USAARL Report No. 2009-11

The Effects of Subthreshold Priming Alerts on Pilots in the USAARL TH-67 Microsim

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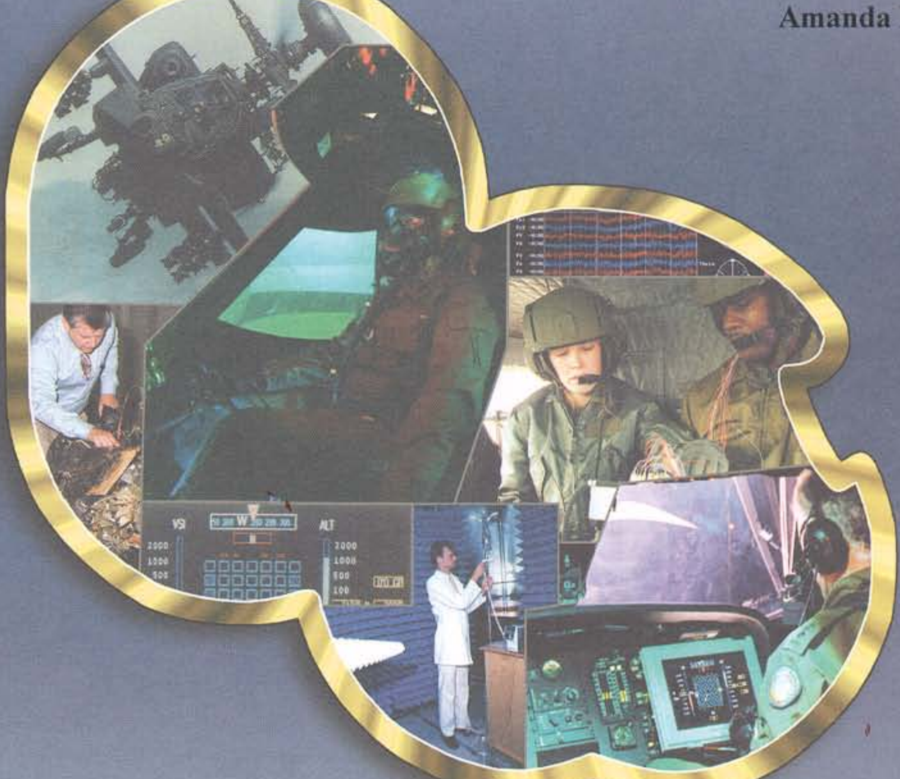

Warfighter Performance and Health Division

June 2009

USAARL

U.S. Army
Aeromedical Research
Laboratory

Human use

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRMC Reg 70-25 on Use of Volunteers in Research.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*: 22-06-2009

2. REPORT TYPE: Final

3. DATES COVERED *(From - To)*:

4. TITLE AND SUBTITLE
The Effects of Subthreshold Priming Alerts on Pilots in the USAARL TH-67 Microsim

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362-0577

8. PERFORMING ORGANIZATION REPORT NUMBER
USAARL 2009-11

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
504 Scott Street
Fort Detrick, MD 21702

10. SPONSOR/MONITOR'S ACRONYM(S)
USAMRMC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The loss of situational awareness is implicated in many aviation accidents. Aircraft flight and systems instrumentation technology has advanced from dials and lighted-strip single-function instruments to visually- and cognitively-demanding multifunction displays (MFD). Twelve rotary wing pilots participated by flying one hour flights in the USAARL TH-67 Microsim. During each flight, pilots were exposed to subthreshold and suprathreshold primes via a frequency scanner. Response times were recorded. Results indicate that pilots responded to cues during the subthreshold periods in 83 of 96 presentations (86.46%). The results indicate that there was a significant association between flight experience and faster subthreshold responses [$\chi 2(42, N = 12) = 60.00, p = .035$]. The objective results indicate that a simple subthreshold priming device successfully alerted pilots. The effectiveness and acceptability of employing subthreshold visual cues was supported by the responses to the subjective post-flight questionnaire. A more comprehensive study using a high-fidelity simulator is in progress.

15. SUBJECT TERMS
subthreshold priming, subliminal messaging, cockpit displays

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UNCLAS	UNCLAS	UNCLAS	SAR	46	Loraine Parish St. Onge, PhD

19b. TELEPHONE NUMBER *(Include area code)*: 334-255-6906

Reset

Acknowledgements

The authors would like to express their sincere gratitude to the following people for their contributions to this project.

- Ms. Elizabeth Stokes for help with all administrative matters.
- Dr. Loraine St. Onge for her editorial assistance and expertise.
- Mr. Jeff Holemo for his ingenuity in designing and creating the electronic apparatus used in this study.
- Dr. David Still for his invaluable assistance with the USAARL TH-67 Microsim.
- Mr. Scott Childress for his photographic and visual arts contributions.

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Introduction and military significance

The loss of situational awareness is implicated as a contributing factor in many military and civilian aviation accidents every year. Situational awareness is the awareness of a large group of factors that are important in keeping the aircraft safe from hazardous situations or potentially dangerous flight paths. These factors include geographical location, weather, tactical environment, weapons capabilities, individual capacities, effective communication, administrative constraints, adherence to proper flight rules, and also spatial orientation (Air Standardization Coordinating Committee, 2001).

Aircraft cockpit flight and systems instrumentation technology is advancing from dials and lighted-strip single-function instruments to visually- and cognitively-demanding multifunction displays (MFD) (figure 1). These displays can present substantial amounts of complex data on a single page. The pilot's visual workload can become quite daunting and can result in the challenging exercise of cognitively processing and maintaining an awareness of all the information presented. This visual overload can sometimes result in the exclusion of other important information presented in the periphery of or external to the MFD.

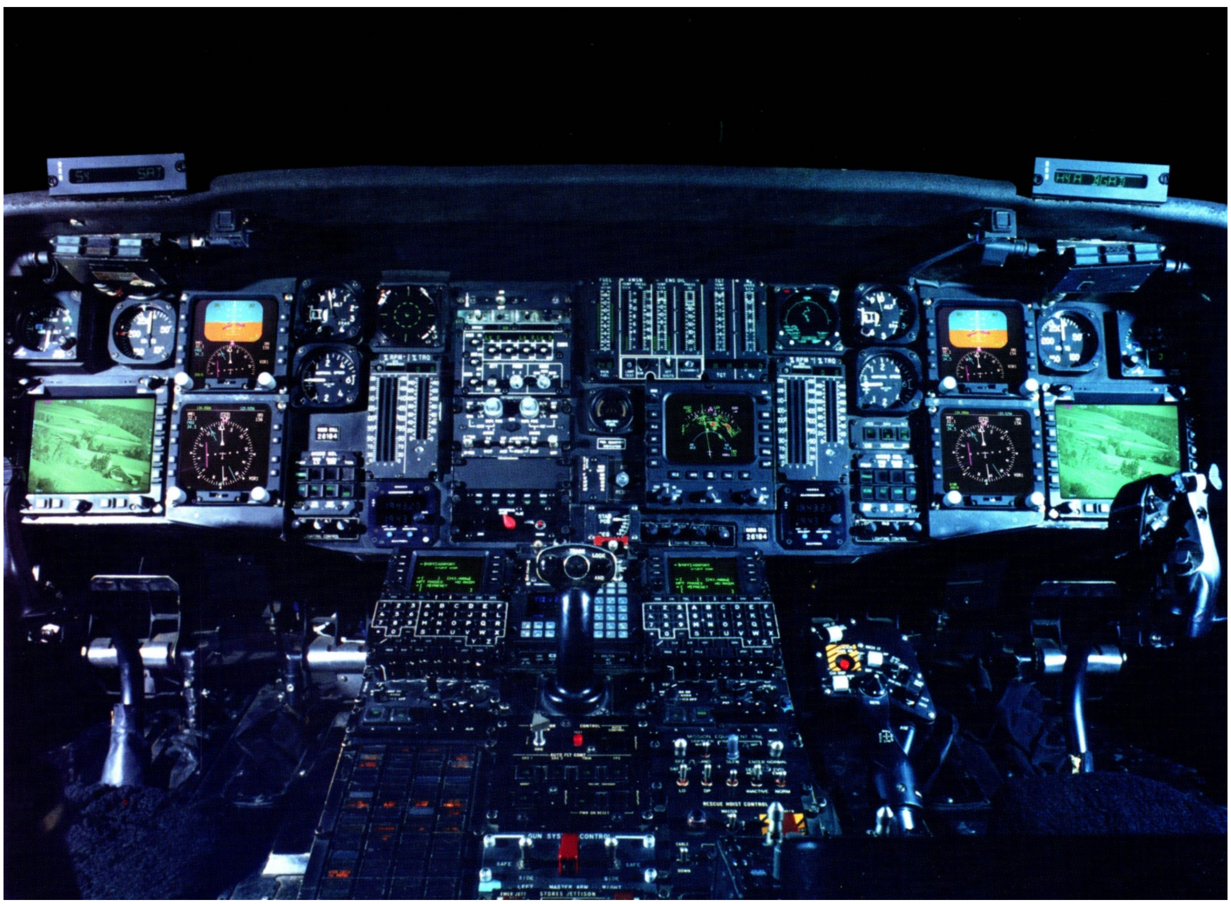

Figure 1. Multifunction displays in the cockpit of an MH-60L.

