making tasks and that video game players, while showing some transfer of skills, still lagged behind professionally trained aviators (Ferraro et al., 2022; McKinley & McIntire, 2009). These outcomes suggest that while general experiential learning aids some cognitive functions, specific aviation-based training remains superior for flight decision-making competence.

Recent research has also emphasized the relationship between working memory and pilot performance. Scarince et al. (2024) investigated how auditory and visual working memory loads impact UAS performance. Participants completed three flight conditions: a baseline flight without cognitive loading, a flight while completing an auditory memory span task (recalling numeric sequences), and a flight with a visual working memory task (change detection among colored squares outside the flight path). Results indicated that introducing concurrent cognitive tasks degraded performance across all domains. Notably, the visual working memory task, which required pilots to divert their gaze from the flight path, produced the most significant performance decrements. Additionally, Clausen et al., (2024), a follow-up study, saw that integrating cognitive components in a simulated flight course decreased flight efficiency for experienced pilots when compared to a baseline course without cognitive workload. These studies highlight the effect of cognitive components on UAS operational performance.

Building upon these findings, Causse et al. (2016) demonstrated that high working memory load in simulated piloting tasks impaired participants' ability to process both written instructions and concurrent spoken auditory messages. During instances of high cognitive load, pilots exhibited decreased accuracy in following target aircraft in addition to diminished responsiveness to critical verbal cues. Brain activity and eye-tracking (Xie et al., 2023) measures revealed that pilots had greater difficulty focusing on new auditory messages under increased cognitive and attentional strain, which compromised their ability to correctly interpret and respond to communications. Results from this study showcase the risk of excessive working memory demands on a pilot's ability to efficiently manage auditory and visual information. The ability to successfully manage the allocation of attentional resources in these conditions is crucial for successful UAS operations that require the processing of dynamic visual feeds while maintaining responsiveness to auditory communications. These studies demonstrate that excessive cognitive strain that results in the simultaneous overload of both the visual and auditory systems can degrade operator performance. Further, such results also emphasize the need for UAS pilot training programs that incorporate strategies for managing cognitive load and attentional strain, especially in instances of competing interaction among domains of visual and auditory cognition.

## Addressing Multitasking and Cognitive Load: The Role of Dichotic Listening

Given the multitasking nature of UAS operations, training programs must prepare pilots to allocate attention effectively across simultaneous auditory and visual streams. Dichotic listening tasks offer a promising tool to simulate these multitasking demands in a controlled environment.

Dichotic listening involves presenting two distinct audio streams—one to each ear—requiring participants to selectively attend to and recall target information (Broadbent, 1958, p. 14; Cherry, 1953). This methodology mirrors real-world auditory filtering challenges faced by UAS pilots, such as dealing with crew communications while listening for air traffic control (Hobbs & Shively, 2014). Among these demands, prior research has also found that discrete alarms tend to elicit faster responses in controlled tasks. However, such tasks fail to simulate real-world conditions in which cognitive demands are more ambiguous and less predictable (Donmaz et al., 2009; Mobley et al., 2021). Integrating dichotic listening tasks into UAS flight simulations could provide dynamic and realistic training stressors, teaching pilots to sustain attention on critical streams while disregarding irrelevant noise.

Recent research has explored the use of dichotic listening tasks to improve selective attention under multitask conditions similar to those encountered in UAS operations. Tallus et al. (2015) conducted a training study in which participants completed forced-attention dichotic listening tasks. Participants were required to consistently report syllables presented to the left ear while omitting interference from any right-ear input. Participants showed measurable improvement in auditory spatial attention allocation, which was marked by an improved ability to override the natural right-ear advantage (REA) typically observed in verbal-related tasks. Additionally, these behavioral improvements were observable as neurophysiological changes associated with better cognitive control in auditory task performance. The findings from Tallus et al., (2015) suggest that dichotic listening tasks can inform targeted training interventions aimed at refining the top-down attentional control utilized by UAS pilots. Training in this domain promotes more effective management of the competing demands of simultaneous auditory and visual inputs during complex UAS operations (Scarince et al., 2024).

