Ipsilateral Versus Contralateral Tactile Alerts for Take-Over Requests in Highly-Automated Driving

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ABSTRACT

One of the most significant concerns regarding the use of Highly-Automated Driving (HAD) is drivers' ability to regain control. Vibro-tactile alerts were already suggested as an effective modality for Take-Over Requests (TOR). However, it is not clear whether such alerts should be ipsilateral or contralateral relative to the location of hazards. Studies regarding tactile directionality in other domains, as well as in non-HAD vehicles have found mixed results. In the current study, 15 participants drove a highly-automated vehicle in a desktop configuration driving simulator. Each participant experienced two TORs in which they were required to regain control and divert the vehicle away from an impending hazard, situated 4 seconds in front of them. The disengagement of the autonomous driver was signaled to drivers using a directional tactile alert. For half of the participants, the tactile alert was directed to the direction of the hazard (contralateral), for the other half, the alert was directed away from it (ipsilateral). Results showed that drivers in both groups made the same amount of errors (initially steering the vehicle in the direction of the hazard before steering it away). However, when using ipsilateral alerts, drivers were faster to steer the vehicle away from the hazard. While this result is in contradiction to previous studies regarding the use of directional cues in driving, it is in-line with research regarding directional responses in other domains. We suggest an explanation for this discrepancy and discuss its implications.

Keywords: Highly-Automated Driving (HAD), Collision avoidance, Vibro-Tactile cues.

1 INTRODUCTION

Every day now, autonomous vehicles are being tested on streets in cities worldwide, and mass production of such vehicles is expected within a few years. However, these initial models would probably not allow Fully-Automated Driving (FAD), but rather Highly-Automated Driving (HAD) which requires occasional interventions of the human driver (e.g., Segal, 2017). This highlights the issue of transferring control between the automated and the human drivers, as has been pointed out by others before (e.g., Louw, Merat, & Jamson, 2015).

When using HAD, a vehicle may encounter situations where it reaches its design limits, or for some reason malfunctions. In such situations, the vehicle is expected to issue a Take-Over Request (TOR) to alert the human driver to take control. When reaching a system limit, it is expected that the vehicle would provide drivers with a sufficient amount of time to regain awareness before transferring the control (SAE International, 2014). However, system failures may cause the system controlling the vehicle to disconnect immediately (e.g., electrical failures in aviation incidents; for example AAIB, 2006). In such cases, the TOR should draw drivers' attention to the road, and, preferably, provide them with immediate information regarding the driving situation.

Among the various possible modalities for alerting drivers about a TOR, vibro-tactile alerts provide significant advantages, such as being gaze-free (Meng & Spence, 2015). Moreover, whether drivers are engaged in the driving task or a secondary task, it is more likely that they are using their auditory and visual senses, leaving the vibro-tactile channel clear for incoming alerts (Petermeijer, Winter, & Bengler, 2016). Previous research have found that vibro-tactile displays result in shorter brake times compared with visual or auditory displays (Scott & Gray, 2008). Nevertheless, vibro-tactile displays are not as effective in providing detailed information (Campbell, Richard, Brown, & McCallum, 2007) and their design must be carefully considered to achieve optimal results. Several studies have examined how adjusting display parameters and applying different designs affect drivers' reaction times, performance and perceptions (e.g., Petermeijer, Cieler, & De Winter, 2017). Other studies focused on the location parameter, investigating the directional potential of vibro-tactile displays for drivers.

The location of vibro-tactile stimuli can be used to map lateral (Straughn, Gray, & Tan, 2009), longitudinal (Ho, Tan, & Spence, 2005) and even vertical information (Salzer, Oron-Gilad, Ronen, & Parmet, 2011). A tactile alert may be either contralateral (indicating the direction of a hazard) or ipsilateral (indicating the direction to steer to avoid the hazard). In non-HAD vehicles, the use of contralateral designs resulted in shorter reaction times (Wang, Pick, Proctor, & Ye, 2007), and was thus recommended as a guideline for the design of in-vehicle vibro-tactile alerts (Campbell et al., 2007). Surprisingly, this advantage of contralateral designs is contradictory to the principal of Stimuli-Response (SR) compatibility (Fitts & Seeger, 1953) according to which people react faster and more accurately when the stimuli and response are compatible (see Proctor & Vu, 2006). Based on the SR compatibility principle it would be expected that drivers react faster when an alert coming from a particular side would require them to steer towards that side, however, this is not the case. Müsseler et al. (2012) suggested that in a dangerous situation, people learn to avoid stimuli and thus to react in the opposite direction. Straughn, Gray and Tan (2009) make a similar claim, proposing that drivers "have learned to turn away from 'naturally occurring' warning signals such as a car horn or the sound of a collision" (p. 112). Another explanation is that drivers do not react solely based on the alert, but instead use it to assess the situation and react accordingly (Petermeijer et al., 2016) thus pointing them to the direction of the hazard reduces the time required to make the decision. Either way, both explanations are based on drivers' awareness of their environment. However, researchers have already suggested that drivers of highly-automated vehicles quickly become disengaged from the driving task (e.g., Jamson, Merat, Carsten, & Lai, 2013). As a result, it is not clear whether they would react to a directional vibro-tactile alert in the same way drivers in manual vehicles do. As drivers become disengaged from the driving task and delegate the control and responsibility to the automated vehicle, they might revert to SR compatible reactions, rather than to driving-contextual reaction. The current study addresses this issue. Specifically, we tested whether the superiority of contralateral alerts in manual driving would apply to TOR alerts or whether, due to drivers' disengagement from the driving task and the SR compatibility principle, ipsilateral alerts would result-in shorter reaction times.