Providing ultra-short (subthreshold, visually masked) *priming* via the MFD is hypothesized as a method of subliminally alerting pilots of or preparing pilots for changing situations and trends without interrupting their primary cognitive task. According to Greenwald, Draine, and Abrams (1996), renowned researchers in the field of unconscious perception, [subthreshold] *priming* is said to occur when the meaning of the *prime* affects the speed and accuracy of response to the target. (What is important about the prime is its association with the target; the strength of that association is what increases reaction time and accuracy.) Research on subthreshold priming and cognition has been pursued since the late 1800's and is the subject of hundreds of empirical studies (Merikle & Reingold, 1998). Merikle and Reingold write that "on the basis of these studies, there is now a growing consensus that perception in the absence of the subjective experience of perceiving is a genuine phenomenon."

To this day, there is often controversy in the literature regarding the effects of subthreshold priming. The debate tends to accept the general premise that subthreshold priming can, under certain conditions and circumstances, provoke an unconscious cognitive response; however, there is much controversy surrounding the internal and external validity of experimental designs, methods, measures, and findings that indicate causation. That being said, in the past decade, promising results have emerged.

In their study, Greenwald, Draine, and Abrams (1996) reliably demonstrated that there was subthreshold activation of meaning by presenting subjects with ultra-short, or imperceptible to conscious processing, visual stimuli. They found that subthreshold priming exists, that the influence of the prime lasts for only 100 milliseconds (ms), and that there is no carry-over from one trial to the next. Their findings are interpreted in the context of the flow of information from a sensory buffer to working memory, which leads to perception. In a study by Sereno and Raynor (1992), fast priming during an eye fixation in reading produced positive, reliable results under certain priming durations. Three studies by Strahan, Spencer, and Zann (2002) suggest that subliminal priming can be used to enhance persuasion, but only when "both the priming of goal-relevant cognitions and the motive to pursue the goal were necessary."

In a report by Draine and Greenwald (1998) titled *Replicable Unconscious Semantic Priming*, the authors describe four experiments that demonstrated unconscious cognition and evidence of subthreshold priming. In their research, subjects classified visually presented target words as pleasant-unpleasant or male-female first names. Experiments 1 and 2 sought to determine whether the response-window procedure would increase the power of the regression method for detecting unconscious cognition. Both semantic priming and prime perceptibility were measured. The purpose of Experiment 3 was to separate effects on priming attributable to prime duration from those due to interstimulus interval (ISI: the time between stimuli). Interestingly, the authors found that longer ISIs result in larger priming effects. Finally, Experiment 4 was designed to confirm that subliminal semantic activation effects warrant interpretation as effects of unconscious cognition and possibly as effects that are dissociated from conscious cognition. Table 1 summarizes their findings.

Table 1.
Summary of findings of Draine and Greenwald (1998).

Prime duration	Evidence of priming effectiveness	Significance
Experiment 1		
17 ms	Very weak priming.	p = .44
33 ms	Substantially stronger.	p = .00001
50 ms	Strong priming effect.	p = .0003
Experiment 2		
17 ms	No significant evidence of priming.	p = .57
33 ms	Substantial priming effect.	$p = 10^{-8}$
50 ms	Substantial priming effect.	$p = 10^{-11}$
Experiment 3		
17 ms with 17 ms ISI*	Evidence of semantic priming.	p = .006
17 ms with 50 ms ISI	Evidence of semantic priming.	p = .008
33 ms with 17 ms ISI	Evidence of semantic priming.	p = .0002
33 ms with 50 ms ISI	Evidence of semantic priming.	$p = 10^{-11}$
Experiment 4		
17 ms	Evidence of priming effects.	p = .0002
33 ms	Evidence of priming effects.	$p = 10^{-11}$

* interstimulus interval

These experiments and other studies indicate the *potential* of using subthreshold priming as a way to produce an emotional predisposition or expectation, or a method of provoking goal-relevant cognition. The literature contains examples of "successful" demonstrations of subthreshold priming and evidence of mental activity without conscious awareness (Bernat, Shevrin, & Snodgrass, 2001; Seiss & Praamstra, 2004), however, without exception, each study was conducted under controlled conditions. Subthreshold priming research remains controversial for a number of reasons; namely, reported findings are statistically weak, there is an inability to replicate findings, and there is a paucity of published replications. More importantly, there is a virtual absence of research in the literature regarding the actual *application* of this effect in any practical manner.

Study objectives

The primary objective of this study was to determine the applicability and effectiveness of using ultra-short subthreshold stimuli via a digital display to alert a cognitively- and visually-loaded aviator of changing mission requirements. A second objective was to study subthreshold priming's influence on the behavior and decision-making of helicopter pilots.

Methods

Participants and setting

This study, a quasi-experimental, time-series design, was conducted by U.S. Army Aeromedical Research Laboratory (USAARL) personnel using the laboratory's TH-67 Microsim (no-motion flight simulator). Thirteen helicopter pilots participated in this study; however, data from the first participant was excluded because technical issues were still being worked out at that time. The volunteers included current and retired U.S. Army military, contract, and Department of the Army civilian rotary wing aviators. Volunteers were accepted on a "first come, first served" basis.

Data collection tools and apparatus

Demographic questionnaire

A demographic questionnaire (appendix A) was administered to more clearly define the sample population.

Stimulus perception data collection sheet

The stimulus perception data collection sheet (appendix B) was used to record the times from stimulus presentation onset to participant perception and the participants' actions during non-stimulus periods. These data points were recorded by a research team member during each research flight.

Post-flight questionnaire

The Post-flight questionnaire (appendix C) was administered to collect subjective data from the participants of their opinions and perceptions regarding the use and applicability of subthreshold priming in aviation.

USAARL TH-67 Microsim

The USAARL TH-67 Microsim (figure 2) utilizes Microsoft® Flight Simulator 2004 software and Flight Link flight controls. It is composed of four main components: 1) desktop computer and video card, 2) displays, 3) flight controls, and 4) a fixed-base seat and wooden mounting platform (sled). The computer video card has two video outputs. One output drives a projector (InFocus) to provide an image 10 feet wide onto a screen placed 10 feet from the volunteer's eyes, thus providing an image subtending 60° horizontally and 40° vertically (figure 2[A]). The simulation software was set to present the same 60° x 40° view of the airspace and terrain. Thus, the physical field of view corresponds to the simulated field of view resulting in a 1x magnification. The second video output drives a LeCie liquid crystal monitor to display the cockpit instrumentation (figure 2[B]). This 14.5-inch wide display is placed 36 inches from the pilot's eyes resulting in a 23°- wide image. The luminance of the out the window and instrument panel images are both about 15 candelas per square meter and the resolution of both displays is set to 1024 by 780 pixels.

Figure 2. USAARL TH-67 Microsim

The USAARL TH-67 Microsim's flight controls are commercially produced off the shelf hardware (Flight Link), a system the U.S. Navy uses in its micro-simulation training. The hardware includes a cyclic arranged to be either centering or non-centering, a collective with a throttle, and anti-torque pedals. The hardware is mounted on a custom wooden sled that includes a seat with a seat back tilt of about 30°. The sled permits length adjustment of the anti-torque pedals, reduces trip hazard by concealing the wiring, and supports the instrument panel monitor.