The current study extends this approach by embedding a dichotic listening task within a simulated flight control environment, requiring participants to manage both a dynamic visual flight task and an auditory attention task concurrently. Short-term memory demands are further integrated via a letter-span repetition subtask, simulating the type of memory load common in real UAS missions. Drawing on classic dichotic-listening work showing that simultaneous, competing auditory streams overload selective attention and degrade verbal recall (Broadbent, 1958; Cherry, 1953) and on training studies demonstrating that listeners can protect target information when competing messages arrive sequentially rather than concurrently (Donmez et al., 2009; Tallus et al., 2015), our first hypothesis (H1) predicted that letter-span accuracy would decline the most in the Synchronous-Call-Sign (SyncCS) condition, be intermediate in the No-Call-Sign (NoCS) condition, and remain comparable to Baseline in the Asynchronous-Call-Sign (AsyncCS) condition. Because visuomotor tracking relies primarily on visual–manual resources, our second hypothesis (H2) predicted that flight-path deviation would increase in the SyncCS condition since this is the only condition with competing demands on visual-manual resources; the AsyncCS condition and the NoCS condition will not differ from Baseline.

## The Current Study

### Method

To examine the effects of divided auditory attention on tasks relevant to UAS operations, the current study employed a within-subjects, dual-task experimental design. This paradigm simulated the cognitive demands of UAS piloting by combining a dichotic listening task with a visual motor tracking task, requiring participants to monitor competing auditory streams, encode verbal information, respond to target commands, and maintain continuous manual control of a visual stimulus. The experiment was structured into repeating trial cycles, with each cycle consisting of four single attention (Phase 1) trials, followed by one split attention (Phase 2) trial. This sequence continued for 20 iterations, yielding a total of 100 trials per participant. Temporal and cognitive load manipulations were within Phase 2 to assess how synchronous versus asynchronous auditory stimuli impact selective attention, working memory, and sensorimotor control under split-attention conditions.

### Participants

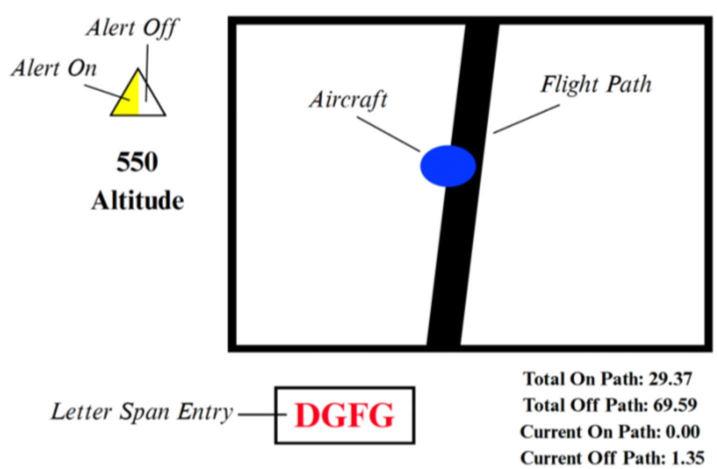
Twenty-nine undergraduate students (17 women, 12 men; *M* = 21.03 years, *SD* = 5.79, *range* = 18–46) were recruited from Texas A&M University–Corpus Christi. No data was recorded based on participant UAS or manned flight experience. The sample was racially and ethnically diverse with 23 identified as White (79.3 %), three as Black/African American (10.3 %), two as Asian/Pacific Islander (6.9 %), and one as other (3.4 %). Separately, 16 students (55.2 %) self-identified as Hispanic or Latino, and 13 (44.8 %) did not. All participants reported normal or corrected-to-normal vision and hearing and received course credit for participation. The study was approved by the university's Institutional Review Board.

