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Attentional Narrowing: a First Step Towards Controlled Studies of a Threat to Aviation Safety

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ATTENTIONAL NARROWING: A FIRST STEP TOWARDS CONTROLLED STUDIES OF A THREAT TO AVIATION SAFETY

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Attentional narrowing - the involuntary restriction of attention to a small set of data or one task/goal - is a major concern in many complex, high-risk domains. Research into this phenomenon is much needed but hampered by the difficulty of inducing it reliably in a controlled experimental setting. The present study tested the effectiveness of loud noise and high task demand for achieving this goal. Seven participants performed a visual search task in the context of a simplified air traffic control simulation. Performance and eye tracking data were recorded. Eye tracking metrics showed a narrowing of participants' visual attentional field under high demand; however, noise did not have a significant effect on attention allocation. The findings from this study represent an important step towards controlled studies of attentional narrowing. They also highlight the promise of eye tracking for detecting, in real time, breakdowns in attentional processes.

Attentional narrowing is a major and growing concern in many complex high-risk domains, such as aviation. Attentional narrowing refers to the "involuntary allocation of attention to a particular channel of information, diagnostic hypothesis, or task goal, for a duration that is longer than optimal, given the expected cost of neglecting events on other channels, failing to consider other hypotheses, or failing to perform other tasks" (Wickens, 2005). The phenomenon has been identified as a contributing factor to all controlled-flight-into-terrain (CFIT) accidents in the US Air Force (Shappell & Wiegmann, 2003). It also played a role in commercial aviation accidents such as the 1972 crash of Easter Airlines Flight 401 in which 103 people lost their lives. In this case, the failure of a landing gear indicator light during approach led all three pilots to focus on diagnosing the problem. As a result, they failed to notice that the autopilot had been disengaged inadvertently, which resulted in the aircraft gradually descending and ultimately crashing into the Everglades (NTSB, 1973).

Despite the potentially catastrophic consequences of attentional narrowing, empirical research into this phenomenon has been hampered by the difficulty of inducing it reliably in a controlled experimental setting. To date, two factors have been identified as likely triggers of attentional narrowing: (1) high motivational intensity and (2) arousal (Friedman & Förster, 2010; Harmon-Jones, Price & Gable, 2012). High motivational intensity refers to either a strong desire to approach and acquire an object associated with positive affect or to avoid negatively loaded stimuli that trigger, for instance, fear or disgust. Arousal, on the other hand, is defined as an energetic state of the organism (Bourne, 2003) which is affected by factors such as high task demand, loud noise, and extreme heat or humidity (Bursill, 1958; Hockey, 1970; Mackworth, 1965). In the presence of high motivational intensity and arousal, attention appears to narrow towards salient stimuli or stimuli that are perceived to be of high importance or priority (Bacon, 1974; Dirkin, 1983). It is important to note that, in most studies, this effect on attention allocation was inferred from performance data. Very few studies (such as Reimer, 2009) have examined the relationship between observed performance decrements and a person's allocation of visual resources. A promising, non-invasive approach to trace those changes is the use of eye tracking, which provides high-resolution data on eye movements and monitoring strategies in real time (Duchowski, 2007).

The goals of this pilot study were to (1) determine the effectiveness of two arousal-related stimuli – intermittent and aperiodic loud noise containing speech (based on Szalma and Hancock (2011)) and high task demand (e.g., Murata, 2004; Rantanen, 1999) – for inducing attentional narrowing, (2) trace how participants' allocation of visual attention is affected by those two factors and (3) identify eye tracking metrics that can capture, early and in real time, a narrowing of the attentional field. The application domain for this study was Air Traffic Control (ATC), a workplace that imposes high task demands and where breakdowns in attention allocation can have catastrophic consequences.

Methods

Participants

The participants in this study were 7 graduate students from the University of Michigan. Their average age was 25.1 years (SD = 4.7). Participants reported normal or corrected-to-normal vision. None of the participants had prior experience with ATC tasks.

Apparatus

The study was conducted using a simplified ATC simulation that was displayed on a 20-inch monitor, placed approximately 24 inches from the participants. Green aircraft icons were presented against a black background (see Figure 1). They were moving across the screen following a straight line, either horizontally or vertically, at a constant speed of 0.15 inches per second. The aircraft speed (shown in yellow) and altitude (shown in white) were presented in a data block to the lower right of the aircraft icon (see Figure 2).

