



Defining and Enhancing Operationally Relevant Auditory Processing Skills

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14. ABSTRACT Military aviation requires its professionals to perform several hearing critical tasks (HCTs) throughout a mission. Such tasks involve the need to hear an excessive amount of auditory information and process it quickly in order to make crucial decisions. Compounding the difficulty of these tasks is the fact that pilots and aircrew must perform HCTs in a hazardous and excessively noisy operational environment. The goal of the current study was to determine if a commercially available CBAT program could enhance speech understanding (i.e., speech recognition or speech intelligibility) in noise and auditory working memory in Army aviators. Despite the limitations and challenges associated with this study, we are able to take away a few key points. The training program employed did not yield enhancements in speech intelligibility in noise or auditory working memory performance. The results of this study, however, are not sufficient to rule out the efficacy of this training type in this population of aircrew given the small sample size as well as limitations in exploring individual differences.					
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Summary

Military aviation is one occupational specialty that requires its professionals (e.g., pilots, aircrew members, flight surgeons, flight medics, etc.) to perform several hearing critical tasks (HCTs) throughout a mission. Such tasks involve the need to hear an excessive amount of auditory information, such as alarm signals and radio communications, and process it quickly in order to make crucial decisions, often with life or death consequences. Compounding the difficulty of these already challenging tasks is the fact that pilots and aircrew must perform HCTs within a hazardous and excessively noisy operational environment.

The presence of background noise substantially degrades the quality of speech signals and can adversely affect the mental effort required to understand the content of verbal messages. In particular, higher-ordered cognitive operations requiring mental resources (e.g., auditory comprehension) reallocate to basic auditory perception. This means mental effort redirects from understanding the speech signals to focusing on simply being able to hear them. As such, it is not surprising that decades of research shows listeners are less likely to understand and retain what is heard when speech signals are degraded.

Some important considerations to note are pure tone hearing thresholds do not predict individual performance on HCTs and even normal hearing listeners can have difficulty understanding speech in the presence of background noise. Furthermore, even if an individual does not display problems understanding degraded speech signals, the cognitive processing required for effective comprehension can be taxing on an individual's mental capacity. As such, performance is not only about how well a person understands a particular set of instructions, but also about how hard a person has to try in order to achieve adequate understanding. Over the course of a long duration mission, the additional effort allocated to speech understanding could potentially increase fatigue of an operator and decrease overall performance.

Previous research suggests that auditory training activities can enhance auditory perception and understanding. Particularly of interest, evidence in the literature exists that supports the use of computer-based auditory training (CBAT) programs that utilize speech-in-noise material to improve speech-in-noise understanding in adults with normal hearing. However, research investigating the effect of auditory training in a military population who perform HCTs is lacking. The goal of the current study was to determine if a commercially available CBAT program could enhance speech understanding (i.e., speech recognition or speech intelligibility) in noise and auditory working memory in Army aviators.

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Background

Currently, pilots monitor several independent radio channels in order to stay in continual communication with other aircrafts, ground troops, and air traffic control during various phases of a mission. Pilots also communicate with each other and with other aircrew members using the internal communication systems. Ultimately, pilots must be able to hear and quickly understand verbal messages critical to mission success and mishap prevention, frequently making split-second decisions that often have life and death consequences (Rabinowitz et al., 2009). Adding to these already challenging hearing critical tasks (HCTs), pilots and aircrew perform HCTs while in an operational environment inundated with high-level noise generated by the aircraft. The current study aimed to determine if computer-based auditory training (CBAT) could enhance speech-in-noise understanding (i.e., speech recognition or speech intelligibility) and auditory working memory in Army aviators.

The ability to hear and understand multiple incoming auditory streams simultaneously requires selective and divided attention. Brungart (2001) reported that when a target speech signal is presented in the context of other competing speech signals, greater informational masking occurs and performance is decreased. Informational masking refers to a situation where a listener has to separate acoustical features of sounds that are similar (e.g., competing speech). The difficulty in understanding speech in the midst of competing talkers is exacerbated by the presence of background noise (Abel et al., 2012) due to energetic masking, which results from the poor signal-to-noise ratio caused by the spectral overlap of the speech and masker (e.g., the noise of an engine). Although these masking effects often lead to difficulties understanding speech, top-down cognitive processing and exerting additional mental effort (i.e., listening 'harder') can overcome these difficulties to some extent.