2 METHOD

2.1 Participants

Seven females and eight males, undergraduate students, aged 22-27 (M = 23.9, SD = 1.57), all having a valid driving license, took part in the research. Participants received bonus course credit for their participation and were free to withdraw from the study at any time.

2.2 Apparatus

Simulator. The research was conducted at the Driving simulator in the Human Performance Evaluation Lab (HPEL) at Ben-Gurion University of the Negev (see Figure 1a). The simulator consists of a 90 degrees display using three 24-inch computer-screens, running a simulation software to illustrate the driving environment (Realtime Technologies Inc. [RTI], Royal Oak, MI). Participants were seated about 1.1 m away from the screens.

Tactile interface. The tactile system consisted of a tactor controller (Eval2.0; Engineering Acoustics Inc. [EAI]) regulating six EAI-C2 tactors stitched to the car seat. The tactors (three on each side) were positioned along the exterior part of the seat, adjacent to participants' thighs (see Figure 1b). The tactile alert was designed as three consecutive pulses (pulse duration: 250 milliseconds, pulse intervals: 450 milliseconds) This signal is perceived as urgent (Van Erp, Toet, & Janssen, 2015).

a b

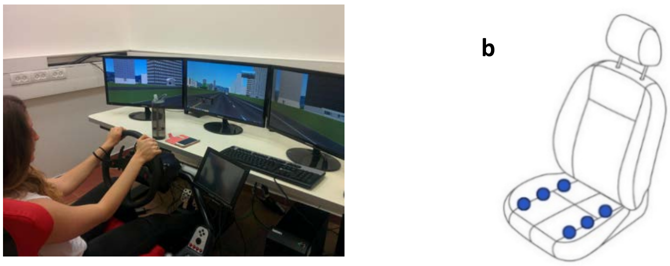

Figure 1. (a) The driving simulator. (b) An illustration of the placement of tactile tactors along the drivers' seat, three on each side

Secondary task. Whenever the automated vehicle had control, participants played a game of Simon to simulate the engagement in a secondary, non-driving-related task. For this game, an array of X colors appeared on the screen. The system presented a sequence of random colors for the participant to repeat (starting with two). Whenever participants repeated the sequence correctly, they were presented with a one-step longer series of colors (three, then four, etc.). If participants made an error, the sequence started again with two colors. The game is visually and cognitively demanding, thus it has higher potential in disengaging drivers from the driving task.

2.3 Driving Scenarios

Participants experienced two different scenarios. In each scenario, a malfunction in the automated vehicle was simulated and participants were required to regain manual control of the vehicle. At the time of the TOR, a materialized hazard (e.g., a vehicle blocking one of the lanes ahead) was situated 120 m ahead of the vehicle, blocking participants' lane and other lanes either to the right of it or left of it. The participant was not able to see the hazard prior to the TOR. Participants had to steer the vehicle away from the hazard, as they did not have enough time to brake and stop the vehicle.

2.4 Experimental Design

Each participant experienced two TORs presented through a directional tactile alert. Participants were randomly assigned to one of two experimental groups. For half of the participants, the tactile alert was directed toward the hazard (contralateral group), whereas for the other half, the alert was directed away from it (ipsilateral group). Presentation time gap between the two succeeding signals was not fixed but did not drop below 3 minutes, to minimize the influence of the previously perceived tactile alert.

2.5 Procedure

Prior to driving the simulator, participants were introduced to the simulator and drove it both manually and in autonomous mode. Additionally, participants were familiarized with the vibro-tactile alert and its directionality as well as with the Simon game and its operation.

2.6 Dependent Variables

Two dependent variables were used. First, to examine whether using different directionality results in better decisions, we tested whether drivers initially steered towards or away from the hazard. The value for this binary variable was either Correct (i.e., first steer away from hazard) or Incorrect (i.e., first steer towards the hazard). Additionally, participants' reaction time was measured as the time between the TOR and the first steering input. A steering input was defined as a 2-degree steering wheel change, as smaller values may be attributed to vehicle stabilization rather than to voluntary inputs (see Gold, Damböck, Lorenz, & Bengler, 2013).

3 RESULTS

3.1 Direction of first steering reaction

Our results show that the error rate did not differ between groups (p = .509; Fisher's exact test), and was near chance level. Participants in the contralateral group made seven correct decisions out of 14, while participants in the ipsilateral group made nine correct decisions out of 16.