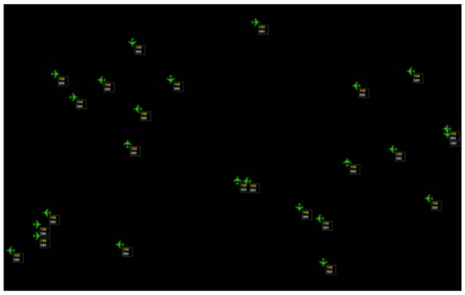


Figure 1. ATC simulation display

Figure 2. Aircraft icon and data block showing airspeed (150 kts) and altitude (FL (flight level) 500)

Tasks

All aircraft were assigned an airspeed of 150 knots and an altitude of 50,000 feet (FL 500). Occasionally, airspeed or altitude deviations occurred (airspeed values in the data block changed to 165 kts, 185 kts or 200 kts; altitude values changed to FL 370, FL 435 or FL 465). Participants were asked to monitor for these deviations and to return the airspeed or altitude to their assigned values as quickly as possible. To do so, they had to left-click the aircraft and choose the appropriate correction from three displayed options (in the case of airspeed deviations, the options were 15 kts, 35 kts and 50 kts; in the case of an altitude deviations, the options were 3,500 feet, 6,500 feet and 13,000 feet). Speed and altitude deviations lasted 6 seconds; if no correction was made during that time, the parameter automatically returned to its prescribed value. If the participant chose the appropriate correction value, the box around the data block turned green for 2 seconds; in case of an inappropriate correction, it turned red.

Experimental Conditions

(1) Noise manipulation. In the loud noise condition, a combination of white noise as well as aviation-related non-speech and speech alerts were presented via headset, at an average amplitude of 95 dBA. The various warnings were presented in an intermittent aperiodic fashion. In the no noise condition, participants were wearing a headset but no noise was presented.

(2) Task demand manipulation. The task demand was varied using the number of aircraft on the screen and the frequency at which speed or altitude deviations occurred. In the low task demand condition, 25 aircraft were presented on the screen, and an altitude or speed deviation occurred every 6 seconds. In case of high task demand, 80 aircrafts were presented, and an altitude or speed deviation occurred once per second.

Experiment Design and Procedure

The study employed a 2 (task demand: low or high) x 2 (noise level: no noise or loud noise) within-subject design. The order in which participants were presented with the two noise conditions was counterbalanced.

Participants were given a 10-minute training session to familiarize themselves with the ATC simulator. Next, they were asked to complete a 12-minute practice scenario during which they were asked to report observed airspeed or altitude deviations as fast as possible, and to apply the accurate correction to the data block. Then, the eye tracker was calibrated, and participants completed the two 12-minute experimental scenarios. Task demand was varied within each scenario, while noise was varied between the scenarios. Each scenario started with a 3-minute low task demand phase, followed by 6 minutes of high task demand, and ended with another 3-minute low task demand period. Participants were offered to take a 5-minute break between the two scenarios. Eye tracker calibration was repeated before each scenario. The entire session took approximately 1.2 hours to complete.

Dependent Measures

Performance data. The performance measure was the detection rate for speed and altitude deviations (expressed as the ratio of detected to total number of deviations), calculated for each of 9 screen sectors and for the overall display.

Eye tracking data. Eye tracking data was recorded using an ASL Eye-Trac D6 infrared-based, desktop-mounted eye tracker which samples at 60Hz. Eye tracking data consists of a series of fixations, or stable points of regard during which information processing occurs (Findlay, 2004), and saccades, or rapid eye movements between fixations during which no processing occurs (Yarbus, 1967). The following eye tracking metrics were calculated from the raw data: (1) the number of fixations on each of the 9 sectors (which can indicate problems with searching for information (Habuchi, Kitajima, & Takeuchi, 2008) and reveals the spread of attention across the screen), (2) the mean fixation duration (which can reflect difficulties with extracting information (Jessee, 2010)), (3) and the mean saccade length (which can provide information on the efficiency of the search; Goldberg & Kotval, 1999). Due to calibration issues, this data is available for only 4 of the participants.

Results

For the data analysis, the screen was divided into 9 sectors of equal size (see Figure 3). The various measures were then calculated for the overall screen and for the individual sectors.

Figure 3. Division of the screen into 9 sectors

Performance Data

The average detection rate for speed and altitude deviations across all participants and conditions was 26.2%. Performance was significantly lower with high task demand, as compared to the low task demand condition (10.7% and 41.7%, respectively; $F(1,26) = 177.2$, $p<0.001$). The performance decrement in the high task demand condition was uniform across sectors (see Figure 4).

27%	20%	20%
39%	31%	31%
25%	20%	27%

Figure 4. Average detection rate for each sector as a function of task demand (expressed as the ratio 'detection rate with high task demand/detection rate with low task demand')

The overall detection rate did not differ significantly between the noise and no-noise conditions (26.4% and 26.0%, respectively). However, detection performance for individual sectors varied somewhat as a function of noise: in the presence of noise, performance for sectors 1, 2, 5, 6 and 7 slightly improved; it tended to decrease for sectors 3 and 9 and remained the same for sectors 4 and 8 (see Figure 5).

116%	118%	68%
98%	114%	139%
117%	99%	86%

Figure 5. Average detection rate for each sector as a function of noise (expressed as the ratio 'detection rate with high noise/detection rate with no noise')

Eye tracking

Number of fixations. Overall, there was a trend towards fewer fixations in case of high task demand, as compared to low task demand (319.5 and 440, respectively). However, when calculated for individual sectors, the number of fixations in central sector 5 increased by 21% with high task demand while most of the other sectors showed a slight decrease in fixations. Noise did not affect the number of fixations.