Speech understanding in noise requires the ability to detect, identify, group, and segregate auditory elements into separate mental representations (i.e., auditory streams or objects). This process has been named auditory scene analysis (ASA) or stream segregation (Bregman, 1990), and involves both peripheral auditory encoding and cognitive processing (Arlinger et al., 2009). According to ASA, the human auditory system groups together sounds originating from the same source while those from different sources are perceptually segregated. Indeed, previous research has linked speech intelligibility performance in adverse listening conditions to central processing and cognitive executive functions, such as working memory (WM), processing speed, inhibition, and attention (Akeroyd, 2008; Anderson et al., 2013; Arlinger et al., 2009; Schneiders et al., 2012; Wingfield & Tun, 2008).

Specifically, working memory capacity (i.e., the ability to store and process information concurrently) seems to influence a listener's speech recognition in noise, whereas other executive function skills, such as attention, influence how a listener focuses on one or more simultaneous sound sources (Akeroyd, 2008; Arlinger et al., 2009). Akeroyd (2008) reported that while there is a link between cognition and speech reception in noise, tests of WM were more effective at predicting speech recognition in noise abilities than other measures of global cognitive skills (e.g., intellectual quotient scores). Given this, it seems reasonable to suggest improving certain executive functions and cognitive skills related to auditory processing may enhance the ability of listeners to understand speech in noisy environments.

Brain enhancement, or rather cognitive training, has been touted as a method to improve cognitive abilities for specific populations such as the elderly, patients with neurological or psychiatric disorders, students who could benefit from accelerated learning, members of the general population at large, and adults who work under demanding conditions (Taya et al., 2015). Specifically, military populations have been identified as an occupational cohort that not only works under demanding conditions, but one that could benefit from cognitive training, as “they need to engage in operations for a long duration with high workloads and pressure, and even a small error in the operations could result in fatal accidents” (Taya et al., 2015, p. 2). While the allure of implementing such ‘brain enhancement’ techniques for improving performance of our military personnel is inviting, the lack of generalizability of cognitive training to other working areas of executive function remains a key criticism (Morrison & Chein, 2011; Taya et al., 2015).

One study suggested that if cognitive training focused on higher-order tasks (i.e., WM or attention), generalization and behavioral performance improvements could likely be achieved (Taya et al., 2015). However, improvements can vary across patients or participants, and are likely the result of individual motivation, mental state at the time of training, and difficulty level of the training task. Wayne et al. (2016) tested speech-in-noise recognition among older adults following cognitive training, specifically the commercially available Cogmed Working Memory Training program (www.cogmed.com), and found no significant improvements to intelligibility performance. It is important to note these studies did not evaluate the use of auditory-specific training materials and their effectiveness for improving speech understanding in noise.

Auditory training is a broad term referring to listening programs that systematically present various sounds such that listeners are taught to make perceptual distinctions between those sounds (Olson, 2015). Numerous auditory training programs exist varying in material content, corresponding visual objects, and delivery methods, but they all aim to increase a listener’s ability to compensate for auditory signal degradation caused by either internal (e.g., hearing loss) or external (e.g., noise) factors (Chilsom et al., 2013). Indeed, several studies have shown auditory training enhances speech understanding in background noise (Burke & Humes, 2007; Cainer et al., 2008; Mossbridge et al., 2006; Olson, 2015; Song et al., 2012; Wright et al., 1997). Findings from these studies are encouraging and suggest the implementation of an auditory training program may be a viable option for enhancing aviator and aircrew performance when listening to multiple radios in a highly noisy environment.

While findings from these above studies are promising, multiple reports suggest that improvement in speech intelligibility due to auditory training is highly variable, with variance tied mainly to individual compliance with completing the program (Olson, 2015; Sweetow & Palmer, 2005). Compliance, or commitment to adhere to and complete the training program, has been reported to be tied to an individual’s motivation to improve listening skills (Sweetow & Henderson-Sabes, 2007). Additionally, an association between perceived difficulties (i.e., perceived handicap) in hearing speech in noise and overall improvement an individual received from treatment has been reported (Sweetow & Henderson-Sabes, 2007). Potential solutions for increasing compliance include programs that could be completed at home (i.e., out of the office) and programs with self-paced training activities.

Computer-based auditory training (CBAT) programs allow the individual to work at their own pace within the comfort of their home. This style of training has been shown to significantly improve verbal WM, verbal learning, memory and global cognition in older adults with hearing loss (Burke et al., 2006; Sweetow & Henderson-Sabes, 2004, 2006, 2007), and adults with schizophrenia (Fisher et al., 2009). One such CBAT program is the Listening and Communication Enhancement™ (LACE™) training program. LACE™ was initially designed for at home use (via compact disk and computer) among older adults with hearing loss as an aural rehabilitation tool to improve listening and communication skills; LACE™ also provides strategies to help compensate in situations when hearing is inadequate (Sweetow & Henderson-Sabes, 2007). The LACE™ training program uses adaptive interactive tasks covering three categories: degraded speech (i.e., competing speaker, speech-in-noise, and time-compressed speech), cognitive skills (i.e., auditory memory, auditory closure), and communication strategies (i.e., helpful hints that improve speech perception).

