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The Effect of An Acoustic Startling Warning On Take-Over Reaction Time And Trunk Kinematics for Drivers in Autonomous Driving Scenarios

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ABSTRACT –The Acoustic Startling Pre-stimulus (ASPS, i.e. a loud sound preceding a physical perturbation) was previously found to accelerate action execution in simple flexion exercises. Therefore in this study we examined if ASPS can accelerate take-over reaction times in restrained teen and adult drivers who were asked to reach for the steering wheel while experiencing sled lateral perturbations simulating a vehicle swerve. Results showed that adult drivers lift their hands toward the steering wheel faster with the ASPS versus without (161 ± 23 ms vs 216 ± 27 ms, $p<0.003$). However this effect was not found in teens or in trials where the drivers were engaged in a secondary task. Adults also showed reduced lateral trunk displacement out of the seat belt with the ASPS. The ASPS could represent a novel warning that reduces take over time and out-of-position movements in critical autonomous driving scenarios.

INTRODUCTION

As autonomous vehicles become a reality, there is a greater potential for driver distraction due to the reduced task load for the human driver. Current forward collision warning (FCW) and lane departure warning (LDW) alone may not be enough to alert the drivers in autonomous scenarios. Young drivers in particular tend to dismiss these warnings as false positives because they occur relatively early (1.7-2 s and 3-4 s respectively) before time of collision (Montgomery, 2014).

Some previous studies testing the efficacy of warning systems are limited by use of non-moving driving simulators. In those simulators, the driver does not experience a real physical perturbation, as they would in a crash, which may cause a startle reflex (Sanders et al., 2015) and alter the drivers' take-over reaction time. An Acoustic Startling Pre-Stimulus (ASPS), which is defined as a 105 dB sound preceding a physical perturbation by 250 ms (Mang et al., 2012) and is an inherent physiological human response, was found to accelerate reaction times in flexion exercises for rehabilitation patients (Sutter et al., 2016). Thus, there is potential to manipulate the physical response to an ASPS for benefit in autonomous driving scenarios. Specifically, a novel warning system, using an ASPS, could be used to reduce the take-over reaction time and accelerate the corrective action in a critical autonomous driving scenario.

Therefore, the primary aim of this study was to examine if ASPS can reduce reaction times to reach and turn the steering wheel when the driver in an autonomous driving scenario is either ready to react or engaged in a texting task. A secondary aim was to compare adult vs teenage drivers in their responses to the ASPS.

METHODS

The study protocol was reviewed and approved by the Institutional Review Board of the Children's Hospital of Philadelphia.

Participants

Seven healthy adult (ages 25 – 37 years, height 177.9 ± 6.0 cm, weight 78.0 ± 12.9 kg) and 7 healthy teenage (age 17 years, height 175.0 ± 7.0 cm, weight 68.4 ± 7.3 kg) male driver volunteers participated in the study. In order to be included in the study, participants needed to hold a valid driver's license.

Sled Apparatus

A custom sled apparatus exposed subjects to low-severity, non-injurious loading conditions that mimic pre-crash swerving events (Kent, 2016). The 1.5m x 1.5m driver compartment (modified from Holt, 2017) was mounted to the cart such that the motion is perpendicular to the

Figure 1: Custom sled apparatus

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occupant (Figure 1). The lateral sled perturbation was similar to an evasive emergency swerve and had a peak acceleration of approximately 0.75 g. A standard vehicle seat and three-point seat belt (over right shoulder of the subject) was integrated into the seating compartment. Only one oscillatory movement (i.e. cycle) was provided, and it consisted of a right swerve (driver's motion into the belt) followed by a left swerve (driver's motion out of the belt).

Human Subject Instrumentation

Kinematic data were captured using an Optitrack Prime13W 8-camera motion-capture system (200 Hz, NaturalPoint, Inc., Corvallis, OR). Photo-reflective markers were placed on participants' head (on a tightly fitted head piece), trunk (bilateral acromion, suprasternal notch, and xiphoid process), upper extremities (bilateral humeral epicondyle, radial styloid process), and the right foot. Markers were also placed on the top of the steering wheel, on the post placed laterally to the steering wheel, on each of the pedals, on the seat, on the seat belt, and on the D-ring.