**Procedure**

Participants were seated at individual computer stations equipped with over-ear headphones and full-sized keyboards. Each participant engaged in a dual-task experimental scenario that simulated the cognitive demands of unmanned aircraft piloting. The experiment was created using PsychoPy version 2024.2.4, an open-source application for creating experiments in behavioral science. The task was run locally on Windows-based machines, with full-screen mode enabled to ensure immersion and eliminate peripheral distractions. Auditory stimuli were pre-recorded and balanced for volume across channels using Adobe Audition, and all visual stimuli were rendered natively within PsychoPy via visual builder and code components. The task structure included two concurrent components:

**1. Dichotic Listening Task**
Participants engaged in a dichotic listening task in which two simultaneous auditory streams were delivered via over-ear headphones. In the left ear, a continuous stream of ambient radio chatter was presented throughout the task. In the right ear, a series of randomized four-letter strings was delivered. Each string was composed from the characters A, S, D, F, and G (e.g., "A-S-D-F," "F-S-F-A"), with the constraint that individual letters could appear no more than twice per string and not in direct repetition (i.e., no sequential duplicates such as "A-A"). Participants were instructed to retain each letter string in working memory and reproduce it using the keyboard with their left hand when prompted. This sequence continued across four cycles (referred to as Phase 1), allowing participants to become familiar with the task under relatively low cognitive load. Beginning on the fifth cycle (Phase 2), an alert would light up on the screen (see Figure 1). This would indicate the shift into phase 2, which would increase cognitive load by embedding altitude adjustment directives into the ongoing left-ear radio stream (see Figure 2). These verbal directives followed a standardized aviation format (e.g., "Bobcat, increase altitude to 1,250"). In half of these Phase 2 trials, the instruction did not include the participant's designated call sign ("Islander") and was to be ignored, serving as a distractor. In the remaining trials, the instruction did include the correct call sign, prompting participants to execute an altitude adjustment using the right-hand arrow keys (↑, ↓) on the keyboard. Phase 2 also introduced temporal manipulation of cognitive overlap. In 50% of phase 2 presentations, the letter span string was delivered synchronously with the altitude directives—resulting in simultaneous demands on auditory attention and working memory. In the remaining 50% of Phase 2 trials, the letter span occurred asynchronously, following the conclusion of the altitude directive. This design allowed for analysis of interference effects and attentional prioritization when competing auditory stimuli occurred concurrently versus sequentially.

**Figure 1. Dichotic Listening Task Screenshot**




*Note.* This figure depicts an edited screenshot of the computer task completed during the experiment. The alert light has been modified to depict its appearance when it is on (yellow) and when it is off (white). Participants used the keyboard to enter the letter span string into an on-screen text box.

**2. Simulated Flight Control Task**
In parallel with the dichotic listening component, participants engaged in a continuous visual-motor tracking task designed to simulate the real-time manual control demands encountered in unmanned aircraft operations. A moving aircraft marker was displayed on the computer screen, progressing across a predefined narrow flight path which would randomly deviate to the left, or right. Participants were instructed to maintain the marker within this path using the numeric keypad: 8 = Up, 2 = Down, 4 = Left, and 6 = Right. To simulate environmental instability and maintain task

