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High Rate of Inattentional Deafness in Simulated Air Traffic Control Tasks

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Abstract

The Air Traffic Control (ATC) environment is complex and safety-critical; operators work in dynamic situations and must make high-risk decisions under stress and temporal pressure. The high perceptual load involved in ATC means that controllers' attention must be shared between several subtasks, with few or no remaining attentional capacity for processing information that is not related directly to the focal task. In this kind of situation, the likelihood of a controller failing to become aware of an auditory alarm, i.e. inattentional deafness, is high. We designed an ecological ATC thanks to the simulation environment called the "LABY"microworld. Twenty participants were required to guide one (low cognitive load) or two planes (high cognitive load) around a given route, while dealing with visual notifications relating to peripheral aircrafts. During the task, participants were played either standard tones which they were told to ignore, or deviant tones ("the alarm", probability = 0.20) which they were told to report (20 alarms per scenario). We hypothesized that the detection rate of auditory alarms will decrease with cognitive workload. In order to explore this possibility, Behavioral results showed that 28.8% of alarms were not reported when guiding one plane, and up to 46.2% when guiding two planes (high load). The cognitive load increase led to a reduced visual notification detection rate, but the performance to guiding the central aircrafts was maintained, as well as the reaction times to report auditory alarms when perceived. This high rate of inattentional deafness is essential to further physiological studies on alarm omission in aeronautics, such as ERP or eye movement analysis. Potential applications are related to the integrative online detection and prevention of alarm omission, and the online measurement of workload in ecological situation.

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*Keywords:*Cognitive load ; Inattentional deafness ; Air Traffic Control ; Auditory alerts ; Laby.

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1. Introduction

Within the safety-critical environment of Air Traffic Control (ATC), operators must deal with dynamic and cognitively demanding tasks whilst confronted with temporal pressure, stress and high-risk decision-making situations. Operators exchange information with pilots and other controllers, and must be vigilant and responsive to the occurrence of various on-screen visual notifications. In addition, auditory warnings such as collision avoidance alerts or danger area infringement warnings are increasingly integrated within ATC workstations. This recent introduction of auditory alerts raises new human factors issues as several theories indicate that high cognitive load context can lead to neglecting auditory alerts. One could argue that the high perceptual and cognitive load typical of ATC operations may consume a large proportion of attentional resources – especially when suboptimal visual designs are used – which in turn can reduce the available attentional capacity for processing the task at hand, and also additional unexpected events. Indeed, according to perceptual load theory [1-3], tasks involving high perceptual load can consume most of attentional capacity, leaving little remaining for processing information that is not directly related to the focal task [4-7] such as unexpected alarms. Moreover, several researches have shown that attentional resources are shared between vision and hearing [8-11]. Finally, some authors also postulate that task with high cognitive load (e.g., load in working memory) can lead to a reduced openness to additional stimuli such as auditory distractors [12-14]. In line with these theories, we suggest that an efficient way to induce inattentional deafness is to use the highest perceptual and cognitive load level to consume attentional resources on the main task for potential other information channels.

We used an ATC-like synthetic environment called Laby [15] which simulates key features of a dynamic visual monitoring radar task. During this classic control task, participants had to guide one (first half of the scenario) or 2 (second half) aircrafts at the same time (fig. 1).We set the Laby parameters to a manual selection of the planes' heading (contrary to automatic selection in our previous study) to reinforce the participants' engagement in the ATC task and to increase the overall cognitive load (see fig. 2).

In addition, participants had to acknowledge notifications displayed close to aircrafts located in peripheral vision, simulating the display of a radar image. The Color-Blink notification design was previously shown to demand more attentional resources than other designs, and is closer to the ecological environment of ATC. Indeed, participants who experienced Color-Blink notifications (fig. 3) demonstrated a lower notification detection rate (compared to other designs, for details see [15]).