Experimental Testing

Participants were asked to align a photo-reflective marker on the steering wheel with the stationary photo-reflective marker on the lateral post positioned next to the steering wheel as soon as the sled moved. Prior to testing, while the sled was not activated, subjects were instructed to perform an "alignment trial" at their comfortable speed to establish a working definition of marker alignment. The participants were then exposed to 5 different testing conditions repeated twice in a randomized order:

1. **Sled only**: sled perturbation only (no ASPS).
2. **Sled + phone:** sled perturbation while subject is texting on their mobile phone (no ASPS).
3. **Startle + sled:** ASPS played 250 ms (at 105 dB for 40 ms) before sled perturbation,
4. **Startle + sled +phone:** ASPS played 250 ms (at 105 dB for 40 ms, Mang et al., 2012) before sled perturbation while subject is texting on a mobile phone.
5. **Catch trial:** ASPS with no sled perturbation

For the conditions with the texting tasks, subjects were instructed to start typing few seconds before the sled moved. A fifth condition consisting of an ASPS only without sled perturbation was used to prevent anticipation of the sled motion. To further prevent potential anticipatory effect, a latency time of a random duration between 1 and 10 seconds between the experimenter instruction, "As soon as the sled starts moving, reach for the steering wheel as fast as you can and align the markers as accurately as you can," and sled activation was also used.

Data Analysis

Kinematic data from the motion-capture was processed using Motive Tracker software (Natural Point, Inc., Corvallis, OR) and then imported into custom-made Matlab (MathWorks 2017, Inc., Natick, MA) programs to extract the relevant kinematic outcome measures for analysis. Data are presented for two outcome measures:

1. Hand lift-off Reaction Time (ms): time between sled onset (i.e. 5% of maximum acceleration) and onset of the first wrist movement (i.e. wrist velocity greater than the mean + 0.5 SD of wrist velocity at rest).
2. Lateral Peak Trunk Displacement (cm): maximum lateral distance reached by the trunk in the out of the belt direction (raw and normalized by the seated height).

A Mixed Repeated Measure 4-way ANOVA was performed to understand the effect of age (adult versus teenager), ASPS (versus without), Secondary Task (versus without), and repetitions (1 versus 2) on the outcome measures. Post-hoc tests were performed using Fisher's HSD. Level of significance was set to $p=0.05$.

RESULTS

A significant 3-way interaction was found between Age, ASPS, and Secondary Task ($p=0.004$, Figure 2), showing that in the adult drivers, Hand Lift-Off Reaction Time was shorter in **ASPS+Sled** (161 ± 23 ms) compared to **Sled only** (216 ± 27 ms) ($p<0.003$). Hand Lift-Off Reaction Time was also shorter in **ASPS+Sled** than **ASPS+Texting+Sled** (210 ± 22 ms) ($p<0.01$). Standard deviation of Hand Life-Off Reaction Time in adults decreased in **ASPS+Texting+Sled** (22 ms) compared to the **Texting+Sled** (55 ms). In the teens, there were no significant differences between conditions ($p>0.11$).

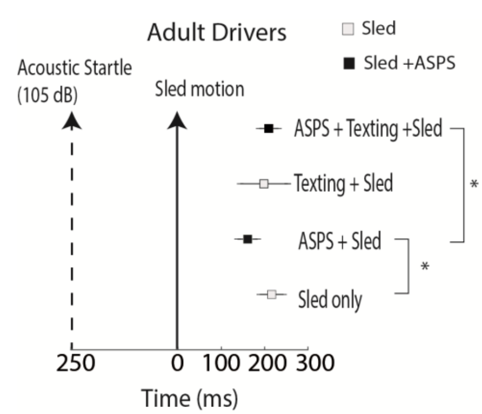

Figure 2: Groups of means and SD of Hand Lift-off Reaction Time in each test condition for two age groups.*p<0.05

A significant 3-way interaction was also found between Age, ASPS, and Repetition (p<0.04) showing that in the adult drivers, ASPS reduced lateral peak trunk excursion in the out-of-the-belt direction in the first repetition (no ASPS 6.6 ± 2.0 cm versus with ASPS 4.9 ± 1.1 cm p=0.05, Figure 3). No benefit was found in repetition 2.

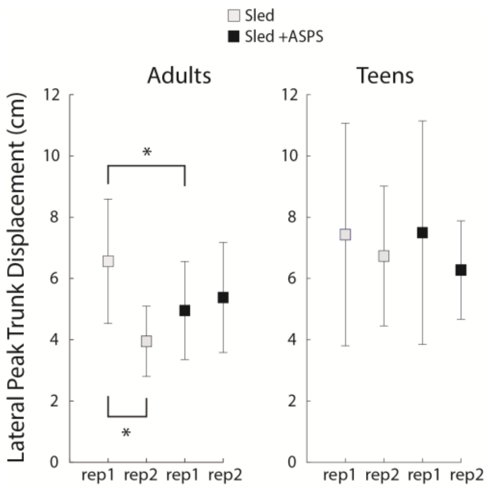

Figure 3: Group means and SD of Lateral Peak Trunk Displacement in the out-of-the-belt-direction for each repetition with the ASPS and without ASPS, for each age group. *p<=0.05

A statistically significant 2-way interaction was found between Age and Secondary Task (p<0.04) showing that in the teen drivers, mobile texting increased lateral trunk excursion in the out-of-the-belt direction (no texting 6.2 ± 1.8 cm versus texting 7.7 ± 3.5 cm p<0.04 Figure 4). No differences were found in adults.