3.2 Response time to the first reaction

The small sample size in the current study did not allow the use of mixed ANOVA to test our hypotheses. Instead, groups were compared using independent-samples t-tests. Response time for participants in the ipsilateral group (M = .82 s, SD = .22) was significantly shorter than response time in the contralateral group (M = 1.23 s, SD = .39), $t(28)$ = 3.38, p < 0.01, Cohen's d = 1.28. Additionally, we examined the *correct response time* which was defined as the time between the initiation of the TOR and a 2-degree steering in the *correct* direction. Again, drivers in the ipsilateral group (M = .99 s, SD = .35) had a significantly shorter reaction time than drivers in the contralateral group (M = 1.38 s, SD = .50), $t(28)$ = 2.41, p < 0.05, Cohen's d = .88. An examination of response time differences between the scenarios revealed that drivers shortened their reaction times from the first to the second scenario (see Figure 2). Nevertheless, drivers in the ipsilateral group exhibited shorter reaction times in both scenarios.

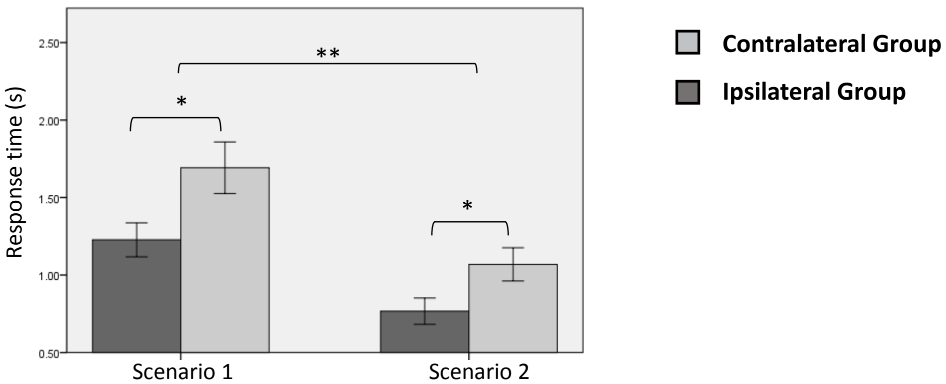

Figure 2. Response times for drivers in both groups, for the first and second scenarios
* p < .05 ** p < .001

4 DISCUSSION AND CONCLUSION

The aim of the current study was to examine the use of directional vibro-tactile alerts for TORs in autonomous vehicles. Specifically, we examined whether ipsilateral or contralateral results in improved drivers' performance. Our results show that in-line with the SR compatibility principle, when drivers are required to regain control of a vehicle after a TOR, ipsilateral alerts lead to faster reaction times. These results are in contradiction with previous driving-related studies (e.g., Wang et al., 2007). Nevertheless, similar results were found in other domains (e.g., aviation; Salzer et al., 2011) or when the context was neutral (Proctor & Vu, 2006). When this discrepancy was previously investigated in driving-related studies, most explanations regarded drivers' context-awareness which led them to regard a vibro-tactile alert as a threat, and therefore to turn away from it (Straughn et al., 2009). These suggestions are based on the fact that drivers perceive the driving task as a threatening situation (Fuller, 1984). However, when being driven in an autonomous vehicle, and taking on a secondary task, drivers may become disengaged from the driving task and therefore also from its context and the sense of threat that relates to it. We suggest that by disengaging from the threat associated with driving a vehicle, when drivers are required to respond to a vibro-tactile alert they revert to the SR compatibility principle rather to the response more compatible with driving. This difference of contextual perception between drivers in autonomous and non-autonomous vehicles implies that when designing alerts and interfaces for autonomous vehicles, knowledge gained in non-autonomous vehicles must be used with care and adapted before it can be applied to autonomous vehicles. Our findings also reveal a significant improvement in reaction time between the first and second trials. In a future study, we intend to examine the effects of experience on drivers' reaction times.

In conclusion, this experiment is a preliminary stage and provides a foundation for further examination in the field of directional vibro-tactile alerts in highly-automated driving. Our findings suggest that for TORs in highly-automated driving an ipsilateral alert may improve drivers' reaction times. However, this claim should be examined after drivers' gain system experience to further validate its significance for the design of TORs.

Acknowledgement Guy Cohen-Lazry is a doctoral student supported by a General Motors (GM Advanced technical Center) Inc. grant (GAC 2406) and Nuphar Katzman is a doctoral student supported by a grant from the US Army Research Laboratory through the GDLS subcontract, GDLS PO 40253724 (B.G. Negev Technologies and Applications Ltd) under Prime Contract no W911MF-10-2-0016 (Robotics Consortium), Robotics CTA 2015-2020, T2C1S3C, Michael Barnes, Technical Monitor. The views expressed in this work are those of the authors and do not necessarily reflect official policy.

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