Presently, there is limited information concerning the application of auditory training to enhance speech recognition or intelligibility in noise among young adults with normal hearing. One study has demonstrated LACE™ to be effective for young adults with normal or near-normal hearing (Song et al., 2012). Specifically, Song et al. (2012) found that short term auditory training (i.e., LACE™) among a cohort of young adults with normal hearing altered the biological mechanisms that subservise speech-in-noise perception and resulted in improved performance on behavioral measures (i.e., Quick Speech In Noise [QuickSIN]). Among a cohort of Veterans with hearing loss aged 58 to 85 years old, LACE™ was found to aid in on-task (i.e., related to training) and off-task (i.e., novel, not related to training) perceptual learning (Sweetow & Palmer, 2005). Such off-task outcomes include a significant increase (with a small effect size) in understanding both rapid speech and speech in noise. Using LACE™, Sweetow and Henderson-Sabes (2004, 2006) demonstrated improvement in speech-in-noise performance across adulthood with standardized assessments as the Hearing in Noise Test (HINT) and QuickSIN.

Criticism regarding the benefit of auditory training has suggested that individuals improve only on the tasks for which they are trained, rather than seeing a global improvement (Henshaw & Ferguson, 2013; Sweetow & Palmer, 2005). While the ultimate goal of the current effort is to determine the efficacy of auditory training for enhancing the ability of aviators to monitor multiple streams of information simultaneously, the current study aimed to evaluate the efficacy of a commercially available CBAT to enhance performance on auditory working memory and speech recognition in noise. Additionally, the study aimed to explore the potential roles of individual differences in performance and the likelihood a listener would be to benefit from auditory training.

Methods

In order to evaluate whether use of a CBAT program, specifically one involving speech-in-noise material, improves speech-in-noise understanding in healthy adults with normal hearing, a pre- and post-test, between-subjects design was used which included an experimental group (two-week CBAT program) and a control group (no CBAT training over two weeks).

Participants

Participants were 16 aircrew members (15 were military Service Members and 1 was a Department of the Army civilian) recruited from the population in and around Fort Rucker, AL (14 were male and 2 were female; $mean_{age} = 38.63$ years, $SD_{age} = 3.93$, $min_{age} = 32$, $max_{age} = 46$). Volunteers were eligible for participation if they met the criteria listed in Table 1. An additional four volunteers were disqualified prior to study enrollment (a total of 20 volunteers).

Table 1. Participation Eligibility Criteria

Determined via Self-Report:

Between 19 to 50 years old

An aircrew member (Military Service Member, Federal Civilian or contractor) whose occupational specialty (i.e., job series) requires the use of flight class standards 1, 2, or 3 (e.g., pilot, pilot applicant, flight surgeon, flight surgeon applicants, aero-medical physician assistants [APAs], APA applicants).

Have current medical clearance for flight operations (DD Form 2992)

Have access to a device with a web browser and internet

Be a native English speaker

Have normal to corrected normal vision

Determined via Study Procedures:

Have normal otoscopic exam, normal tympanometry, and normal to near normal hearing

Earn a Word Auditory Recognition and Recall Measure (WARRM) word recognition score of at least 50%

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Materials

Otoscopic exam.

The otoscopic exam is a standard clinical evaluation performed by completing a physical inspection of the participant's outer ear and ear canals with a lighted otoscope. Participants were eligible for the study if their tympanic membrane (TM) was visible, appeared normal, and ear canals were free of debris and excessive cerumen (earwax).

Tympanometry.

The Grason-Stadler TympStar ProTM tympanometer measures the flexibility of the TM and can indicate abnormal middle ear function (e.g., TM perforation, otitis media with effusion, severe cold). A small probe (rubber eartip) was placed in the entrance of the external auditory meatus (ear canal) to completely seal the opening to the canal. A 226-Hertz (Hz) tone was introduced through the probe while a mild positive and negative pressure was applied. Participants were eligible for participation if their peak pressure (daPa) was between -100 and 100, compliance [tympanic membrane movement noted in milliliters (ml)] was between .200 and 1.40, and ear canal volume [centimeters squared (cm³)] was between .630 and 1.46.

Pure tone audiometry.