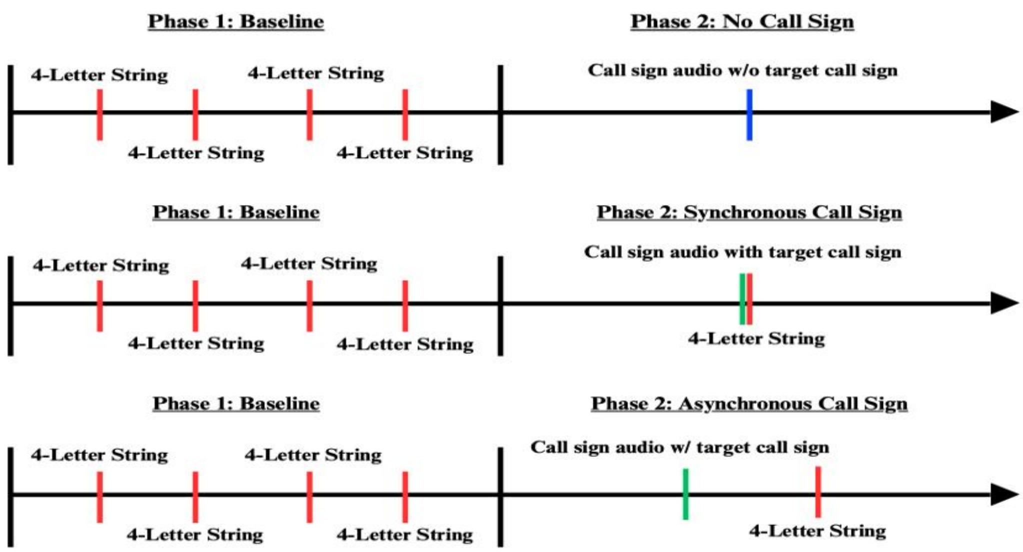
complexity, randomized drift was applied to the aircraft marker at irregular intervals. This drift varied in both intensity and directionality, requiring participants to apply continuous and precise manual corrections to remain within bounds. This task was performed concurrently with the auditory attention demands of the dichotic listening task, thereby replicating the divided attention and sensorimotor coordination required of UAS pilots. Participants had to simultaneously process auditory commands, retain verbal information in working memory, and maintain visual-motor control—mimicking the cognitive workload and multitasking profile of real-world drone operations.

**Measures**

To evaluate the effects of divided auditory attention and temporal interference on participant performance, three primary outcome measures were collected:

**Altitude Instruction Accuracy:** This metric measured the percentage of correct altitude adjustments made in response to call sign–relevant instructions embedded within the left-ear audio stream during Phase 2. Instructions not containing the participant's call sign were intended as distractors. Errors included both false alarms (responding to irrelevant call signs) and misses (failing to respond to the correct call sign). This measure was used to assess auditory discrimination, selective attention, and response inhibition under multitasking conditions.

**Figure 2. Dichotic Listening Task by Condition**



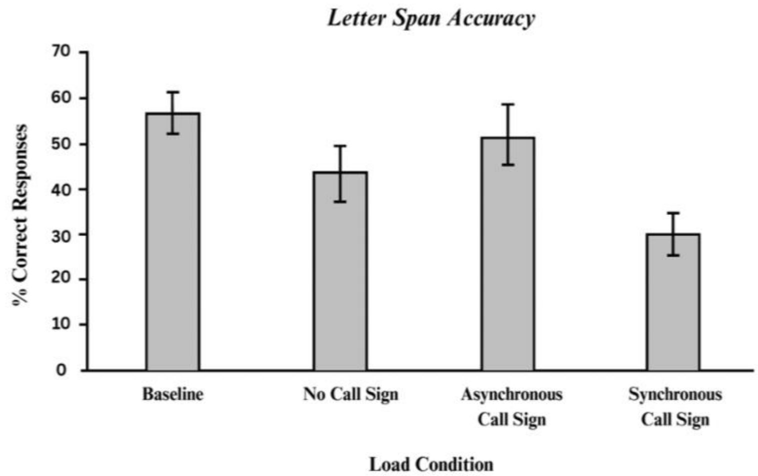

*Note.* Figure 2 depicts the timeline of Phase 1 (Baseline condition) and Phase 2 (NoCS, SyncCS, and AsynCS conditions) and the onset of audio in each phase. Audio featured commands using either the target call sign relevant to the participant (“Islander”) or a non-target call sign.