The Color-Blink notifications required a sustained visual search to be perceived, and could sometimes go unnoticed if the controller was not actively monitoring the radar screen. This notification design was then chosen to induce a higher visual attention in the participants, more likely to cause inattentional deafness. To further improve the level of realism, each participant performed the task according to various levels of perceptual load (number of aircraft in the visual scene) and two levels of cognitive load (tempo, i.e. the number of events per unit of time) with various numbers of aircrafts in the visual scene (between 5 and 21). Simultaneously with the ATC task, participants were asked to respond to the occurrence of low probability tones and to ignore high probability tones, as an indicator of inattentional deafness. One could predict that the introduction of the second aircraft in the ATC task would increase the inattentional deafness rate, in comparison to the one aircraft condition. This might demonstrate a reduced availability of the attentional resources for processing the auditory stimuli. According to the initial study comparing the two notification types [15, 16], we also hypothesized that the ATC task would consume fewer attentional resources when performed with Box-Animation compared to Color-Blink notifications. Consequently a lower subjective mental load, a better detection rate and higher ERPs amplitude should be observed with Box-Animation than Color-Blink notifications.

2. Material and methods

2.1. Ethic statement

All participants were informed of their rights and gave written informed consent for participation in the study, according to the Declaration of Helsinki. The research was carried out fulfilling ethical requirements in accordance with the standard procedures of Université Laval.

2.2. Participants

Twenty volunteers, all students of Université Laval were recruited for this study (Mean age = 23.5 years, Standard Deviation = 4.2). None had a history of neurological disease, psychiatric disturbance, substance abuse, or took psychoactive medications. They all received full information on the experiment protocol, signed an informed consent and received compensation for their participation in the study. Each participant went through a training session of 10 minutes, and then had to complete two Laby scenarios. After the two scenarios, participants performed a control task to ensure they perceived the auditory alarms normally. Finally, they answered questionnaires about their performance and the design of the task. The whole procedure lasted 1 hour.

2.3. The Labymicroworld and the oddball task

The LABY microworld is an ATC simulation software. It is built around the main task of guiding one or two aircrafts around a route shown on the display screen (Fig 1). Participants had to monitor the path and altitude of these aircrafts. For this purpose, they were given instructions, with a pop-up window close to the aircraft, to enter control commands using drop-down menus (Fig. 2). Participants were penalized in their overall score in one of two ways. A deviation in the assigned route resulted in the aircraft crossing the border of the assigned route, and a visual alert in the center of the screen. An error in the altitude instructions resulted in the aircraft maintaining its trajectory, no alert, and continued control. The simulation ended as soon as the first aircraft reached the arrival area at the end of the corridor.