The Grason-Stadler AudioStar ProTM audiometer and Telephonics TDH-50P headsets were used to measure hearing thresholds to pure tones. Testing was completed monaurally for both the right and left ears. The participant listened for a pure tone (test frequencies: 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kilohertz [kHz]), and the intensity of the pure tone varied based on the listener's response. If the listener responded accurately (i.e., pressed the response button when they heard a tone), the pure tone decreased by 10 dB HL (hearing loss in decibels). If the listener responded inaccurately (i.e., pressed the button in the absence of a pure tone), the intensity increased by 5 dB HL. This bracketing method continued until the listener's auditory threshold was determined for all test frequencies. Threshold was defined as the softest level (dB HL) to which a listener heard a tone at least 50% of the time. Zero (0) dB HL is the average threshold for human adults who demonstrate no hearing loss. Participants were eligible for the study if they demonstrated hearing within (near) normal limits (0 to 25 dB HL) at each test frequency.

Shipley Institute of Living Scale.

The Shipley Institute of Living Scale (SILS) assesses general intellectual functioning in adults and adolescents and detects cognitive impairment in individuals with normal original intelligence. The SILS yields three major summary scores: vocabulary, abstraction quotient, and combined total scores. The vocabulary subscale consists of 40 multiple-choice verbal reasoning questions that primarily tap crystallized intelligence. The abstraction subscale includes 20 series completion items of inductive reasoning that tap fluid ability (Zachary, 1986). Convergent validity of both the vocabulary and abstraction measures with crystallized and fluid intelligence (respectively) has been assessed and confirmed in a general population (Matthews et al., 2011). The SILS was administered to participants via the paper AutoScore Form (W-177D) and pencil.

Digit Span task.

The Digit Span task (Miller, 1956) is a standard cognitive test for working memory (attention, short-term memory, and verbal working memory) (see Conway et al., 2005 for a review). Participants recall strings of numbers that increase in length. The number of digits increases by one until the participant consecutively fails two trials of the same digit span length or when the maximal length is reached. The longest string length accurately recalled is recorded. This task was administered and data recorded electronically.

Word Auditory Recognition and Recall Measure.

The Word Auditory Recognition and Recall Measure (WARRM) measures auditory working memory for speech (Smith et al., 2016). The WARRM provides several outcome measures: word recognition score (percent correct), judgment score (percent correct), and word recall score (percent correct and span score — the maximum set size for which at least three of the five trials in the set are recalled correctly). One hundred monosyllabic target words are arranged in set sizes of 2, 3, 4, 5, and 6 words with 5 trials in each set size. Target words are presented in quiet after the carrier phrase “You will cite the word.” The target word always changes, and the participant repeats back the word heard (word recognition score). Upon repeating each word, participants engage in a processing task where they report if the first letter of the target word belongs to the first half (A-M) or the second half (N-Z) of the alphabet (judgment score). At the end of each trial, a recall prompt (i.e., brief 500 Hz tone) is presented. At the prompt, the participant recalls all the words from that trial that they remember (word recall score and recall span). Testing was delivered binaurally through the Telephonics TDH-50P at 50 dB HL and scoring was done manually on a word-by-word basis by two raters using paper scoresheets. Participants were eligible for participation in this study if they earned a word recognition score of at least 50%.

100 word Speech Reception in Noise Test.

The 100 word Speech Reception in Noise Test (SPRINT₁₀₀) is a clinical test of speech recognition in noise that consists of 100 monosyllabic words presented in a background of multi-talker babble noise. The speech-to-babble ratio (+9 dB) is such that normal-hearing listeners should identify 95-100% of the words correctly. The SPRINT₁₀₀ score is the total number of monosyllabic words correctly identified (and corresponding percentile ranking based on a standardization sample; Cord, Walden, & Atack, 2019). The SPRINT₁₀₀'s test-retest reliability has been shown to be robust for Soldiers with H-3 profiles (Cord, Walden, & Atack, 2019). Testing was delivered binaurally through the Telephonics TDH-50P at 50 dB HL and scoring was done manually on a word-by-word basis by two raters using paper scoresheets.

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Aviation Speech in Noise Test.

Aviation Speech in Noise Test (ASINT) presents twenty phrases from each signal-to-noise ratio (SNR) level (SNR Levels: high, medium, low), equaling 60 phrases total. Testing was delivered binaurally through the Telephonics TDH-50P at 50 dB HL and scoring was done manually on a word-by-word basis by two raters using paper scoresheets. The total correct (raw and percent) were calculated for each phrase and list. Note that if a participant gave multiple answers for a perceived phrase, only the first phrase answer was counted.