**Letter Span Recall Accuracy:** Accuracy of letter span recall was operationalized as the proportion of correctly reproduced four-letter strings entered via keyboard. A string was counted as correct only if all four characters were entered in the correct order. Accuracy was compared across synchronous and asynchronous conditions within Phase 2 to determine the effects of temporal overlap on working memory performance.

**Flight Path Adherence (Tracking Time):** The visual tracking component of the task measured the percentage of total time that the simulated aircraft marker remained within the designated flight path displayed on screen. This was recorded continuously throughout both phases and served as an index of sustained visual attention and manual control performance under increasing cognitive load.

These three metrics provided complementary indices of multimodal attention management, cognitive interference, and task prioritization under dual-task conditions. Together, they enabled an integrated assessment of how dichotic listening and cross-modal demands impact operationally relevant behaviors in simulated UAS control.

**Figure 3. Mean Letter-Span Accuracy Under Four Cognitive Load Condition**




*Note.* Error bars represent ±1 SE calculated within subjects (Cousineau–Morey adjustment); N = 26. Higher scores on the letter-span measures indicate better recall.

## Results

Preliminary screening showed no missing data. One participant was removed due to a technical error. Two additional participants were removed for consistently low letter-span accuracy across conditions. Because Mauchly's test indicated a violation of sphericity, $\chi^2(5) = 13.78$, $p = .017$, Greenhouse–Geisser corrections ($\varepsilon = .78$) were applied to all within-subjects tests. Pairwise comparisons for simple effects were made with Bonferroni-adjusted confidence intervals.

### Letter-span recall

Letter span accuracy scores were collected; participant responses that were 100% accurate compared to the presented letter span were counted as correct. Mean recall declined as concurrent task demands increased (see Figure 3). A one-way repeated-measures ANOVA revealed a significant main effect of cognitive-load condition, $F(2.19, 54.71) = 8.87$, $p = .001$, $\eta_p^2 = .26$. Pairwise comparisons showed that Baseline condition ($M = 56.35$, $SD = 22.18$) produced significantly higher scores than the NoCS condition ($M = 43.08$, SD = 30.04), $p = .021$, and the SyncCS condition ($M = 30.00$, $SD = 23.49$), $p < .001$. The AsyncCS condition ($M = 51.54$, $SD = 34.02$) did not differ from the Baseline trials ($p = .626$) or the NoCS condition trials ($p = .375$) but significantly outperformed the SyncCS condition ($p = .036$).

### Off-path deviation

Tracking performance showed only a weak sensitivity to cognitive-load manipulations. The overall effect of load on track-deviation counts did reach significance, $F(2.13, 53.18) = 2.28$, $p = .11$, $\eta_p^2 = .08$. Post-hoc comparisons revealed that baseline trials produced fewer deviations ($M = 39.47$, $SD = 22.91$) than the NoCS condition ($M = 48.46$, $SD = 31.96$;), Bonferroni-adjusted $p = .040$), (see Figure 4). Because this contrast emerged in the absence of a significant omnibus test, it should be interpreted cautiously. Note that higher off-track values reflect poorer tracking accuracy.