Communication scanner display

For this study, the USAARL TH-67 Microsim was equipped with an additional display simulating a frequency hopping communication scanner through which the participant received sub- and supra-threshold notification of mission updates (figure 2[C] and figure 3). The pilot was instructed to frequently refer to the display as part of the usual flight instrument crosscheck. The display and its supporting software were created and programmed in-house and enabled the researchers to program and display single-digit characters at precise durations in milliseconds.

Figure 3. Simulated communication scanner display and control screen.

Discrete monitor

Located on the left side of the cockpit instrument panel, a screen (figure 2[D]) displayed mission changes to the pilot. This screen is termed the "discrete monitor" because it requires the pilot to press a button in order to reveal the message. In actuality, it is merely a screen remotely displaying a PowerPoint presentation (appendix D) to the pilot. The presentation slides were advanced at the appropriate predetermined times by a research technician located behind and out of the view of the participant.

Procedures

Participants were allowed sufficient time to read and ask questions regarding the informed consent document. Following completion of the informed consent and an unconditional consent for use of picture and sound, a demographic questionnaire (appendix A) was administered and each aviator received a pre-mission briefing (appendix E) which explained the forthcoming flight mission profile (appendix F). After the briefing, the participant was escorted to the USAARL

TH-67 Microsim for their familiarization and data collection flights. Familiarization involved the participant flying the USAARL TH-67 Microsim for up to 10 minutes or until he stated he was comfortable enough with the controls to begin data collection.

The flight profile required the pilot to perform familiar, standard flight maneuvers such as a takeoff, straight and level cruise flight, turns, and climbs and descents. During the flight, the pilot saw a single-digit display of constantly flashing characters (0 through 9 at a presentation rate of 500 ms with a 50 ms ISI) mounted on the instrument panel. These numbers served as visual masks for subthreshold presentations. The display itself simulated a frequency hopping communication scanner through which the pilot received notification of mission updates. The pilot was instructed to frequently refer to the display as part of the usual flight instrument crosscheck. The pilot sought the presentation of a capital letter "E" (the alerting stimulus) within the flashing numbers as an indication that a mission change was received. The "E" was used as the alerting stimuli because it was easily programmed into the low-fidelity communication scanner. Over the course of the 1-hour flight, the pilot received eight, 4-minute presentation periods via the communication scanner. It was only within these 4-minute presentation periods that the alerting stimulus (the capital letter "E") appeared within the flashing sequence. The appearance of the alerting stimulus informed the pilot of a mission change. Once the alerting stimulus was noted and responded to, the pilot referred to the discrete monitor on the left side of the cockpit in order to read and follow the mission change instructions.

For the initial takeoff to a hover, the participant received a suprathreshold alerting stimulus. The eight subsequent 4-minute presentation periods throughout the 1-hour flight contained 2 minutes of subthreshold stimuli presentation immediately followed by 2 minutes of suprathreshold stimuli presentation (details below). The semi-randomized intervals between the presentation periods were instituted to prevent the pilot from recognizing an established presentation pattern. The stimuli periods were presented per the schedule in table 2.

Table 2.
Presentation periods during data collection flight.

Presentation Period	1	2	3	4	5	6	7	8
Presentation period in minutes of elapsed mission time	5-9	11-15	19-23	26-30	34-38	41-45	47-51	53-57
Intervals between presentation periods in minutes	-	2	4	3	4	3	2	2

Based on the significant priming effects discovered by Draine and Greenwald (1998) at the 50 ms duration, subthreshold prime durations for this study were set at 50 ms. Therefore, for the first 2 minutes of the 4-minute presentation period (the subthreshold period), the masking numbers were presented at the rate of 500 ms with a 50 ms ISI; however, the "E" had but a 50 ms presentation followed immediately by the masking numbers. The second two minutes of the presentation period were characterized by a suprathreshold presentation of the characters at presentation duration of 500 ms and 50 ms ISI. That is, even the “E” remained on for a suprathreshold period of 500 ms. If responded to by the pilot within the first 2 minutes of the presentation (subthreshold) period, the alerting stimulus was turned off until the next prescribed time per table 2. If the alerting stimulus was not responded to within the first 2 minutes, the suprathreshold presentation was presented immediately at the 500 ms presentation rate until responded to, for a maximum of 2 minutes.

A research team member, located in the room with the participant and USAARL TH-67 Microsim, controlled the precise onset of each presentation period and recorded the precise times (to the second) at which the pilot indicated stimulus perception, whether orally or by action. *By action* refers to physically referring to the discrete monitor to view a possible mission change. In addition, the research team member recorded all physical references during periods of no stimulus presentation (between presentation periods) to note and record *guesses* on the part of the participant (appendix B). Upon completion of the approximately 1 hour flight, the participant completed the Post-flight questionnaire (appendix C) and was released from the study. Total participation time lasted approximately 2 hours of one day.

Results

All statistical analyses were performed using SPSS® 13.0 with significance set at an alpha level of .05 for all statistical tests.

Demographics

A total of eleven males and one female participated in this study. All volunteers were recruited from the local pilot population at Fort Rucker, AL. This large population of aviators includes permanently assigned instructor pilots and transient pilots attending various aviation courses.

Flight Activity Categories (FACs) and Readiness Levels (RLs)

Flight Activity Categories (FACs) 1-3 are designated by military aviation unit commanders based on the proficiency required by a particular job or position within an aviation unit. FAC levels are important in that they mandate minimum semiannual and annual aircraft and simulator hourly requirements for an aviator. Readiness Levels (RLs) 1-3 are the levels of an aviator's proficiency to perform the unit's mission regardless of specific job or position. An RL1 aviator is ready to perform a combat mission, whereas an RL3 has yet to demonstrate proficiency in basic flight tasks. In other words, the implication is that FAC 1s and RL 1s are the most flight proficient while FAC 3s and RL 3s are the least proficient. Therefore, the expectation is that the most proficient aviators will possess better instrument scanning and flight performance skills than those least proficient. Figures 4 and 5 show the distribution of the FACs and RLs of the 12 participating pilots. Note that FACs are not applicable (N/A) to civilian pilots, student pilots, and graduate pilots not assigned to a permanent unit (in a transient status).

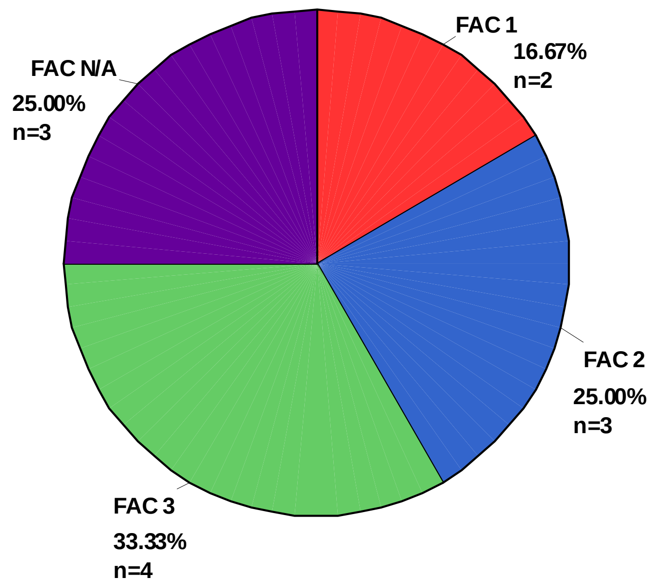

Figure 4. Distribution of Flight Activity Categories.

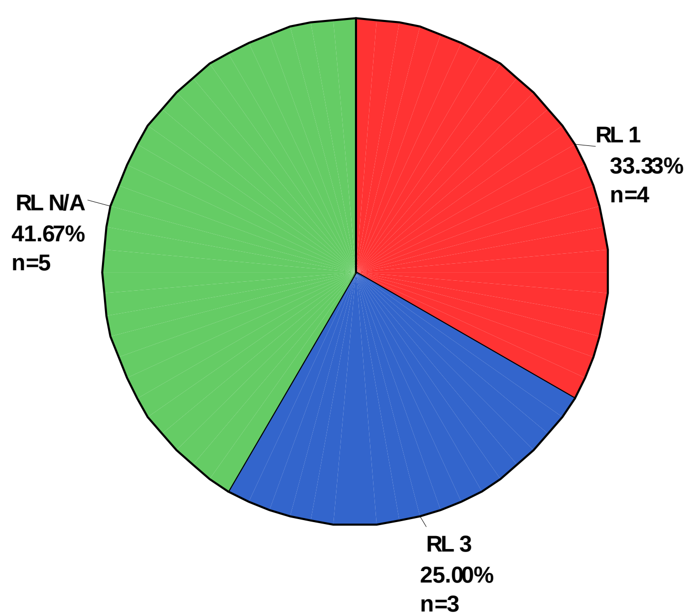

Figure 5. Distribution of Readiness Levels.