Instructions read to the participant were:

“You will be hearing a recording of a man's voice saying some phrases. At the same time, in the background, there will be the sound of a Black Hawk helicopter in flight. I want you to repeat back the words that the man is saying. Some of the words may be difficult for you to hear. If you're not sure what the word is, take a guess. You will be hearing the words and the helicopter noise in both earphones at the same time.”

ASINT with task switching.

Participants completed the ASINT task again with different combinations of phrases and SNR levels than the first administration. Simultaneously, participants completed Psytoolkit's task switching activity (<https://www.psytoolkit.org/experiment-library/taskswitching.html>) on a laptop computer. This activity is referred to as ASINT with task switching (ASINT-TS). Task switching tasks are designed so that participants rapidly alternate between two different cognitive tasks. During this activity, participants viewed different alphanumeric stimuli appear on a quadrant plane. They responded to the stimuli according to rules based on the type and location of alphanumeric item. Specifically, the alpha- (consonant/vowel) or -numeric (odd/even) quality of the stimulus and its quadrant location (top/bottom/left/right) determined the correct response, which was either the “b” or “n” key. Data related to task engagement (e.g., correct responses, reaction times) were recorded electronically.

Intervention

Participants in the experimental group were given a unique email address, password, and access code separate from any personal accounts and that contained no identifying information to complete the Listening and Communication Enhancement™ (LACE™) Online (LACE™ OnLine [LOL]) Program, <https://www.lacelistening.com> (Neurotone, Inc.). The LACE training is an interactive and adaptive computer-based program that consists of 11 training sessions, each of which are approximately 20 minutes in length. Participants were instructed to complete all training sessions in two weeks (approximately 2 hours per week). The following training tasks were included in the LACE Program:

Competing speaker.

The participant listened for sentences presented at the same time as another single talker spoke, with the goal of trying to listen to and repeat (aloud or silently, whichever they preferred) what was heard. The initial signal-to-noise ratio (SNR) was + 10 dB (i.e., the signal of interest (target talker) was 10 dB louder than the noise (competing talker). Once the sentence was played, the participant was visually presented with the sentence, and asked if they understood every

word in the sentence. The sentence was then presented again in both the auditory and visual mode. If the participant responded “yes,” the competing speaker’s volume was increased by 4 dB (increasing the noise level, decreases the SNR, making the auditory task more challenging). If the participant responded “no,” the competing speaker’s volume was decreased by 4 dB (decreasing the noise level, increases the SNR, making the auditory task less challenging). In both instances, the loudness level of the signal of interest was not altered. This adaptive strategy continued for five presentations, and then the noise levels were altered by either + 2 dB. A decrease in score indicates improvement.

Speech-In-Noise.

Similar to the competing speaker task, the participant listened for sentences that were displayed in the presence of noise (multitalker babble), with the goal of trying to listen to and repeat what was heard. The initial SNR was + 10 dB. Once the sentence was played, the participant was visually presented with the sentence and asked if they understood every word in the sentence. The sentence was then presented again in both the auditory and visual mode. If the participant responded “yes,” the next sentence was presented at the same intensity level, and the multitalker babble was increased by 4 dB. If the participant responded “no,” the multitalker babble was decreased by 4 dB. In both instances, the intensity level of the signal of interest did not change. This adaptive strategy continued for five presentations, and then the noise levels were altered by either + 2 dB. A decrease in score indicates improvement.

Word memory.

The participant was asked to listen to sentences of varying lengths, and using a provided visual target word (TW), identify the word presented just before the TW from a multiple-choice option bank. Once the participant selected an answer, the sentence was then presented visually again with the correct word underlined. The bracketing method for this task was two correct responses increased the level (i.e., more challenging) and two incorrect responses decreased the level. An increase in score indicates improvement.

QuickSIN™.

QuickSIN™ is an objective test of comprehension of speech in noisy environments. Scoring is a ratio of the SNR required to understand speech (i.e., spoken sentence) compared to the volume of the background noise. The lower the number, the better the individual’s ability to understand speech-in-noise. Each dB of improvement (i.e., lower score) is equivalent to 10% improvement in the ability to understand speech in noisy environments.

Procedure

Participants completed baseline measures in Session 1, were randomly assigned to the control group or the experimental group (LACE™ adaptive training), and then returned to the laboratory approximately two weeks later to complete follow-up measures at Session 2. A member of the research team ensured compliance with the CBAT for the experimental group. Due to a technical failure, one participant’s profile was unavailable; however, the individual verbally confirmed compliance.

Session 1.

All participants gave written informed consent prior to participation in this study. After providing consent, participants completed a brief demographics questionnaire reporting age, sex, branch of service, years in aviation, current job, if they had been exposed to any loud sounds within the past 12 hours (and if so, if hearing protection was used), if American English is their native language, and if they had normal or corrected to normal vision. Participants also indicated if they had access to a device with a web browser and internet. Participants were included in this study if they met all of the self-reported eligibility requirements listed in Table 1.