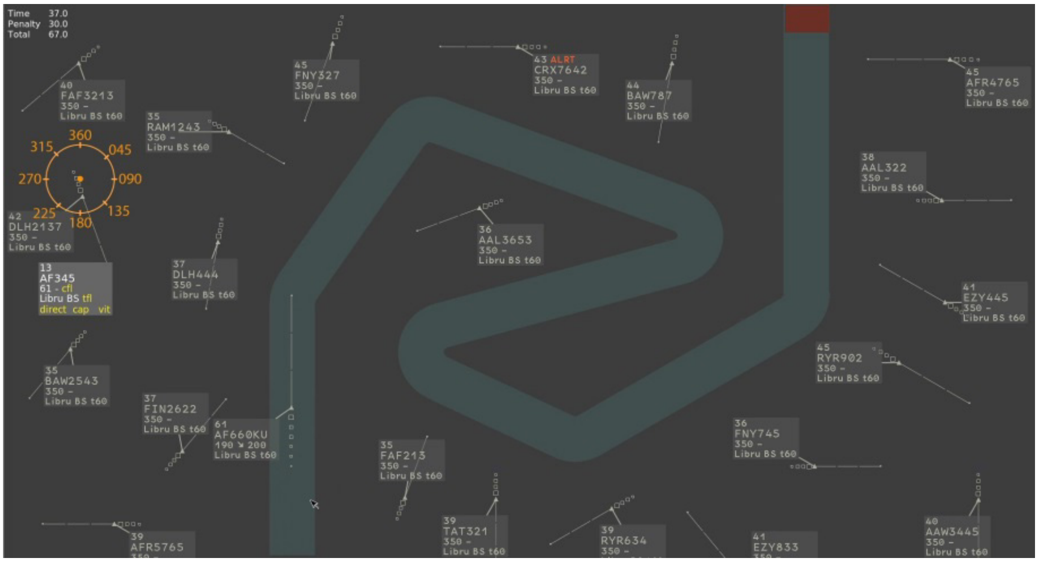

Fig. 1.Exemple of Laby scenario, with one aircraft to guide in the corridor and 21 peripheral aircrafts. A Color-Blink notification is displayed on the top of the image. On the top left corner is displayed a compass rose to help participants anticipate the planes' heading.

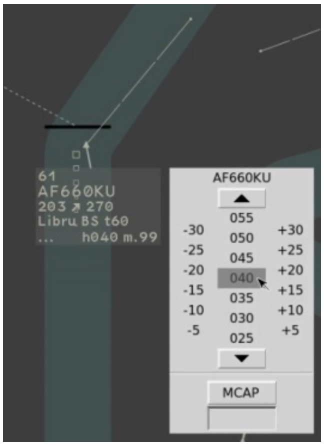

Fig. 2. The window used to select the heading of the plane, which appeared when clicking on the plane's label.

In addition to these central aircrafts, participants had to manage a set of static aircrafts located in the peripheral vision around the main aircrafts corridor, simulating the display of a radar image (Fig. 1). The number of peripheral aircrafts (between 5 and 21) depended on the visual load level of the scenario. The Color-Blink visual notifications could be displayed for these peripheral aircrafts (Fig. 3), which participants had to acknowledge by clicking on the aircraft associated with the notification. Only one notification related to the peripheral aircraft was issued at a time. The aircraft with the notification was randomly selected among the static aircrafts. The notification disappeared as soon as the participant clicked on the associated aircraft. If the participant did not react within a given time, the notification disappeared and the score was decreased. Thirty-four visual notifications were displayed in each scenario.

Fig. 3. The Color-Blink notification design: the text 'ALRT' switches from white (1a) to red (1b) at a rate of 200 ms white on 800 ms red.

In parallel to the ATC task, participants had to perform an auditory alarm detection task. Standard tones (1000 Hz, 52.5 dB, 500 ms long, probability = 0.8) and deviant tones (2000 Hz, 52.5 dB, 500 ms long, probability = 0.2) were randomly played. The mean time window between successive tones was 2.6 seconds. Participants were told to consider the deviant tones as auditory warnings and to report them as fast as possible by pressing a specific button. The auditory oddball detection task had no impact on the score. The number of auditory alarms (20) was the same in each scenario, 10 in the first half (with one main aircraft) and 10 in the second half (two aircrafts).

In order to determine individual baseline auditory detection rate, participants were asked to perform an auditory oddball control task. This oddball control tasks was similar to the auditory oddball task administered in parallel to the ATC task, the only difference was that a white cross was displayed at the center of the screen instead of the ATC task. The oddball control taskwas completed after the two ATC scenarios. A 42dB white noise was played continuously during each ATC scenario and during the oddball control task.

2.4. Statistical analysis

Statistical analyses were performed using Statistica 7.1 (StatSoft ©). Results were considered statistically significant at p < .05. Mean percentage of correct responses to the central aircraftsaltitude instructions, visual notifications detection rate, auditory alarm detection rate and reaction times were calculated for each half of the two scenarios. We defined a cognitive load factor (low: 1 central aircraft vs. high: 2 central aircrafts) and a visual load factor (low vs. high). Visual load * cognitive load interactions were not analyzed. Behavioral data were assessed by 2*2 ANOVAs to investigate the effect of the factors cognitive and visual loads during the ATC task.

3. Results

3.1. Performance to the central aircraft guiding task

There was no significant effect of the number of central aircrafts in the corridor (cognitive load) nor of the visual load on the correct altitude instructions rate (resp. $F(1, 19) = 0.86$, $p = .36$, $\eta^2p = .04$ and $F(1, 19) = 0.64$, $p = .43$, $\eta^2p = .03$).

