Measuring Susceptibility to Alerts while Encountering Mental Workload

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Abstract
This work-in-progress reports two studies that test if cognitive load reduces human susceptibility to auditory alerts. Previous studies showed that susceptibility (measured using Event-Related Potentials) is reduced when people perform visual or manual tasks, including in driving settings. We investigate whether a cognitively distracting task, without visual and manual components, also reduces susceptibility. Study one suggests that, outside of a driving context, performance of such a cognitively distracting task reduces susceptibility to auditory alerts compared to baseline without distraction. Study two suggests that susceptibility is also reduced when people perform a cognitively distracting task during automated driving. The results have important implications for semi-automated vehicles. Such vehicles rely on alerts to initiate a take-over of control by the human driver. However, if the human is distracted by another task - be it visual, manual, or cognitive - they might not always detect the alert, as their susceptibility is reduced.

Author Keywords
Cognitive load; event related potential; automated driving; driver distraction; oddball task; verb generation task

CCS Concepts
•Human-centered computing → Empirical studies in HCI;

Introduction

Semi-automated vehicles, such as at SAE level 3 [8], can control (part of) the driving task in a specific operational design domain, such as on a regular highway under normal traffic and weather conditions. However, at times there might be conditions where the car cannot continue the drive, such as when it encounters roadworks, or if weather conditions change. In such cases, the car can issue an alert to the human to take-over (part of) the control of the vehicle. As with many other in-car alerts, the alert might be presented auditory. But how susceptible are people to such auditory alerts?

Previous research demonstrated that, compared to a baseline stationary condition, people's susceptibility to auditory alerts is reduced when they are driving [23, 25], or when they are being driven by a (simulated) automated vehicle [23]. More generally, susceptibility to alerts is reduced when performing a visual or manual task [2, 7, 15, 18, 19, 23, 25].

A limitation of preceding work is that susceptibility to auditory alerts during automated driving has not been investigated under conditions that include performance of additional non-driving tasks [23]. This limits scalability to everyday settings, as a meta-review suggests that people tend to perform non-driving related tasks more frequently under automated driving conditions [4]. Might such distraction reduce susceptibility to alerts even further? As the types of tasks that people want to perform in automated vehicles is diverse [16], studying the general impact of distraction on susceptibility requires a principled approach. As previous studies have only investigated susceptibility while performing visual and/or manual tasks, we investigate whether susceptibility is also reduced during cognitive distraction without visual and manual components.

To this end, we apply the procedure to test susceptibility to alerts that all the previously mentioned studies applied to detect susceptibility to alerts: an auditory novelty oddball paradigm [5, 6, 12, 17]. In this paradigm participants hear sounds frequently. The large majority of sounds are constant tones, or standards (typically around 80% of stimuli). Occasionally, other environmental sounds are played [5], such as sneezes or dog sounds. These other stimuli are referred to as 'novels', as they are typically unique and novel within the context of the experiment.

Using Electroencephalography (EEG) Event-Related Potential (ERP) techniques [14], one can measure the electrical activity in the brain in response to a novel sound and how this differs from the electrical activity in response to the standard tone. Under stationary conditions, the novel sound produces a positive peak in frontal regions of the brain (electrode FCz), roughly 300-400 ms after stimulus presentation. The common interpretation of this so-called fP3 response (also referred to as novelty P3) is that it prepares the brain to orient to a suddenly changing environment [12]. Within the context of a vehicle, the fP3 response can be interpreted as the brain's response to a sudden sound, such as to a truck that honks, or an unexpected alert that goes off in the car. Previous work has shown that the fP3 response is reduced when performing other tasks, including when one is driven by an automated vehicle [23].

We want to investigate whether susceptibility to auditory signals, measured as fP3 response magnitude, is also reduced when one is performing a cognitive task that does not involve a visual or manual response. To this end, we probe fP3 response while participants are thinking about their response to a verb generation task. In the verb generation task [1, 20], a participant gets presented with a noun, and needs to respond by generating a verb that is relevant to the noun (e.g., "apple-bite", "ship-sail"). Thinking about

which verb to generate is associated with frontal brain activity [1]. Moreover, dual-task experiments show that the verb task can reduce performance on other tasks, including driving [9, 13, 21, 24]. We investigate whether such mental distraction also reflects in the fP3 response and associated reduced susceptibility.

Study 1: Measuring susceptibility while being mentally distracted

Method in brief

The aim of the first study was to measure whether susceptibility to alerts was reduced under cognitive distraction: when participants think about a verb to generate. Thirteen participants (8 M; 5 F) took part (M = 23, SD = 2.6 years of age). The experiment was approved by the ethics committee of the Faculty of Social and Behavioral Sciences of Utrecht University (FETC16-042). Participants gave written informed consent and were compensated with 12 euro for their time.