Next, participants underwent an audiometric screening. They were eligible for participation if they had a normal otoscopic exam, normal middle ear function (determined by tympanometry), and normal hearing (determined by pure tone audiometry). Next, participants were seated in an audio booth, where they completed the WARRM task. They were eligible to continue participation if they earned a word recognition score of at least 50%. After the WARRM, participants were seated at a conference table, where they completed the SILS. They were given 10 minutes to complete the vocabulary section and 10 minutes to complete the abstraction section of the SILS. Next, participants completed the digit span task on a laptop computer. Participants were then seated the audio booth again, where they completed the SPRINT₁₀₀ and then the ASINT. After the ASINT, participants were seated at the conference table for a practice session of the task switching task on the laptop. They then returned to the audio booth and completed the ASINT while simultaneously working on the task switching task (i.e., ASINT-TS). After the ASINT-TS, participants were informed whether they were in the control or intervention group, and those in the intervention group were given an introduction to the LACE™ training program. They were provided with a unique email address, password, and access code separate from any personal accounts and that contained no identifying information to complete the training.

Session 2.

Approximately two weeks after participating in Session 1, participants returned to the laboratory for the second session. They again underwent the audiometric screening, WARRM, SPRINT₁₀₀, ASINT, and ASINT-TS using the same methods as before. The word lists for the WARRM and SPRINT₁₀₀ were different from the participants' first session, and the combination of phrases and SNL's in the ASINT and ASINT-TS were different from the first session as well.

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Table 2. Tasks per Session in Order of Administration

Session 1	Session 2
Audiometric Screening*	Audiometric Screening*
WARRM	WARRM
SILS	
Digit Span Task	
SPRINT ₁₀₀	SPRINT ₁₀₀
ASINT	ASINT
ASINT-TS	ASINT-TS

*Note: Audiometric screening included the otoscopic exam, tympanometry, and pure tone audiometry.

Quality control and statistical analysis.

A ten percent validation check was employed to check accuracy for any manually entered data. No errors were identified. Prior to analyses, the data distributions for each outcome variable were inspected for outliers, impossible values, technical errors, and normality. For the primary outcomes variables, differences scores were calculated by subtracting performance at pre- from post-intervention. To evaluate the efficacy of the training to enhance auditory working memory and speech recognition in noise, independent-samples t-tests were used to compare means between the control and experimental groups. Potential confounding factors were explored for outcomes with significant differences between groups.

Results

Fifteen participants completed both test sessions (four were disqualified and one did not complete the second test session) yielding eight participants in the control group and seven in the experimental group. Summary statistics for demographics and individual differences are presented in Table 3.

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Table 3. Summary Statistics for Demographics and Individual Differences by Group

		N	Mean	SD			
Age	Overall	15	38.53	4.05			
	Experimental	8	37.9	3.91			
	Control	7	39.3	4.39			
		Male	Female				
Sex	Overall	13	2				
	Experimental	7	1				
	Control	6	1				
		Army	Other				
Branch	Overall	15	0				
	Experimental	8	0				
	Control	7	0				
		Military	DAC	Neither			
Affiliation	Overall	14	1	0			
	Experimental	7	1	0			
	Control	7	0	0			
		0	1 - 5	5 - 10	10 - 15	15 - 20	20+
Years of Aviation Experience	Overall	1	3	5	2	3	1
	Experimental	0	2	3	1	1	1
	Control	1	1	2	1	2	0
		Rated Aviator			Flight Student		
Job	Overall	12			3		
	Experimental	7			1		
	Control	5			2		
		N	Mean	SD			
Working Memory Capacity (Digit Span Score)	Overall	15	6.27	1.07			
	Experimental	8	6.38	1.41			
	Control	7	6.14	2.12			
		N	Mean	SD			
General Intelligence (SILS: Estimated WAIS-R)	Overall	15	109.73	5.54			
	Experimental	8	108.63	6.91			
	Control	7	111.00	3.51			
		N	Mean	SD			
General Intelligence (SILS: Abstraction Quotient)	Overall	15	110.80	8.24			
	Experimental	8	111.00	9.50			
	Control	7	110.57	7.28			

Note: SD denotes standard deviation. DAC denotes Department of the Army Civilian.

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Word Auditory Recognition and Recall Measure (WARRM)

No outliers were identified in the WARRM data and the distribution appears to be normal. Summary statistics are presented in Table 4.