Positions/jobs

Figure 6 illustrates the distribution of the subjects' current positions or jobs.

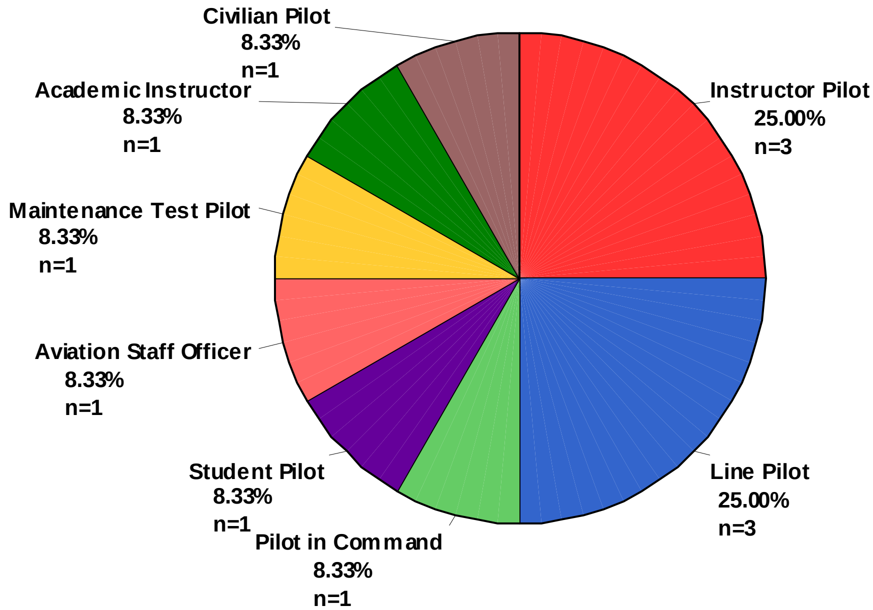

Figure 6. Distribution of positions/jobs.

Aircraft currency and experience

Army Regulation 95-1(Headquarters, Department of the Army, 2008) defines "aircraft current" as having flown an aircraft as a pilot or pilot in command within the last 60 days. Eight of the twelve participants were current in an Army aircraft (four in a UH-60, three in a CH-47, and one in an AH-64). The remaining four were seasoned pilots with no less than 1000 hours of flight experience.

Total flight hours and simulator flight experience are presented in figures 7 and 8, respectively. Total flight and simulated flight hours are usually reflective of an aviator's level of maturity, responsibility, and ability.

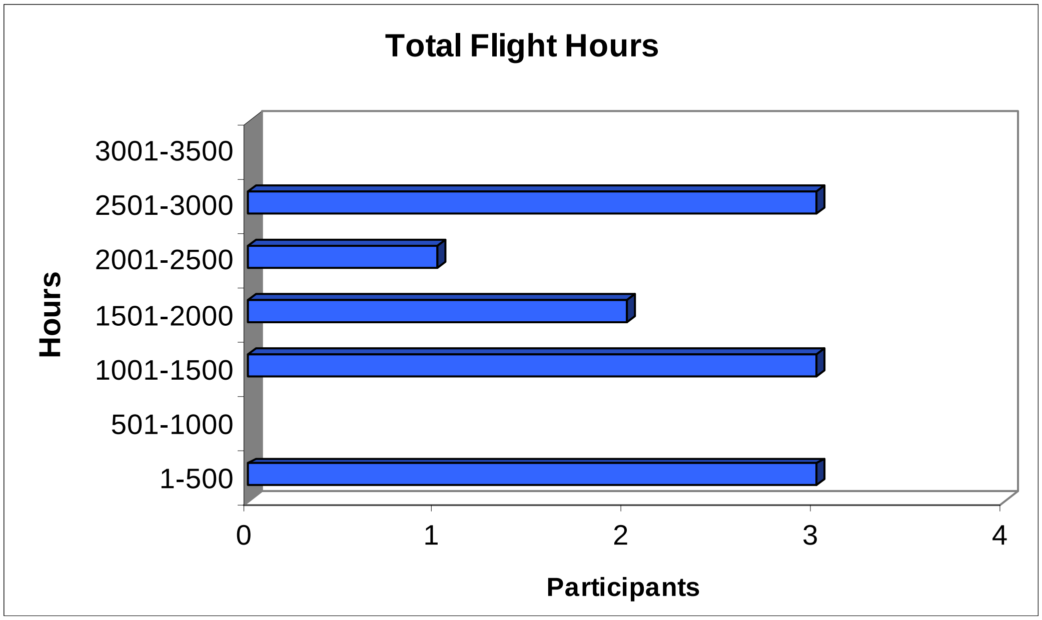

Figure 7. Total Flight Hours of Participants.

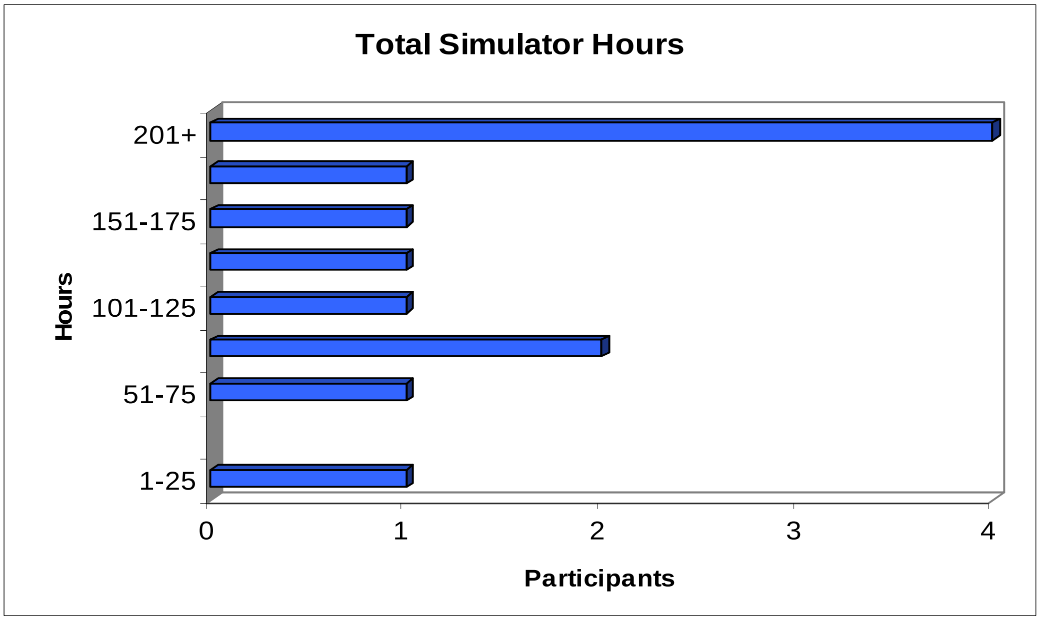

Figure 8. Total Simulator Hours of Participants.

Pilot responses to subthreshold and suprathreshold visual cues

Figure 9 is a histogram of the frequency at which the visual cues (subthreshold and suprathreshold) were responded to by all of the participants. Each of the twelve participants was presented eight stimulus periods of up to 4 minutes duration for a total of 96 periods. Participants were first presented with up to 2 minutes (120 s) of subthreshold cues followed immediately by up to 2 minutes of suprathreshold cues. Results indicate that pilots responded to cues during the subthreshold period in 83 of the 96 presentations (86.46%) (figure 10). The average subthreshold response occurred at 31.35 seconds. Eight of the 12 participants responded to all of their alerting cues during the 2-minute subthreshold presentations.

