To cite this version: Fabre, Eve Florianne and Peysakhovich, Vsevolod and Causse, Mickaël *Measuring the Amplitude of the N100 Component to Predict the Occurrence of the Inattentional Deafness Phenomenon.* (2016) In: AHFE 2016 International Conference on Neuroergonomics and Cognitive Engineering, 27 July 2016 - 31 July 2016 (Orlando, United States).

Measuring the Amplitude of the N100 Component to Predict the Occurrence of the Inattentional Deafness Phenomenon

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Abstract. In the field of aviation, a significant amount of accidents are attributable to a phenomenon called inattentional deafness, defined as "the propensity to remain unaware of unexpected, though fully perceptible auditory stimuli such as alarms". The present study aimed at testing the impact of cognitive load on the perception of auditory information unrelated to the piloting task at stake in an ecological flight context. Pilots had to perform simultaneously a piloting task (i.e., approach and landing) in a A320 flight simulator and a passive auditory oddball task, with standard (80%) and deviant (20%) tones played. Lower N100 amplitudes were found in response to deviant tones when the piloting task was associated with a high cognitive load than a low cognitive load, demonstrating that cognitive load disrupts the perceptual processing of auditory stimuli, which is likely to trigger inattentional deafness in pilots.

Keywords: Human Factors · Aeronautics · Inattentional Deafness · N100 · Passive Oddball Task

1 Introduction

In the field of aviation, a significant amount of accidents are due to a phenomenon called inattentional deafness (i.e., the propensity to remain unaware of unexpected, though fully perceptible auditory stimuli such as alarms). For instance, in the famous crash of Eastern Air Lines Flight 401 in the Everglades, the pilots were obsessed by a burnt-out landing gear indicator light and did not perceive the auditory alarm indicating the disengagement of the autopilot [1]. This crash among others (e.g., First Air flight 6560), suggests that an unexpected event associated with a high cognitive load is likely to increase the occurrence of inattentional deafness.

Various experiments investigated the inattentional deafness phenomenon in the laboratory [2] [3] [4]. To study the inattentional deafness phenomenon in the context of aeronautics, Giraudet and colleagues [4] used an aviation-like task in which the level of cognitive load varied. This aviation-like task was coupled with an alarm detection task (i.e., active oddball task, for a review see [5]). The results showed that an increase in cognitive load leads to a decrease in alarm detection performance and is associated with a decrease in P3b amplitude. However, the amplitude of the N100 component was not affected. Taken together these results demonstrate that tasks associated with high level of cognitive load may enable the perceptual processing of the alarms (i.e., no modulation of the N100 amplitude) but may disrupt cognitive processes, which is likely to trigger inattentional deafness. In this study, the piloting task was very simplified and not totally ecological. Moreover, pilots were explicitly informed that they had to attend auditory information in order to complete the alarm detection task, which may have artificially enhanced the sensitivity to the auditory alarms.

The present study aimed at testing the impact of cognitive load on the perception of auditory information unrelated to the piloting task in an ecological flight context. Fifteen pilots performed two approaches/landings in the A320 flight simulator of ISAE-Supaéro. In the first flight scenario, the approach/landing procedure was associated with a low cognitive load (i.e., Ceiling And Visibility OK, normal functioning of the flight instruments), while the second flight scenario was more complex with a covered weather and a malfunction of flight instruments to manage (i.e., high cognitive load). In addition to the piloting task, pilots had to perform a passive auditory oddball task (i.e., participants had not to react to the tones), with standard (80%) and deviant (20%) tones played in the flight simulator. Brain electrophysiological measurements (i.e., ERPs) in response to deviant sounds were measured in both scenarios. An important amount of studies demonstrated that both the N100 component and the P3b component indexed the processing of auditory stimuli. The N100 component is a negative-going ERP, peaking in adults between 80 and 120 milliseconds after the onset of a stimulus, and distributed mostly over the frontal-central region of the scalp [6]. It indexes the perceptual processing of the stimulus and was also found to be larger in response to non-targets and infrequent stimuli [7]. The P3b is a positive-going ERP, observed in a time window between 300 to 600 ms at the central-parietal region of the scalp and known to reflect the occurrence of cognitive and attentional processes (for a recent overview, see [8]). If cognitive load disrupts the perceptual processing of infrequent/deviant auditory information at an early stage, we predicted to observe lower N100 amplitudes in response to deviant tones in the high-load scenario compared to the low-load scenario. While in the case it disrupts later attentional and cognitive processes, we may observe lower P3b amplitude in the high load scenario than in the low load scenario.

2 Material and Methods

2.1 Participants

Sixteen healthy participants (*MAge* = 32 years old, *SD* ±10), all native French speakers, participated in this study. They were recruited on the ISAE-supaéro campus. All were right-handed (as assessed by the Edinburgh Handedness Inventory, [9]) private pilots with a valid Private Pilot License. They had normal auditory acuity and normal or corrected-to-normal vision. None of the participants reported a history of prior neurological disorder. 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 the University of Toulouse.