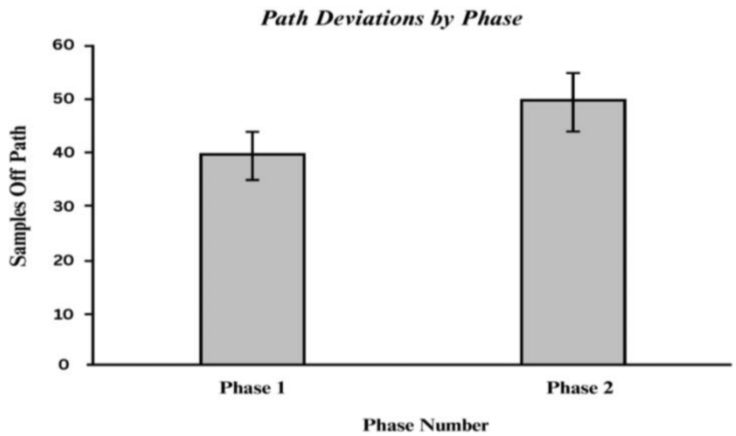
### Altitude Instruction Accuracy

Altitude instruction accuracy measured the percentage of correct altitude adjustments made in response to call sign–relevant instructions embedded within the left-ear audio stream during Phase 2. A paired-samples t-test revealed no significant difference between the cognitive load conditions, AsyncCS and SyncCS, $t(25) = –1.10$, $p = .283$ (two-tailed).

### Performance Tradeoffs

To examine potential tradeoffs between cognitive and flight-related tasks, bivariate correlations were computed among letter span score, path deviation, and altitude instruction accuracy within each load condition. In the asynchronous condition, letter span was strongly negatively correlated with path deviation ($r$ = –.697), indicating that better memory performance was associated with reduced time off path. Letter span was also moderately positively correlated with altitude accuracy ($r$ = .481), and altitude accuracy was moderately negatively correlated with path deviation ($r$ = –.531). In the synchronous condition, a moderate negative correlation was found between altitude accuracy and path deviation ($r$ = –.419).

**Figure 4. Mean Path Deviation by Phase**




*Note.* The figure illustrates the mean number of times subjects deviated off path during the respective phases. Phase 1 included only the Baseline condition, while Phase 2 included the NoCS, SyncCS, and AsynCS conditions. Error ±1 *SD* calculated within subjects (Cousineau-Morey adjustment); $N$ = 26.

## Discussion

This study examined whether the timing of competing auditory streams disrupts both verbal working memory and visuomotor tracking during a dual-task UAS simulation. As predicted in H1, synchronous call sign traffic produced the steepest decline in letter-span accuracy, whereas asynchronous traffic did not differ from Baseline. In contrast, H2 was not supported; although flight-path deviation worsened from Phase 1 to Phase 2, the three Phase-2 conditions (NoCS, AsyncCS, SyncCS) did not differ from one another.

Classic dichotic-listening studies show that when two spatially separate streams arrive simultaneously, the selective-attention filter quickly saturates, degrading recall unless the listener can momentarily retune the filter to favor one channel over the other (Broadbent, 1958, pp. 251–252; Cherry, 1953). The synchronous call sign condition reproduced that overload: the call-sign directive intruded during rehearsal of the four-letter string, forcing the phonological loop to juggle two verbal codes and depressing accuracy. When the directive followed the letters (asynchronous call sign), rehearsal time was preserved and recall returned to baseline. Participants may also have adapted strategically in the asynchronous blocks: because call signs always followed—never coincided with—the letter string and there was no no-call-sign counterpart, they could anticipate the pattern and pre-allocate attention. These results echo Tallus et al.'s (2015) training data which found evidence to support the transfer of dichotic listening training to stimuli presented unilaterally (i.e., asynchronously to either the right or left ear) with increased responses to stimuli presented to the left ear. In synchronous conditions, no observed increases in responses to stimuli presented to the left ear for participants trained in a forced attention task designed for participants to prioritize responses to left ear input over right ear input as initially expected. These findings suggest a more prominent role for temporal patterns and familiarity with stimuli when preserving information related to target directives.

The study predicted (H2) that flight-path deviation would increase only when altitude-change directives overlapped synchronously with the letter-span stream (SyncCS condition), because that timing forces visual-manual resources to compete. Contrary to this prediction, the effect of auditory-load was nonsignificant, and the three Phase-2 blocks (NoCS, AsyncCS, SyncCS) did not differ significantly from each other. However, phase-level comparison revealed that flight-path adherence deteriorated from Phase 1 to Phase 2, indicating that once altitude directives were introduced, tracking performance suffered broadly, but not in a condition-specific manner. Unequal trial counts may have contributed to the insignificant findings between conditions. Participants completed 80 Baseline trials, whereas across all Phase 2 only 10 NoCS and five trials each in the AsyncCS and SyncCS blocks. The sparsely sampled Phase-2 conditions likely produced noisy deviation estimates.