Table 4. Descriptive Statistics by Group of WARRM Performance Outcomes

	Overall		Experimental		Control	
	Mean	SD	Mean	SD	Mean	SD
Pre-intervention						
Word Recognition Score	98.96	1.09	99.22	0.91	98.66	1.26
Recognition - Rater Agreement %	99.23	0.87	99.28	1.04	99.17	0.71
Word Judgment Score	96.34	4.78	97.06	3.85	95.51	5.87
Judgment - Rater Agreement %	99.64	0.84	99.42	1.10	99.89	0.30
Word Recall Score	88.19	7.66	90.39	6.39	85.68	8.70
Recall - Rater Agreement %	98.01	1.95	97.48	2.20	98.61	1.56
Word Span Score	4.74	0.92	5.08	0.64	4.36	1.08
Span - Rater Agreement %	90.40	20.27	92.50	21.21	88.00	20.53
Post-intervention						
Word Recognition Score	99.17	0.96	99.05	1.13	99.31	0.78
Recognition - Rater Agreement %	99.53	1.07	99.50	1.41	99.57	0.57
Word Judgment Score	96.42	3.25	94.78	3.68	98.29	1.08
Judgment - Rater Agreement %	98.97	2.84	98.07	3.76	100.00	0.00
Word Recall Score	89.06	9.09	88.82	11.94	89.33	5.15
Recall - Rater Agreement %	99.00	1.39	98.79	1.85	99.24	0.63
Word Span Score	5.05	0.81	5.27	0.91	4.79	0.65
Span - Rater Agreement %	95.47	15.41	92.00	21.06	99.43	1.51

Note: SD denotes standard deviation.

The results of the independent samples *t*-tests did not support any difference between groups on word recognition, $t(13) = -1.47, p = 0.16$; word judgment, $t(13) = -2.07, p = 0.07$; word recall, $t(13) = -1.34, p = 0.20$; or word span, $t(13) = -0.63, p = 0.54$. No further analyses were explored.

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100 word Speech Reception in Noise Test (SPRINT₁₀₀)

One outlier (> 3 standard deviations from the mean) was identified. Even when removing this outlier, the data distribution appears non-normal and thus a non-parametric equivalent of the independent-samples *t*-test was used, the Mann-Whitney *U* test. Table 4 presents the summary statistics. The results of Mann Whitney *U*-tests did not support any difference between groups on number correct, Mann–Whitney $U = 24.00$, $n_1 = 7$, $n_2 = 8$, $p = 0.69$ two-tailed; or percentile rank, Mann–Whitney $U = 20.50$, $n_1 = 7$, $n_2 = 8$, $p = 0.39$ two-tailed. No further analyses were explored.

Table 5. Descriptive Statistics by group of SPRINT₁₀₀ Performance Outcomes

	Overall		Experimental		Control	
	Mean	SD	Mean	SD	Mean	SD
Pre-intervention						
Number Correct	93.07	6.33	95.13	1.87	90.71	8.79
Percentile*	88.10	22.83	96.25	3.15	78.79	31.86
Rater Agreement %	96.27	2.12	96.13	1.81	96.43	2.57
Cohen’s Kappa Between Raters	0.61	0.21	0.54	0.22	0.69	0.19
Post-intervention						
Number Correct	95.30	4.08	96.44	1.35	94.00	5.75
Percentile*	93.53	14.45	98.00	0.00	88.43	20.74
Rater Agreement %	97.00	2.20	96.38	1.51	97.71	2.75
Cohen’s Kappa Between Raters	0.58	0.27	0.42	0.23	0.76	0.20

Note: SD denotes standard deviation.

*Based on published normative data

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Aviation Speech in Noise Test (ASINT)

No outliers were identified and the data appear normally distributed. Table 4 presents the summary statistics. Independent samples t-tests did not find any difference between groups on percent correct in the high SNR condition, $t(13) = -1.47, p = 0.16$; medium SNR condition, $t(13) = -2.07, p = 0.07$; low SNR condition, $t(13) = -1.34, p = 0.20$; or total percent correct, $t(13) = -0.63, p = 0.54$. No further analyses were explored.