As tasks we combined a 2-stimulus novelty oddball task [17] with a verb task [1, 20]. For the oddball task, participants heard a sequence of stimuli presented at 75 dB using Earlink earphones. Of these, 80% were standards (1000Hz tones), and 20% were novels from a database [5].

For the verb task, participant were presented with nouns. A Dutch list was generated based on the original English list [1]. We removed words that scored low on imaginability or which were too long (more details to follow in full paper). Our final word list consisted of 144 words. These words were pronounced by a text-to-speech program, and audio files were speeded up or slowed down such that each work took exactly 400 ms to pronounce.

The study design had a single-factor within-subjects manipulation, that manipulated the interval between the offset of the noun (verb task) and onset of the oddball stimulus (either standard of novel). This interstimulus interval was either 0, 200, or 400 ms. In this way, we could measure whether susceptibility changed over time. We also included a baseline control condition in which an oddball stimulus was not preceded by a noun.

We measured human behavior using a Biosemi active two system at 2048 Hz with 64 active Ag-AgCl electrodes, positioned following 10/10 system. ERP response was measured in 12 experiment blocks. Each block tested each condition, presented at random. Each block had 80 oddball stimuli (64 standards, 16 novels) and 24 nouns (8 per interstimulus interval condition, of which 4 followed by a standard and 4 by a novel). In total, per condition we measured 48 novel and 48 standard responses. These were used to calculate a difference wave.

Preliminary Results

A one-way ANOVA of interstimulus interval (0, 200, 400 ms and baseline control) on fP3 response resulted in a significant effect, $F(3,36) = 4.86$, $p = .006$. A holm-corrected post-hoc test showed that the baseline condition (M = 10.4 µV, SD = 4.7 µV) had a significantly higher fP3 amplitude compared to all the other conditions in which the oddball presentation was preceded by a noun (all ps < .05). The amplitudes for the three different interstimulus interval conditions where a noun was presented before the oddball were comparable: 0 ms (M = 5.7 µV, SD = 5.1 µV), 200 ms (M = 5.8 µV, SD = 3.9 µV), and 400 ms (M = 5.9 µV, SD = 6.3 µV). In other words, thinking about generating a word reduces susceptibility to novel sounds, at least within the 400 ms following noun presentation. Visual or manual components are not needed to reduce susceptibility to sounds.

Study 2: Measuring susceptibility while being driven and while mentally distracted

Method in brief

The aim of the second study was to measure susceptibility to alerts under simulated automated driving and cognitive distracting conditions. Does load reduce even further when also being driven by an automated vehicle? 24 participants (3 M; 21 F) took part (M = 22.8, SD = 7.2 years of age). The experiment was approved by the ethics committee of the Faculty of Social and Behavioral Sciences of Utrecht University (FETC16-042). Participants gave written informed consent and were compensated with 12 euro for their time.

We again used the 2-stimulus novelty oddball task [17] as a probe for susceptibility. We used a one-way within-subjects design with four levels. In three conditions, the participants were driven by a simulated automated vehicle (1) without any distraction, (2) with the verb generation task, and (3) with a "repeat" condition in which participants had to repeat nouns. The fP3 response in these three automated driving conditions was compared to a baseline control condition in which participants were stationary (not driving). In cases where the verb (repeat or generate) task was used, oddball stimuli were presented instantly (i.e., 0 ms after the offset of a noun). The study followed a blocked design, with block order counter balanced. We had 3 blocks per condition (total: 12 blocks). For each condition, 48 novel oddball responses were measured.

Preliminary Results

The last data of this study is pre-processed at the moment. Qualitatively, so far the data suggests that fP3 response is again reduced under conditions with distraction due to either having to repeat a noun, or due to having to generate a word. Further details will be reported on our poster.

General Discussion

We investigated whether distraction due to a cognitive task (verb generation task) reduces the susceptibility to novel sounds, as measured using a novelty oddball paradigm. Our results suggest that this is indeed the case. Performing a cognitive task reduces the fP3 response and associated susceptibility to auditory signals. This was both observed in a single-task condition of verb generation (study 1) and when combined with automated driving (study 2).

These results are important for semi-automated driving. Semi-automated vehicles (such as at SAE level 3, [8]) typically rely on auditory signals to signal a transition of control. Our results suggests that drivers might occasionally miss such sounds when they are working on other tasks. In the design of automated vehicles, these limitations to human susceptibility should be taken into account. For example, by providing early warnings [3, 22], or more general, by reconsidering attention management (see also [10, 11]).

Future work can look into the implications and generalizability of these findings further. For example, how they generalize to multi-modal alerts, and to a wider variety of alerts, including more traffic related sounds.

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