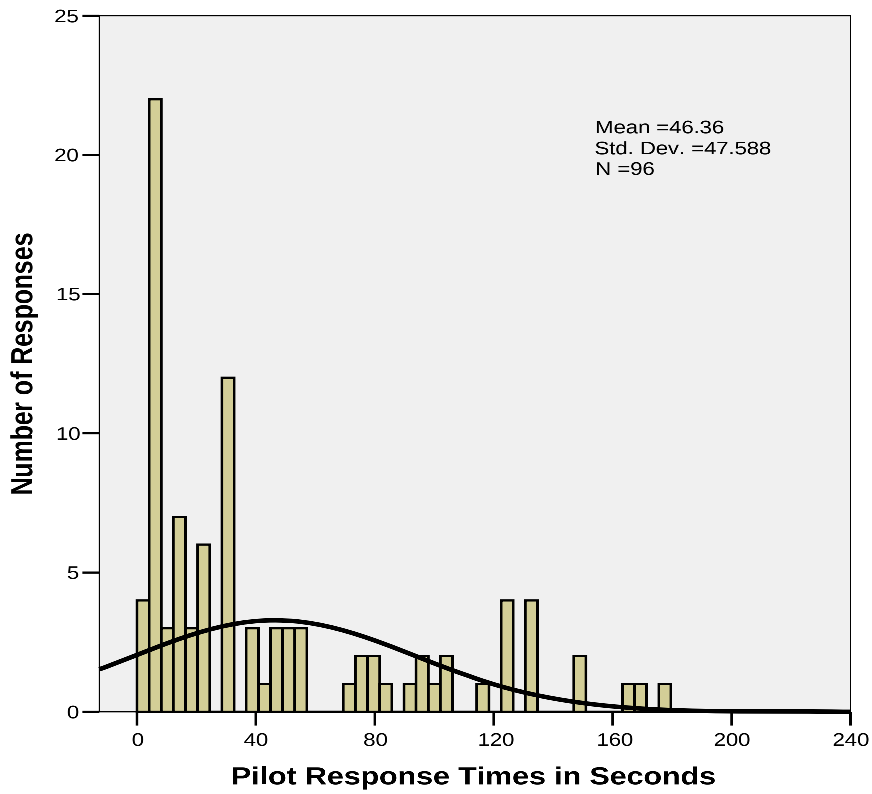

Figure 9. Frequency and times of all responses during subthreshold (0-120 s) and suprathreshold (121-240 s) presentation periods.

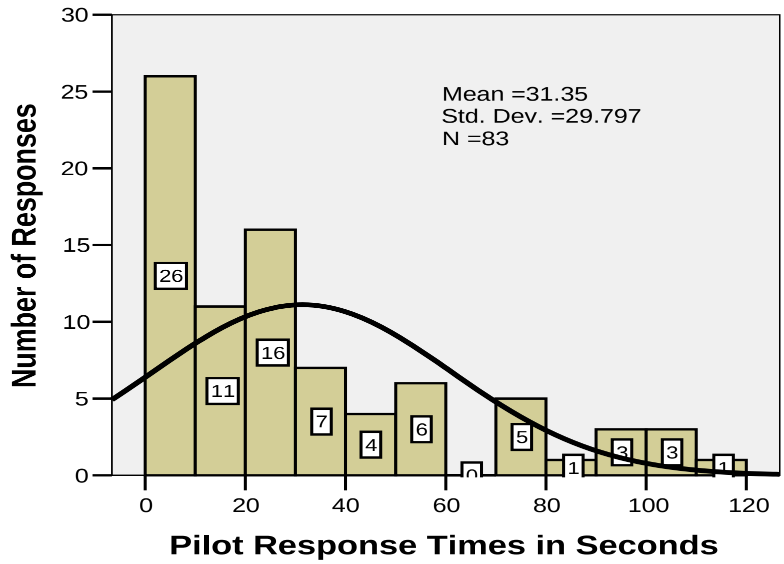

Figure 10. Frequency and times of responses during the subthreshold presentation periods (within the first 120 seconds of each period).

Subthreshold cues were not responded to during 13 of the 96 2-minute presentation periods (13.54%), and therefore, suprathreshold cues were subsequently presented. Figure 11 presents the frequency and times of the 13 suprathreshold responses (the second, 120-second period). The spike in the number of detections within the 120 to 140 second range (the first 20 seconds of suprathreshold presentation) is understandable as we would expect prompt detection of a suprathreshold signal. The average response time was 22.23 seconds into the suprathreshold period. A single sample *t*-test was used to evaluate the impact of subthreshold cuing. The dependant variable was the proportion of subthreshold presentation responses to total presentations. The results were statistically significant ($t(11) = 5.515$, $p < .001$).

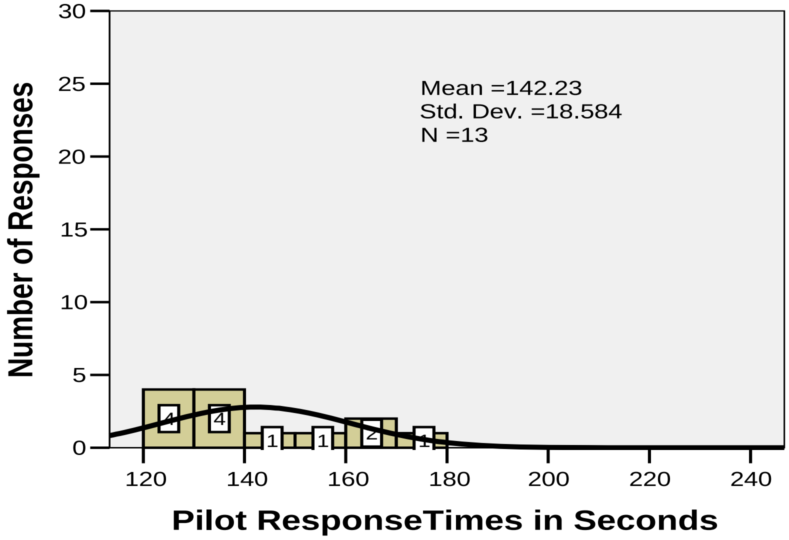

Figure 11. Frequency and times of responses during the suprathreshold presentation periods (after the first 120 seconds of each period).

Ten of the 12 participants checked for mission changes without being visually cued (undirected responses). This was done 29 times over the entire study and could be viewed as infrequent considering each 1-hour flight had a minimum of 28 minutes during which no cuing was ever present. That 28-minute minimum is exclusive of the time in which cues are not present as the result of cue responses. In other words, cuing periods were presented in accordance with the prescribed schedule in table 2. Since the average response occurred 31 seconds into the period, the inference is that there were now approximately 28 more minutes (8 periods x 3.5 minutes remaining of the presentation period) in which cues were not present for a total of 56 minutes (28 + 28) per each 1-hour flight. Hence, when viewed in aggregate, undirected responses were infrequent given that they only occurred 29 times over the average 11.2 hours of cue-free time. A *Z*-test for two proportions conducted at a Confidence Level (CL) of 100% indicated that the difference between the proportion of undirected responses and the proportion of directed responses was significantly different ($Z = 5.34$, $p < .05$). A CL of 100% is indicative of the likelihood that the difference in proportions is NOT due to random chance. Figure 12 presents the undirected responses by participant.

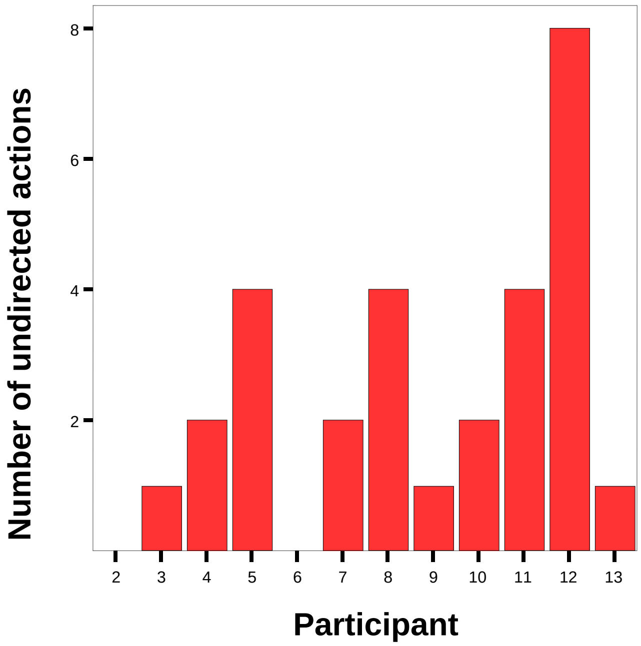

Figure 12. Number of undirected responses by participant.