The analysis of reaction times showed a significant effect of the cognitive load ($F(1, 19) = 31.20$, $p< 0.001$, $\eta^2p = .62$), with greater reaction times with two aircrafts(M = 5.49, SD = 1.44) than one aircraft in the corridor (M = 3.98 s, SD = 0.45), and no effect of the visual load ($F(1, 19) = 1.43$, $p = .25$, $\eta^2p = .07$).

3.2. Visual notifications detection rate

There was a significant effect of the cognitive load on the notification detection rate($F(1, 19) = 37.46$, $p< .001$, $\eta^2p = .66$), and no effect of the visual load ($F(1, 19) = 3.74$, $p = .07$, $\eta^2p = .16$). Fewer notifications were detected with two planes (M = 47.45%, SD = 17.73) than with one plane (M = 62.25%, SD = 17.08).

There was also a significant effect of the number of planes on the reaction times to visual notifications ($F(1, 19) = 13.43$, $p< 0.01$, $\eta^2p = .412$), with greater reaction times with two planes (M = 3.16 s, SD = 1.09) than one plane (M = 2.70, SD = 0.44), and no effect of the visual load ($F(1, 19) = 0.19$, $p = .67$, $\eta^2p = .01$).

3.3. Auditory alarm detection rate

There was a significant effect of the number of planes on the auditory alarms detection rate ($F(1, 19) = 24.50$, $p< .001$, $\eta^2p = .56$), and no effect of the visual load ($F(1, 19) = 0.11$, $p = .75$, $\eta^2p = .006$). Fewer alarms were reported with two planes (M = 53.79%, SD = 30.81) than with one plane (M = 71.24%, SD = 21.84), as showed in fig. 4.

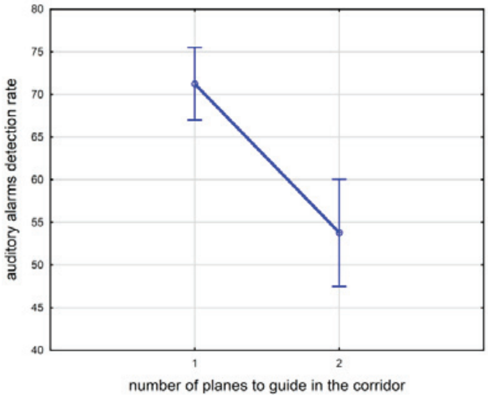

Fig. 4. The auditory detection rate for the one (left) and two (right) planes conditions ($p< 0.001$).

There was no effect of the number of planes on the reaction times to auditory alarms (*F*(1, 19) = 1.04, *p*= 0.32, *η* = .05), and no effect of the visual load (*F*(1, 19) = 1.02, *p* = .32, $\eta^2 p$ = .05).

4. Discussion

The current study used the impact of cognitive and perceptual load on the inattentional deafness phenomenon during a simulated ATC task to create a very engaging and demanding task. The main objective of this study was to investigate if a decent rate (near 50%) of inattentional deafness could be observed, enabling future physiological analysis on this repetitive phenomenon, such as ERP analysis, eye movement or pupil dilatation. For this purpose, we used the ecological ATC simulation Laby, with one and two aircrafts to guide along a corridor. The Color-Blink notification design, not very perceptible, allowed us to createa demanding visual search in addition to the ATC task, and so induceda high perceptual load.

Our main result is that we reached an inattentional deafness rate of 28.8% with one aircraft to guide, and up to 46.2% with two aircrafts. The absence of a significant effect of the cognitive load (number of aircrafts to guide)on the reaction times of reported alarms suggest unreported alarms are indeed caused by inattentional deafness, and not a lack of time to answer when having two planes to guide. Participants' priority remained focused on auditory alarms, when these alarms where perceived. Having around the same number of missed and reported auditory alarm allows future investigation with electro-encephalography and ERP measurements. Furthermore, aprotocol enabling a great number of inattentional deafness occurrences opens the way to other physiological measurements, such as eye tracking, which could reveal physiological correlates of inattentional deafness, leading to online detection of this critical phenomenon.