Our findings do not suggest performance tradeoffs between cognitive and flight-related tasks. For example, better memory performance (letter span) was associated with improved, not worsened, flight metrics. The consistent directionality of correlations implies that participants who performed well on one task tended to perform well across the board. This may reflect stable individual differences in cognitive capacity or task engagement, rather than a redistribution of limited cognitive resources.Visual–manual steering and auditory–verbal processing appears to draw upon partially distinct resource pools (Wickens, 2008). Participants likely adopted a task-management strategy that paused letter-span rehearsal during call-sign directives but never relinquished cursor control. The small, nonsignificant rise in off-track samples thus reflects a strategic trade-off, not a true capacity failure. Our data refine prior UAS findings by Scarince et al. (2024) and Causse et al. (2016) by showing that when an additional task begins matters: synchronous auditory-verbal load disproportionately impairs memory yet leaves manual tracking resilient in novice operators. For experienced pilots—who allocate attention more fluidly (Donmez et al., 2009)—the trade-off curve may shift; an idea future studies should test.

**Practical implications**

Together, the findings point to three complementary pathways for improving operational safety and efficiency in the UAS. First, communication protocols can be re-timed so that non-urgent radio traffic is withheld until memory-intensive checklist items, such as entering GPS waypoints or updating flight plans, are complete, thereby preventing the most disruptive temporal overlaps. Second, adaptive ground-station automation could monitor real-time workload indicators (e.g., keystroke latency, heart-rate variability) and automatically throttle, queue, or re-order dispatcher messages whenever the operator's cognitive load spikes, releasing them only when spare capacity is detected. Finally, simulator curricula should deliberately vary the temporal relationship between verbal inputs and concurrent memory tasks, giving trainees repeated practice at allocating attention when auditory messages arrive either concurrently with or staggered after ongoing rehearsal demands; this rehearsal builds the top-down control strategies needed to manage genuinely busy radio environments. Taken together, these timing-focused adjustments, spanning protocol design, intelligent automation, and targeted training, offer a pragmatic route to mitigating cross-channel interference in UAS missions.

**Limitations and future directions**

The study's primary constraint lies in its highly controlled, laboratory-style task, which—while intentionally simplified for novice participants—only approximates real-world aircraft-monitoring demands. Because the sample consisted of undergraduates rather than certified UAS pilots, the findings may not extend to professional crews. With just 26 usable cases, the study was sufficiently powered to detect large effects but likely missed finer load-by-task interactions. Moreover, the simulator lacked operational pressures such as tight mission timelines or unexpected system warnings.Future studies should break up recall accuracy by each letter position to see whether the synchronous call-sign interferes with the very first intake of information, the ongoing rehearsal loop, or the final recall stage. A scheduled Fall 2025 replication will introduce an Asynchronous–No-Call-Sign control (letter span delivered after distractor chatter with no altitude directive) and rebalance the trial structure to roughly 50:50 between single- and split-attention phases, eliminating the current practice asymmetry. Parallel efforts will test experienced UAS operators in a high-fidelity simulator, coupling performance metrics with physiological such as, heart-rate variability, to model moment-by-moment resource reallocations. Together, these refinements should help clarify not only whether divided-attention costs emerge, but where in the working-memory timeline and for whom they are most acute, further informing targeted training interventions for both novice and expert drone pilots.

In conclusion, temporal overlap between verbal radio traffic and memory rehearsal imposes a measurable cost on working-memory accuracy without equivalently degrading continuous tracking. Integrating temporal-load management into communication protocols and simulator curricula could enhance both safety and efficiency in UAS operations.

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