Associations between the sample population and visual cue responses

Crosstabulations were performed to identify possible associations between the population demographic factors and the participants' performance in responding to the subthreshold visual cues. Demographic factors included job title, FAC, RL, total flight time, and total simulator time. Performance measures included the number of subthreshold responses, the average time of subthreshold responses, the minimum time of subthreshold responses, the maximum time of subthreshold responses, and the number of times participants checked for mission changes when no cues were present (undirected responses).

Of all the possible associations (appendix H), the only association that was statistically significant was that of job title and minimum time of subthreshold acknowledgments [$\chi^2(42, N = 12) = 60.00, p = .035$]. Cramer's V and the contingency coefficient, nominal symmetric measures of strength and significance of the relationship, indicated that there was a strong, highly significant relationship between the job title and quickness of response (.464, $p < .001$ and .549, $p < .001$, respectively). Instructor pilots and line pilots (typically flying more frequently and having more experience than the other groups) were significantly faster at responding to the subthreshold visual cues than others tested. Those in jobs where flying is less frequent took longer in responding to the subthreshold cues.

The number of times participants checked for mission changes without being visually cued was individualized (figure 12) and was not significantly linked to participant demographics. In fact, matching those participants with the most undirected mission checks with their specific statements in the post-flight questionnaire (appendix G) showed the individualized nature.

Participant 12 (with eight undirected responses) "felt late" in checking for mission changes. Participants 5, 8, and 11, each with four undirected responses, were individually motivated by the urgency of the implied task, fear of missing the cue, and pride and gratification in being cued, respectively. Interestingly, they all felt that the subthreshold cuing worked, and that it was not a distraction to the flying pilot.

Post-flight questionnaire

The post-flight questionnaire (appendix C) was administered following each flight to collect subjective data from the participants of the participants' opinions and perceptions regarding the use and applicability of subthreshold priming in aviation. A summary and characterization by the research staff of the subjective comments follows. Note that some participants had multiple comments for a single question. Appendix G contains all of the specific comments recorded.

Question 1: Describe the feeling that motivated you to check the separate monitor for flight instructions.

Participants were motivated by different reasons which included expectations of mission change (two comments), boredom/seeking another task (three comments), a "sense" or "urge" to check for a cue (three comments), and a fear of missing the cues (five comments),

Question 2: When you checked the monitor, were you motivated by the [priming cue] in the communication scanner or purely by chance?

Ten participants answered that they were either motivated by the priming cues or "mostly" motivated (one) by the priming cues. One individual provided an answer that did not address the question.

Question 3: Has participation in this experiment influenced your opinion of sub-threshold priming/subliminal messaging?

Five participants responded that they felt that subthreshold cues worked and two expressed no change in opinion due to their lack of experience with this technology. One participant felt that subthreshold priming sped up pilot reaction time and the scanning of flight instruments. One commented that subthreshold cues increased pilot workload and another claimed that UH-60s already have audio and subliminal warnings. (The second author is a UH-60 instructor pilot and has no knowledge of any subliminal warnings in the UH-60.)

Question 4: In your opinion, do you think sub-threshold cues could benefit a cognitively overloaded aviator?

Eight participants replied "yes," two replied "no," and two replied "maybe."

Question 5: How do you think this technique could be incorporated into cockpit design? What systems would benefit from this feature?

Three participants suggested integrating the technology into head-up displays while four recommended integration into aircraft flight and systems (glass cockpit) instrument displays. One thought that the Area Navigation (RNAV) system would be the best device for this technology and one suggested that subthreshold cues be incorporated into the pilot's kneeboard. Two were unsure how to incorporate subthreshold cues and one recommended that it not be incorporated.

Question 6: Were the subthreshold cues a distraction?

Six participants felt that the cues were a distraction, whereas five responded the cues were not a distraction. Two pilots answered "maybe."

Question 7: Did you take your attention away from other tasks to concentrate on NOT missing the "E?"

Seven participants responded that their attention was diverted, with two others reporting that their attention was only sometimes diverted. Three pilots indicated that the E did not divert their attention.

Question 8: Were you worried or distracted about this additional task?

Consistent with the preceding question, seven participants answered "yes" indicating they were worried or distracted with the additional task of looking for cues. Five answered "no" indicating they were not worried or distracted.

Question 9: Did the placement of the countdown indicator distract or interrupt your usual instrument scanning pattern?

Five pilots agreed that the placement of the communication scanner did distract or interrupt their usual scan while five did not. Two reported that the scanner affected their scan somewhat.

Discussion

All participants were volunteers who responded to a solicitation by the principal investigator for participants in the Fort Rucker, Alabama area. To participate in the study, the volunteer could be a rated aviator in any type of Army aircraft, since no aircraft-specific skills were required to fly the USAARL TH-67 Microsim. The results of the demographic survey indicated that a satisfactory distribution of pilots holding different jobs and/or positions was achieved in the study. This distribution provided important perspectives from those who fly missions, from those who train other pilots to fly missions, and from those who command those who fly missions. The population distribution reassured the research team that the subjects' assessments had the desired diversity.

Another rationale of the demographic survey was to examine whether there were any relationships between the demographic categories (positions/jobs, FACs/RLs, aviation experience and aircraft type) and subthreshold perception. The crosstabulation of these factors showed the only association to be that experienced pilots (instructor pilots and line pilots) were more likely to perceive the subthreshold signal. This finding was not surprising as it is likely attributable to a more practiced and proficient scan of the flight instruments which would have included the communication scanner display through which the cues were presented. It was interesting to note that the number of undirected responses (checking for mission changes in the absence of cues) showed no relationship to participant demographics.

The objective results of this study indicate that a simple subthreshold priming device successfully alerted pilots flying the USAARL TH-67 Microsim to check a separate monitor for new flight instructions (mission changes). Eighty-six percent of the pseudo-randomly-presented visual cues (83 of 96 times) were detected in an average of 31 seconds during the subthreshold presentation period. In addition, a *Z*-test for two proportions provided confidence and evidence that there was minimal guessing or random checking for the presence of cues. This significant difference in the proportion of undirected and directed responses provided assurance that the responses during the subthreshold cuing periods were not due to random chance, but an indication of the detection and effectiveness of the cues.

The effectiveness and acceptability of employing subthreshold visual cues was supported by the responses to the post-flight questionnaire. The majority of the sample population reported that their actions were a result of their perception of or being "motivated by" the subthreshold cuing. Most felt that subthreshold visual cuing could benefit a cognitively overloaded aviator; however, it is noteworthy that about half of the respondents indicated that the cues were a distraction and thus, diverted their attention away from other tasks. It is possible that the configuration of the display device used in this study (the communication scanner) diverted attention away from the primary flight instruments. Future studies will incorporate the subthreshold cuing into the primary instruments minimizing any issues of distraction.

Study limitations

The study was limited by funding resources which resulted in a small sample size and the use of the USAARL TH-67 Microsim instead of a dynamic flight simulator with a realistic cockpit instrument display through which the visual priming cues could be presented. Future study of this technology will include a larger sample size and the incorporation of visual cues into familiar instrument displays in a high fidelity, motion-based simulator.

Conclusions

This study sought to apply selected laboratory theories, practices, and methods substantiated by the literature to the complex visually- and cognitively-demanding aviation operational environment, a condition which had never been tested. The focus of the research was limited to exploring the potential for improving the provocation of goal-relevant cognition and persuasion in pilots. Note that no purposeful attempt was made to explore subthreshold priming as a method of producing an emotional predisposition or expectation. The study was conducted to seek evidence of whether the application of subthreshold visual priming could serve as a method of reducing conscious cognitive workload and improve helicopter flight situational awareness. Based on the findings of this preliminary effort, it is reasonable to conclude that there is evidence of possible benefits, albeit through improved presentation, of applying this technology to operational flying tasks. This study has demonstrated the promise that subthreshold cuing could be used to alert pilots to subtle trends and changes in aircraft systems, provide subtle reminders during operations at precise times, and assist pilots in regulatory compliance without overt signals. The results of this study represent an initial step in the development of a novel informational display technique.