2.2 Material

Oddball Sounds. One of two 50 dB (SPL) tone types lasting 100 ms was randomly played. The tone was either standard (frequency = 1900 Hz, p = 0.9) or deviant (frequency = 1950 Hz, p = 0.1).

Fig. 1. Illustration of a participant in the flight simulator.

The Flight Simulator. The experiment took place in the PEGASE simulator (i.e., an A320 simulator; see Figure 1) at the ISAE-Supaéro. PEGASE simulator lies on pneumatic jacks that enable to recreate realistic accelerations. It comprises: a cabin equipped with various types of display existing in aircraft cockpits, a 3-axis platform for movement restitution, 3D display of the outside world, the whole set-up (i.e., management, simulation and graphics) is managed by 18 PC type microcomputers.

2.3 Procedure

First, participants were sat on a chair while the EEG cap and the electrodes were placed on their hands. Participants were then invited to take the commandant's place in the simulator. They performed a flying training session of fifteen minutes in the simulator. They were then given the flight instructions. They were asked to perform two flights from Bordeaux (France) to Toulouse (France) of twenty minutes each and were informed of the runway they would have to land on. During the flight, they were continuously given ATC instructions they had to follow. They were informed that they could not reply to these instructions or communicate with the air controllers. In the low load flight, the cognitive load associated with the flight was low with Ceiling And Visibility OK (CAVOK, no clouds below 5000 feet above aerodrome level visibility is at least 10 kilometers no current or forecast significant weather such as precipitation, thunderstorms, shallow fog or low drifting snow) and normal functioning of the flight instruments. In the high load flight, the visibility was very low making visual flight impossible, and the flight instruments provided fluctuating information (i.e., a fluctuant δ was added to the correct flight parameters making the piloting task more complex). Half of the participants started with the low load flight scenario, while the rest of them started with the high load flight scenario. Participants were told that two types of tones would be played along the flights but they would not have to do anything special in response to these sounds.

2.4 Electroencephalography

EEG was amplified and recorded with an ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands) from 32 Ag/AgCl active electrodes mounted on a cap and placed on the scalp according to the International 10–20 System (FP1, FP2, AF3, AF4, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, CP5, CP1, Cz, CP2, CP6, P7, P3, Pz, P4, P8, T7, T8, PO3, PO4, O1, Oz, O2) plus two sites below the eyes for eye movements monitoring. Two additional electrodes placed close to Cz, the Common Mode Sense (CMS) active electrode and the Driven Right Leg (DRL) passive electrode, were used to form the feedback loop that drives the average potential of the participant as close as possible to the AD-box reference potential. Electrode impedance was kept below 5 kΩ for scalp electrodes, and below 10 kΩ for the four eye channels. Skin-electrode contact, obtained using electro-conductive gel, was monitored, keeping voltage offset from the CMS below 25 mV for each measurement site. All the signals were (DC) amplified and digitalized continuously with a sampling rate of 512 Hz with an anti-aliasing filter with 3 dB point at 104 Hz (fifth-order sinc filter); no high-pass filtering was applied online. The triggering signals to each word onset were recorded on additional digital channels. EEG data were off-line re-referenced to the average activity of the two mastoids and band-pass filtered (0.1 – 40 Hz, 12 dB/octave), given that for some subjects the low-pass filter was not effective in completely removing the 75 Hz artifact. Epochs were time locked to the onset of the tones and extracted in the interval from -200 ms to 800 ms. Segments with excessive blinks and/or artefacts (such as excessive muscle activity) were eliminated off-line before data averaging. The lost data (due to artefacts) were equal to 45%. A 200 ms pre-stimulus baseline was used in all analyses.

3 Results

A 2 x 3 (Scenario [Low Load, High Load] x Electrode [Fz, Cz, Pz]) repeated measures ANOVA was conducted to assess mean amplitudes in the 100 - 180 ms time window. The analysis revealed a main effect of Electrode [$F(2, 15) = 7.79$, $p < .01$, $\eta p2 = .34$], with greater negativities at Fz ($M = -1.47$ µV, $SD = 1.43$) than at Cz ($M = -1.01$ µV, $SD = 1.29$) and Pz ($M = -.82$ µV, $SD = 1.35$), but significant differences between Cz and Pz ($p < .50$). The analysis also revealed a main effect of scenario [$F(1, 15) = 4.72$, $p < .05$, $\eta p2 = .24$], with greater negativities observed in response to infrequent tones in the low load scenario ($M = -1.55$ µV, $SD = .99$) compared to the high load scenario ($M = -.65$ µV, $SD = 1.43$). However, the Scenario x Electrode interaction was not significantly different [$F(2, 30) = .56$, $p = .58$, $\eta p2 = .04$]. See Figure 2. for grand average ERP waveforms.