Table 6. Descriptive Statistics by Group of ASINT Performance Outcomes

	Overall		Experimental		Control	
	Mean	SD	Mean	SD	Mean	SD
Pre-intervention						
High SNR: % Correct	98.40	3.87	99.60	0.74	97.03	5.50
Medium SNR: % Correct	60.57	18.63	63.80	19.33	56.89	18.55
Low SNR: % Correct	54.96	16.44	59.93	13.25	48.35	19.10
Total % Correct	71.80	11.29	74.45	10.37	68.77	12.32
Rater Agreement %	91.51	6.74	90.44	7.60	92.74	5.95
Post-intervention						
High SNR: % Correct	98.11	4.69	99.09	1.55	97.14	6.56
Medium SNR: % Correct	74.20	15.11	80.05	13.13	66.40	14.99
Low SNR: % Correct	58.31	8.65	54.59	8.05	62.56	7.72
Total % Correct	76.23	7.26	76.43	8.14	76.01	6.75
Rater Agreement %	94.06	5.31	95.53	3.70	92.39	6.61

Note: SD denotes standard deviation.

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ASINT with Task Switching (ASINT-TS)

No outliers were identified and the data appear normally distributed. Summary statistics are presented in Table 6. The results of the independent samples t-tests did not support any difference between groups on percent correct in the high SNR condition, $t(13) = -1.47, p = 0.16$; medium SNR condition, $t(13) = -2.07, p = 0.07$; low SNR condition, $t(13) = -1.34, p = 0.20$; or total percent correct, $t(13) = -0.63, p = 0.54$. No further analyses were explored.

Table 7. Descriptive Statistics by Group of ASINT-TS Performance Outcomes

	Overall		Experimental		Control	
Pre-intervention	Mean	SD	Mean	SD	Mean	SD
High SNR: % Correct	98.19	2.08	98.45	2.17	97.83	2.09
Medium SNR: % Correct	71.15	12.84	74.13	14.50	67.74	10.68
Low SNR: % Correct	60.54	16.41	65.53	12.26	54.84	19.54
Total % Correct	75.80	8.38	78.76	6.28	72.41	9.63
Rater Agreement %	91.49	7.38	91.88	5.28	91.06	9.70
Post-intervention	Mean	SD	Mean	SD	Mean	SD
High SNR: % Correct	99.07	2.02	99.66	0.64	98.28	2.96
Medium SNR: % Correct	74.01	10.62	73.58	11.33	74.50	10.62
Low SNR: % Correct	72.04	11.88	70.84	12.75	73.24	11.84
Total % Correct	81.65	6.00	81.60	5.92	81.70	6.55
Rater Agreement %	92.39	6.65	94.38	5.82	90.11	7.23

Note: SD denotes standard deviation.

Discussion

The primary objective of this study was to evaluate whether the use of a two-week, self-paced, computer-based, auditory training program could enhance the ability of normal hearing aviators to detect speech-in-noise and auditory working memory span. The data collected did not support efficacy for these performance outcomes. A number of factors need to be considered when interpreting the null results from this study. Arguably, the sample size poses the most significant challenge to detecting an effect if one exists. Given the small sample size, we would assume that any detected effect must be large. Thus, the lack of significant effects may be a reflection of the degree of impact the training may have on an individual. Secondly, individual differences may be masking any potential effects. Despite our intent to evaluate confounding factors, the small sample size again limited the utility of further statistical tests. Third, we only included one type of training and thus variations on the content or format may have implications not recognized in this study. A broader set of training needs to be evaluated in order to generalize beyond the single training included thus far. Finally, baseline ability may limit the utility of such a training program in that high-performers are less likely to experience enhancement over average or low-performers.

Conclusion

Despite the limitations and challenges associated with this study, we are able to take away a few key points. The training program employed did not yield enhancements in speech intelligibility in noise or auditory working memory performance. The results of this study, however, are not sufficient to rule out the efficacy of this training type in this population of aircrew given the small sample size as well as limitations in exploring individual differences.

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Appendix A. Acronyms and Abbreviations

APA	aero-medical physician assistant
ASA	auditory scene analysis
ASINT	Aviation Speech in Noise Test
ASINT-TS	ASINT with Task Switching
CBAT	computer-based auditory training
cm ³	Ear canal volume measured in centimeters cubed
daPa	peak pressure
daPa	peak pressure
dB HL	hearing loss in decibels
HCTs	hearing critical tasks
HINT	Hearing in Noise Test
Hz	Hertz
LACE™	Listening and Communication Enhancement™
LACE™ LOL	Listening and Communication Enhancement™ OnLine
ml	Compliance (tympanic membrane movement noted in milliliters)
QuickSIN	Quick Speech in Noise
SD	standard deviation
SILS	ShIPLEY Institute of Living Scale
SNR	signal to noise ratio
SPRINT ₁₀₀	100 word Speech Reception in Noise Test
TM	tympanic membrane
TW	target word
USAARL	U.S. Army Aeromedical Research Laboratory
WARRM	Word Auditory Recognition and Recall Measure
WM	working memory

U.S. Army Aeromedical Research Laboratory Fort Rucker, Alabama

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