Future research

A more comprehensive study is currently funded and under development by USAARL researchers that will provide subthreshold visual priming to pilots via a multifunction display of primary flight instruments while flying familiar flight tasks in a high-fidelity simulator. The design and findings of this future study should aid in validating the utility of this technology for an aviation application.

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Appendix A
Demographic questionnaire.

Answering each question is important to this study; however, you have the right to refuse answering specific questions without repercussion.

Please circle the responses that most accurately answer the following questions.

1. What term best describes your current position or job title?

Student Pilot   Line Pilot (PI)

Pilot-in-Command (PC)   Unit Trainer (UT)

Instrument Examiner (IE)   Instructor Pilot (IP)

Standardization Instructor Pilot (SIP)   Aviation Platoon Leader

Aviation Staff Officer (any level)   Maintenance Test Pilot

Aviation Company Commander   Aviation Battalion Commander or above

2. What is your current Flight Activity Category (FAC) designation?

1   2   3   NA

3. What is your current Readiness Level (RL)?

1   2   3   NA

4. How many total flight hours have you logged (exclude simulator)?

1-500   501-1000   1001-1500   1501-2000   2001-2500   2501-3000

3001-3500   3501-4000   4001 or greater

5. How many <u>total</u> simulator have you logged?

1-25 26-50 51-75 76-100 101-125 126-150

151-175 176-200 201 or greater

6. If current, in what aircraft are you current? (List all if more than one type.)

<u>Appendix B</u>
<u>Stimulus perception data collection sheet.</u>

Presentation Period	Time of Presentation Period Onset	Time of Pilot Acknowledgement [Ressponses]	Reference to Separate Display	Remarks/ Notes
Nonstimulus Period				
Nonstimulus Period				
Nonstimulus Period				
1				
Nonstimulus Period				
Nonstimulus Period				
Nonstimulus Period				
2				
Nonstimulus Period				
Nonstimulus Period				
Nonstimulus Period				
3				
Nonstimulus Period				
Nonstimulus Period				
Nonstimulus Period				
4				
Nonstimulus Period				
Nonstimulus Period				

Nonstimulus Period				
5				
Nonstimulus Period				
Nonstimulus Period				
Nonstimulus Period				
6				
Nonstimulus Period				
Nonstimulus Period				
Nonstimulus Period				
7				
Nonstimulus Period				
Nonstimulus Period				
Nonstimulus Period				
8				
Nonstimulus Period				
Nonstimulus Period				
Nonstimulus Period				

Appendix C
Post-flight questionnaire.

It is important to answer each question honestly; however, you have the right to refuse answering specific questions without repercussion.

1. **Describe the feeling that motivated you to check the separate monitor for flight instructions.**

2. **When you checked the monitor, were you motivated by the "E" in the communication scanner or purely by chance?**

3. **Has participation in this experiment influenced your opinion of sub-threshold priming/subliminal messaging? Please explain.**

4. **In your opinion, do you think sub-threshold cues could benefit a cognitively overloaded aviator?**

5. **How do you think this technique could be incorporated into cockpit design? What systems would benefit from this feature?**

6. **Were the sub-threshold cues a distraction?**

7. Did you take your attention away from other tasks to concentrate on NOT missing the "E"?

8. Were you worried or distracted about this additional task?

9. Did the placement of the countdown indicator distract or interrupt your usual instrument scanning pattern?

Appendix D
Mission changes PowerPoint presentation.

The following slides were presented via the discrete monitor.

TAKEOFF
TO A 5FT HOVER

1

FLY RUNWAY HEADING;
CLIMB & MAINTAIN 800’ MSL

2

TURN TO HEADING 090

3

CLIMB & MAINTAIN 1000’ MSL

4

TURN RIGHT TO HEADING 180

5

TURN LEFT TO HEADING 090

6

TURN RIGHT TO HEADING 180;
DESCEND & MAINTAIN 800' MSL

7

TURN RIGHT TO HEADING 270;
CLIMB & MAINTAIN 1200' MSL

8

EXECUTE A LEFT 360° TURN

9

Appendix E
Premission briefing.

You have been assigned to fly a VFR reconnaissance mission in search of a band of eight potential terrorists infiltrating the country on foot. You will depart from Chigger Army Airfield on a flight of approximately 1 hour. The mission is critically important to national security. Due to national security reasons, you must fly the mission precisely as vectored by the National Command Authority via a separate display (covered monitor) on the left side of the cockpit. Your position will be constantly monitored by an US Air Force E-3 Airborne Warning and Control System (AWACS). You have been chosen for this mission because of your well-known precision flying ability. The weather for the mission is clear, with a minimum of 3 statute miles of visibility, and the winds are calm ETA through 1 hour.

You will be flying a spec ops OH-67 helicopter at 90 KIAS which has been uniquely equipped with a frequency hopping communication scanner. The communication scanner will be scanning 10 secure channels (0-9) and will appear as a single-digit display of flashing characters. Your cue that a mission change (heading or altitude change) has been transmitted will be the presence of a capital letter "E" within the flashing numbers on the scanner display. (Before the flight, a demonstration of the communication scanner display will be provided.) If you fail to notice the capital letter "E" after a certain period of time, the flashing will slow down so that you might better see the "E" within the number sequence.

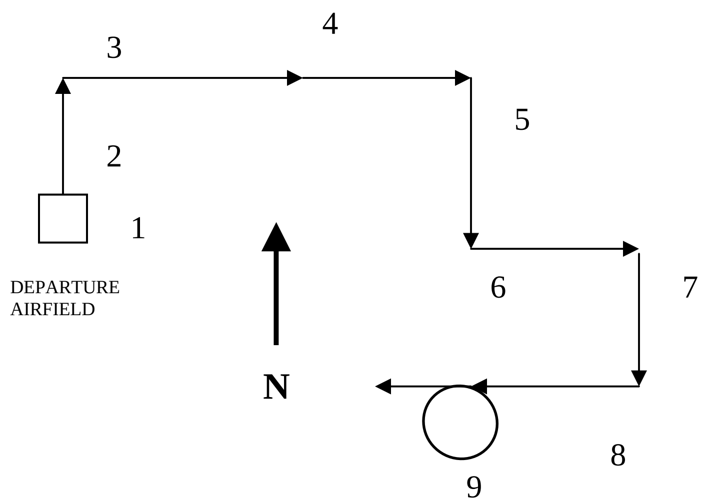
Upon noticing the capital "E," you will refer to the separate display for your next mission instructions. Again, your mission is to fly as precisely as possible while searching for infiltrating terrorists. During the mission, any personnel sighted will be reported using the code word "bogey" via the VHF radio, frequency 123.4.

Note that this flight profile is in no way intended to represent any current or future real world missions. It was devised solely for research purposes. Do you have any questions?

Appendix F
Flight mission profile

Fly all maneuvers at 90 KIAS.

1. Takeoff to a 5 ft hover
2. Fly runway heading; climb & maintain 800 ft MSL
3. Turn to heading 090
4. Climb & maintain 1000 ft MSL
5. Turn right to heading 180
6. Turn left to heading 090
7. Turn right to heading 180; descend & maintain 800 ft MSL
8. Turn right to heading 270; climb & maintain 1200 ft MSL
9. Execute a left 360^o turn



Appendix G
Results of post-flight questionnaire.

Subject	Question
	1) Describe the feeling that motivated you to check the separate monitor for flight instructions.
2	Knowing that mission changes would come from the monitor and believing that I was missing seeing the cue.
3	Finding the E on the separate panel was tedious and apprehensive. I felt relief being able to check the text panel although it altered my flight control due to upper torso movement.
4	Flying for an extended time with no activity outside the aircraft.
5	Urgency
6	I seemed to be drawn to the counter. An urge to look.
7	Intentional + forced at first but later became more natural. Sometimes had a “sense” the E appeared.
8	Fear of crashing.
9	Getting tired of flying the same mission. I wanted a change so I could try a different maneuver
10	Because I was told that is what I had to do to complete the mission.
11	Personal pride and gratification to be able to add something else to just flying the helicopter.
12	I felt late.
13	The sequencing numbers cued me to look at the monitor when necessary. Although the numbers became annoying towards the end.