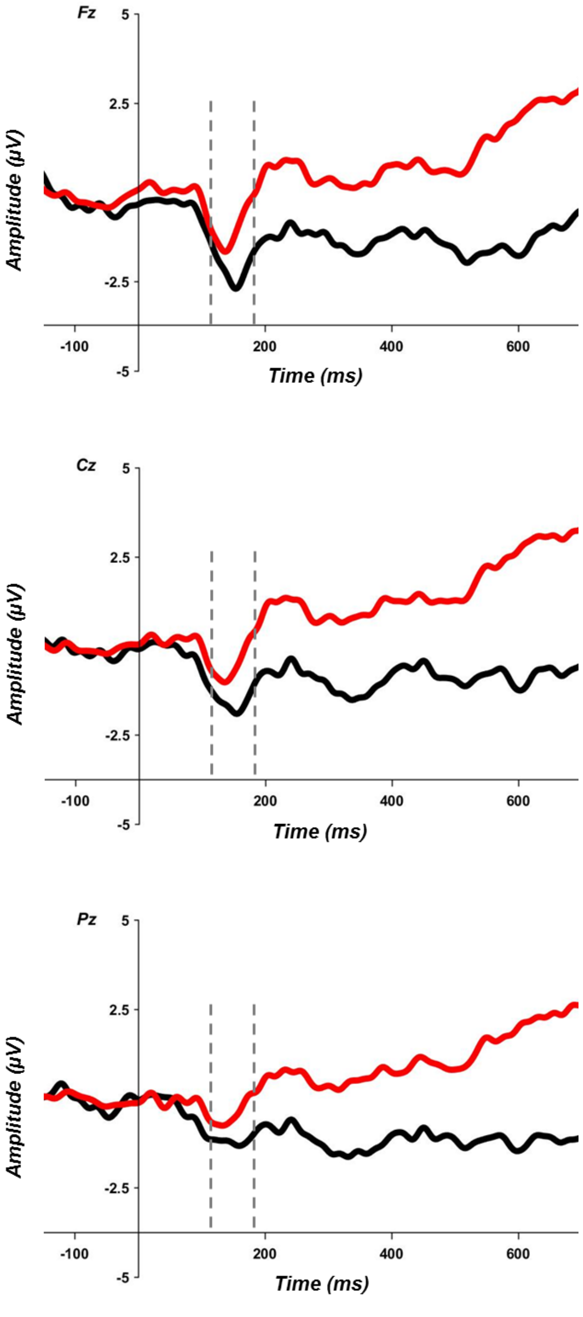

Fig. 2. Grand average ERP waveforms at Fz, Cz and Pz electrodes for infrequent tones in the low load condition (black line) and in the high load condition (red line).

4 Discussion

The present experiment aimed at testing the “permeability” of the pilots to unrelated auditory stimuli depending on the cognitive load of the piloting task at stake. Subjective measurements revealed that participants were more cognitively charged in the high load flight scenario than in the low load flight scenario, confirming that high load scenario generated greater cognitive load in participants than the low load scenario. Moreover, lower N100 amplitudes were found in response to infrequent tones in the high load scenario than in the low load scenario. The N100 component was found to index the perceptual processing of auditory stimuli but also the early allocation of attentional resources to these stimuli [6]. The electrophysiological results of the present study demonstrate that the perceptual processing of auditory stimuli (i.e., such as alarms) may be disrupted in pilots performing high cognitive load piloting tasks. We conclude that pilots are less likely to process auditory information unrelated to the task at stake in a complex situation (i.e., malfunction of flight instruments), which may lead them to become “deaf” to auditory alarms.

These results are in line with the results of a recent study [10] that showed that when the cognitive workload was high, visually impaired pilots showed lower N100 responses to infrequent auditory stimuli compared to when the cognitive workload is low. In the contrary, using an active oddball task, Giraudet and colleagues [4] found no modulation of the N100 amplitude, but a decrease in P300 amplitude in response to infrequent tones when the cognitive load associated with the task increased. This difference in results is likely to be due to the nature of the oddball task that was active in the study of Giraudet and colleagues [4] and passive in the present study. Using an active oddball task is interesting in that it enables to measure behaviorally the inattentional deafness phenomenon, by counting the amount of missed hits. However, as mentioned in the introduction section, it may also modify the attentional focus of the pilots, because it increases artificially the attention toward auditory information (i.e., the pilots are expecting the occurrence of the auditory stimuli) which may modify the way auditory stimuli are processed. While Giraudet and colleagues [4] concluded that an increase in cognitive load may lead to disrupting the processing of auditory alarms at a late stage (i.e., cognitive process), we argue that when pilots do not attend to the auditory stimuli, an increase in cognitive load may disrupt the processing of these auditory stimuli at an early stage (i.e., perceptual). Future studies should confirm this hypothesis.

Various solutions can be used to prevent the occurrence of the inattentional deafness in the cockpit. First, a recent study has demonstrated using a simulated piloting task that spoken distractors (i.e., words) are more likely to be intensively processed than simple tones [11]. We argue that critical information such as the disengagement of the auto pilot should be indicated using a spoken alarm like “autopilot disengaged” and not simple tones as has been the case up to now. Second, now two main ERP components associated with the occurrence of the inattentional deafness phenomenon (i.e., the N100 and the P3b components) have been identified, we argue that more work should be done to implement Brain Computer Interfaces enabling the detection of decreased N100 and P3b responses to auditory alarms to inform the pilots they may suffer from inattentional deafness.

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