89%	90%	73%
99%	121%	108%
73%	85%	92%

Figure 6. Average mean number of fixations on each sector as a function of task demand (expressed as 'number of fixations with high task demand/number of fixations with low task demand')

Mean fixation duration. The mean fixation duration was slightly higher with high task demand, compared to the low task demand condition (1.02 seconds and 0.70 seconds, respectively). The sectors that showed the strongest increase in the mean fixation duration (110-123%) were sectors 1, 2, 3 and 5 (see Figure 7). Noise did not affect mean fixation duration.

110%	123%	115%
102%	123%	100%
96%	97%	92%

Figure 7. Average mean fixation duration on each sector as a function of task demand (expressed as 'mean fixation duration in the high task demand condition/mean fixation duration in the low task demand condition')

Mean saccade length. There was a trend towards shorter mean saccade lengths with high task demand, as compared to low task demand (65.3 pixels and 75.0 pixels, respectively), but was not affected by noise. However, there was an interaction between noise and task demand such that a decrease in mean saccade length was less pronounced for high task load in the presence of noise (see Figure 8).

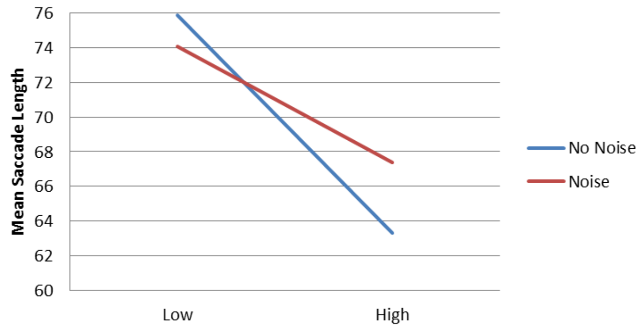
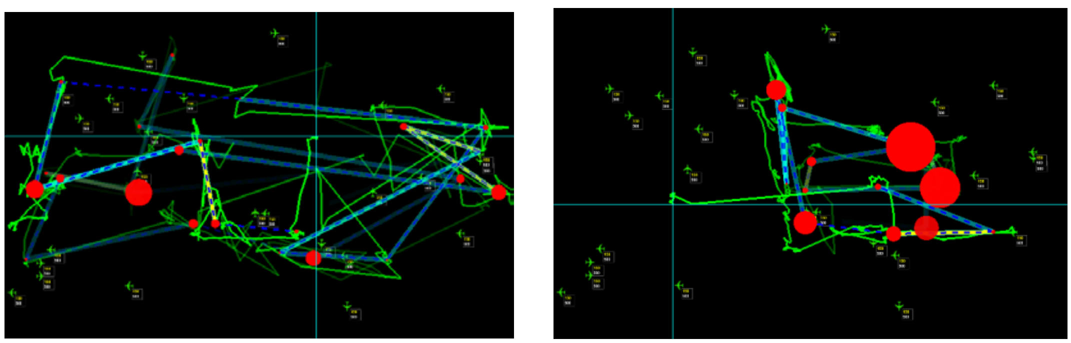


Figure 8. Interaction effects of noise and task demand on mean saccade length.

Figure 9 illustrates the above mentioned changes for one participant's scan pattern in the (a) no noise/low task demand condition and the (b) noise/high task demand conditions. In the latter case, fixations are more closely spaced and longer fixation durations are observed.



(a) (b)

Figure 9. Example of one participant's scan pattern over a period of 20 seconds in (a) the no-noise, low task demand condition and (b) the noise and high task demand condition (the size of the red circles represents fixation duration)

Discussion

The present study examined the effectiveness of two factors – loud noise and high task demand – for inducing attentional narrowing in the context of a simulated simplified ATC task. Results showed that task demand, but not noise, significantly affected both participants' performance and their attention allocation. In the high task load condition, significantly fewer airspeed and altitude deviations were detected. The eye tracking data reveal that this performance decrement resulted from a narrowing of the visual attentional field. The number of fixations in the central sector increased at the expense of more peripheral fixations, and longer fixation durations and shorter mean saccade lengths were observed. In combination, these effects resulted in a slower and more confined visual scan during high task load.

There are several possible reasons why noise may not have affected attention allocation and performance. First, loud noise has been shown to degrade performance on complex tasks (i.e. multi source tasks or tasks with a high signal rate) but it benefits the performance of simple tasks (Hockey, 1970). The task of detecting altitude and speed deviations may not have been sufficiently complex to be affected by noise. Also, noise is known to increase arousal which, in turn, is linked to performance by an inverted U-shaped curve (Yerkes & Dodson, 1908). The Yerkes Dodson law states that the highest level of performance is reached at an intermediate level of arousal. The noise level that participants experienced in this study may not have been sufficient to raise their level of arousal to the point where a decrease in performance would be observed. Finally, the fact that the alerts in the noise condition were not associated with actual threats may have reduced their effectiveness.

In conclusion, the findings from this study represent an important first step towards enabling controlled studies of attentional narrowing. High task demand is an effective manipulation for inducing the phenomenon, and the eye tracking metrics proved useful for gaining insight into underlying attentional processes and for detecting and possibly counteracting the phenomenon in real time.

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