Subject	Question
	2) When you checked the monitor, were you motivated by the “E” in the communication scanner or purely by chance?
2	I began to focus on it during straight and level flight but didn’t pay too much attention to it when changing flight profiles.
3	Saw the E approximately 5 to 6 times clearly. The rest of the times it was a mere flash of the E that motivated me to look at instructions monitor.
4	Mostly by the “E”. I tried to make it to make it part of my crosscheck inside the cockpit.
5	Both, the implied task of checking for new orders also motivated me to check the screen.
6	I looked at the monitor only after the “E”.
7	Both: the E was seen directly once and the rest by chance.
8	I was motivated by the “E”.
9	On several occasions I found myself wanting to check the monitor because I thought I saw an “E”. Other occasions I know I distinctively saw the “E”.
10	By the E or thinking I saw the E.
11	I was prompted by the “E”.
12	By the E.
13	By the E.

Subject	Question
	3) Has participation in this experiment influenced your opinion of sub-threshold priming/subliminal messaging?
2	I felt that it distracted me from focusing where I needed to during the flight.
3	Yes. From the point of view of pilot workload it increased dramatically. I would recommend subliminal messaging be enhanced to a more noticeable threshold.
4	I fly the UH-60, the aircraft already has audio and subliminal warnings on the UFD (Upfront Display). I use it a lot in the aircraft.
5	Yes, lets me know that you can be programmed to take flash cues while multitasking.
6	Not really since I don’t have any experience in that area.
7	Not really since it was not something I had previously considered.
8	I think it works great.
9	I feel it requires the pilot to adjust his or her scan from what they are custom too. Makes the pilot react quicker or scan quicker.
10	No, not really. I have always felt subliminal messages prompt us.
11	Yes, since I was able to recognize and be prompted by the “E”. I feel an aviator could be prompted in this manner.
12	Yes I think it would make a useful tool for knee board testing.
13	Not really, I feel that having the sequencing numbers was more of a distraction.

Subject	Question
	4) In your opinion, do you think sub-threshold cues could benefit a cognitively overloaded aviator?
2	Possibly, but not something that has to be viewed for too long of a duration.
3	No, not in the demonstrated present form. Perhaps a blinking light with accompanied aural cue.
4	Yes, if the aviator has been trained to use them and it is a normal part of their crosscheck.
5	Maybe, initially my complete concentration was on waiting for my cues.
6	Honestly, no idea, maybe.
7	Absolutely, providing it was reliable in repetition.
8	Yes
9	If the aviator was well trained to adjust their scanning techniques, yes. But otherwise it greatly increased workload.
10	Yes
11	Yes as long as it is used to supplement and not to add another item in the crosscheck.
12	Definitely
13	No, I think it may be more of a hindrance.

Subject	Question
	5) How do you think this technique could be incorporated into cockpit design? What systems would benefit from this feature?
2	Possibly into the ANVIS HUD, but any other place may be distracting.
3	Mission enhancing thru electronic planning page in glass cockpit display or a visual cue to view a laptop for mission change criteria.
4	All modern aircraft with glass cockpits would benefit. The cue should stand out from the other visual cues. It should turn a different color or stay on a lot longer than the normal cues. Also, associate it with a distinct tone.
5	Maybe incorporate it as a digital backup in the RNAV/moving map segment of the instrument panel.
6	Heads up display, either through goggles or aimed at the windscreen.
7	Could be incorporated similar to experiment. Unsure as to best system for incorporation.
8	Messaging systems would be easily incorporated into UH60M 1553 Data Bus.
9	I feel it should not be incorporated into cockpit design.
10	I have no clue modern cockpits have a lot going on already.
11	engine torque, oil temp, oil pressure. systems that get overlooked but are important to check
12	Electronic kneeboard testing. Map checkpoints. Fuel checks.
13	Maybe in a see-thru HUD display so I do not focus on something other than my normal scan.

Subject	Question
	6) Were the subthreshold cues a distraction?
2	Yes
3	Yes, definitely a distraction to scanning outside.
4	No, they are a valuable tool if the aviator is trained to use them.
5	No
6	Maybe the anticipation.
7	Not at all.
8	No.
9	Yes, because like I said previously, I am custom to the scan I have been using. If the pilot was trained on using these cues it could be beneficial. I am also a low experienced aviator so my scanning techniques are not as developed as an experienced aviator.
10	Yes because I focused on the little box thingy.
11	No if it is incorporated into an existing system or crosscheck. It would be if a pilot was expected to monitor for the cues.
12	No
13	Yes

Subject	Question
	7) Did you take your attention away from other tasks to concentrate on NOT missing the “E?”
2	Yes
3	Definitely yes. My attention to detail was diminished.
4	Yes, because it was not part of my crosscheck. If I flew with it often it would not be a distraction.
5	Yes, initially.
6	Sometimes
7	No
8	I incorporated it in my normal scan.
9	Sometimes I found myself concentrating on the “E” and other times concentrating on the flying and missing the “E”.
10	Yes, a lot.
11	Yes, at times.
12	No
13	Yes

Subject	Question
	8) Were you worried or distracted about this additional task?
2	A little distracted.
3	Yes, apprehension level increased due to worry of missing mission objectives.
4	No.
5	Initially, but I reverted back to fundamental flying and incorporated the “E” into my scan, which made it more simple.
6	Yes
7	No.
8	No.
9	Not worried or distracted except for the fact I was afraid of missing the “E” when I was reading the new mission on the screen.
10	Yes
11	It was an additional focus, not really a distraction.
12	No
13	Yes

Subject	Question
	9) Did the placement of the countdown indicator distract or interrupt your usual instrument scanning pattern?
2	Yes, until I realized what would cue me to seeing a mission change, which was the number sequence stopped and started over.
3	Yes. Definitely. It has a focusing affect where subconsciously I kept staring at it although trying to focus outside the aircraft.
4	Not during daytime but it is in a bad location for night flight.
5	Would have preferred it placed w/ the other instruments.
6	Not really.
7	It was somewhat of an interruption
8	No
9	Yes, definitely.
10	Yes
11	No
12	No
13	Yes

Appendix H
Crosstabulation table.

a = .05 * = significance	Job Title	Flight Activity Category	Readiness Level	Total Flight Hours	Total Simulator Hours
Number of Subthreshold Acknowledgments	χ^2(28, *N* = 12) = 39.00, *p* = .081	χ^2(12, *N* = 12) = 12.75, *p* = .387	χ^2(8, *N* = 12) = 10.00, *p* = .265	χ^2(16, *N* = 12) = 15.25, *p* = .506	χ^2(28, *N* = 12) = 37.875, *p* = .101
Average Time of Subthreshold Acknowledgments (seconds)	χ^2(77, *N* = 12) = 84.00, *p* = .274	χ^2(33, *N* = 12) = 36.00, *p* = .330	χ^2(22, *N* = 12) = 24.00, *p* = .347	χ^2(44, *N* = 12) = 48.00, *p* = .314	χ^2(77, *N* = 12) = 84.00, *p* = .274
Minimum Time of Subthreshold Acknowledgments (seconds)	* χ^2(42, *N* = 12) = 60.00, *p* = .035	χ^2(18, *N* = 12) = 22.25, *p* = .221	χ^2(12, *N* = 12) = 13.15, *p* = .358	χ^2(24, *N* = 12) = 24.00, *p* = .462	χ^2(42, *N* = 12) = 54.75, *p* = .090
Maximum Time of Subthreshold Acknowledgments (seconds)	χ^2(70, *N* = 12) = 76.00, *p* = .291	χ^2(30, *N* = 12) = 31.00, *p* = .415	χ^2(20, *N* = 12) = 24.00, *p* = .242	χ^2(40, *N* = 12) = 43.00, *p* = .344	χ^2(70, *N* = 12) = 76.50, *p* = .278
Total Number of Non-directed Events	χ^2(28, *N* = 12) = 28.00, *p* = .464	χ^2(12, *N* = 12) = 20.00, *p* = .067	χ^2(8, *N* = 12) = 9.867, *p* = .275	χ^2(16, *N* = 12) = 16.00, *p* = .453	χ^2(28, *N* = 12) = 28.00, *p* = .464

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