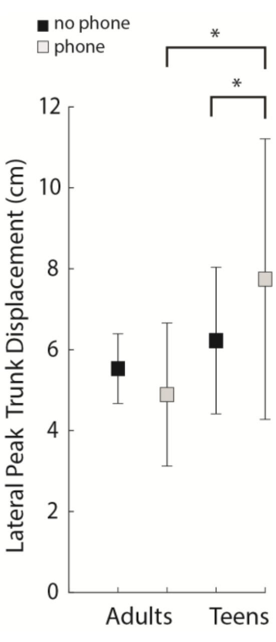

Figure 4: Group means and SD of Lateral Peak Trunk Displacement in the out-of-the-belt-direction for each repetition for trials with texting and without the texting task for each age group. *p<0.05

When normalized to seated height, lateral peak trunk excursion showed the same statistical differences between conditions also.

DISCUSSION

The aim of this study was to understand if a novel take over warning for critical autonomous scenarios based on the startle reflex could reduce take over reaction times in adult and teenage male drivers either when they were ready to react and when they were engaged in a mobile texting task. The results showed that when adult male drivers were ready to react, they lifted their hands from their lap towards the steering wheel more quickly when exposed to the ASPS. The differences in Hand Lift-Off Reaction Time between the ASPS condition and the no ASPS condition when the adult male drivers were ready to react was relatively small (55 ms) but statistically significant. It is plausible that 55 ms might not be enough time to avoid a crash completely but by accelerating the initiation of a corrective response, 55 ms may be enough to reduce the severity of the crash and allow enough time for the driver to return to an optimal, more upright, position of the trunk within the seat-belt and therefore reduce the risk of injury in the subsequent crash. In agreement with the above interpretation, lateral trunk displacement out-of-the-belt was reduced in the ASPS conditions in adult drivers, confirming that ASPS could potentially "startle" the occupant in a more advantageous position within the seat-belt in case the vehicle crashes.

When adult male drivers were texting, the ASPS did not decrease their Hand Lift-Off Reaction Time, however the between-subjects variability was smaller compared to the condition with texting and no ASPS. This may suggest that ASPS leads to more consistent take-over reaction times between drivers, which could be an advantage when designing the timing for triggering countermeasures (e.g. pre-pretensioners) during pre-crash maneuvers.

No effect of ASPS was observed in the teenage male drivers. The texting task had a detrimental effect on both age groups for the Hand lift-off Reaction Time, but only the teen drivers showed an increase in lateral peak trunk excursion in the texting task. A potential explanation could be that the teenage male drivers used only one hand to grab the steering wheel in 57% of trials; in contrast, the adult male drivers only used one hand to grab the steering wheel in 34% of trials. It is plausible that holding the steering wheel with one hand could have increased lateral trunk excursion, particularly when the teens were holding the phone. These findings are line with previous investigations that found that teenagers engage in more risky behaviors (Steinberg, 2007) such as using one hand to reach the steering wheel. Teens were also found to use cell phones while driving, even at high-risk speeds (McDonald et al., 2018). The difference in efficacy across age groups for the ASPS warning system may indicate the importance of age considerations in the design of effective automotive warning systems for all demographic driving and purchasing a vehicle.

A limitation of our study is that we did not give instructions in how to reach the steering wheel (one hand or two hands) since we wanted to understand the natural behavior of the drivers during critical autonomous scenarios. The lack of these instructions potentially impacted our reaction time since the variability in responses due to the use of one or two hands may have masked the influence of the ASPS.

CONCLUSION

The ASPS warning system was effective in reducing the time for adult male drivers to lift their hands to begin a corrective movement in conditions where the drivers were ready to react. This suggests that ASPS may be useful early in the corrective action performed during an evasive maneuver. The reduction in lateral trunk displacement out-of-the-belt in ASPS conditions also showed that ASPS could be used to "startle" the occupant into a more optimal position within the seatbelt. ASPS reduced the variability in responses when the drivers were engaged in a secondary task, suggesting that it could help design a consistent timing for triggering countermeasures during pre-crash maneuvers. Teenage male drivers did not reduce take-over time with the ASPS and they tended to reach for the steering wheel with one hand only. Future investigations will focus on sex differences in take-over reaction times and in response to the ASPS.

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