The visual load manipulation did not result in any significant effect on the performance to the guiding task, the notification detection or the auditory alarm detection. The cognitive load on the other hand, had an effect on the reaction times to the guiding task, resulting from the doubled amount of instructions to give to the two aircrafts in the high cognitive load condition. Participants did not commit more errors in the instructions but gave them significantly later.

The increase in cognitive load from the second aircraft also resulted in fewer visual notifications being reported and greater reaction times. Participants' prioritieswere to stay on the corridor, and to report auditory alarms. Visual notifications were neglected when the second aircraft appeared in the corridor.

In conclusion, our findings indicate the Laby task designed for this experiment is very efficient to induceinattentional deafness, under different levels of cognitive load. Given the amount of repetition of inattentional deafness in this procedure, we plan on analyzing the eye movements of participants to examine the possibility of fixation duration as an easily observable indicator of inattentional deafness.

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References

[1] Lavie N (1995) Perceptual load as a necessary condition for selective attention. Journal of Experimental Psychology-Human Perception and Performance 21: 451-468.

[2]Lavie N, Hirst A, de Fockert JW, Viding E (2004) Load theory of selective attention and cognitive control. Journal of Experimental Psychology: General 133: 339.

[3] Lavie N, Tsal Y (1994) Perceptual load as a major determinant of the locus of selection in visual attention. Perception & Psychophysics 56: 183-197.

[4] Hughes RW, Hurlstone MJ, Marsh JE, Vachon F, Jones DM (2013) Cognitive control of auditory distraction: Impact of task difficulty, foreknowledge, and working memory capacity supports duplex-mechanism account. Journal of Experimental Psychology: Human Perception and Performance 39: 539.

[5] Moore DR, Fuchs PA, Rees A, Palmer A, Plack CJ (2010) The Oxford Handbook of Auditory Science: The Auditory Brain: Oxford University Press.

[6] Spence C, Read L (2003) Speech shadowing while driving on the difficulty of splitting attention between eye and ear. Psychological science 14: 251-256.

[7] Wood NL, Cowan N (1995) The cocktail party phenomenon revisited: Attention and memory in the classic selective listening procedure of Cherry (1953). Journal of Experimental Psychology: General 124: 243.

[8] Brand-D'Abrescia M, Lavie N (2008) Task coordination between and within sensory modalities: Effects on distraction. Perception & psychophysics 70: 508-515.

[9] Macdonald JS, Lavie N (2011) Visual perceptual load induces inattentional deafness. Attention, Perception, & Psychophysics 73: 1780-1789.

[10] Santangelo V, Olivetti Belardinelli M, Spence C (2007) The suppression of reflexive visual and auditory orienting when attention is otherwise engaged. Journal of experimental psychology Human perception and performance 33: 137.

[11]Sinnett S, Costa A, Soto-Faraco S (2006) Manipulating inattentional blindness within and across sensory modalities. The quarterly journal of experimental psychology 59: 1425-1442.

[12] Berti S (2013) The role of auditory transient and deviance processing in distraction of task performance: a combined behavioral and event-related brain potential study. Frontiers in human neuroscience 7.

[13] Berti S, Schröger E (2003) Working memory controls involuntary attention switching: evidence from an auditory distraction paradigm. European Journal of Neuroscience 17: 1119–1122.

[14] Munka L, Berti S (2006) Examining task-dependencies of different attentional processes as reflected in the P3a and reorienting negativity components of the human event-related brain potential. Neuroscience letters 396: 177–181.

[15]Imbert J-P, Hodgetts H, Parise R, Vachon F, Tremblay S (2014) The LABY microworld: A Platform for Research, Training and System Engineering.

[16] Giraudet L, Berenger M, Imbert J-P, Tremblay S, Causse M (2014) Inattentional Deafness in Simulated Air Traffic Control Tasks: A Behavioral and P300 Analysis.