Where's My Cellphone: Non-contact based Hand-Gestures and Ultrasound haptic feedback for Secondary Task Interaction while Driving

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Abstract—Drivers regularly use their smartphones to perform secondary tasks while driving, which can negatively impact traffic safety. In such complex interaction, multimodal feedback has been associated with lowering driver distraction. We investigated four methods for completing a phone-based secondary task while driving: smartphone in hand, smartphone in a rack, buttons on the steering wheel with Head-up-display (HUD), and mid-air gestures with an ultrasound haptic feedback and a HUD. Participants (N=16) drove the Lane Change Test (LCT) simulator with each method to complete predefined secondary tasks. To measure performance in primary task, we recorded lane deviations and for secondary task we measured response times and errors. Additionally, the participants filled in the NASA-TLX questionnaire and ranked each method according to their preferences. The results showed that the performance and preference for the hand and rack conditions were similar, while performance with buttons and gestures was worse, even with ultrasound haptic feedback, than in hand and rack conditions. The results highlight the importance of rigorous user testing when introducing new modalities for in-vehicle interaction to enhance primary and secondary task performance.

Keywords—Tactile feedback, mid-air gestures, Ultra-haptics, in-vehicle interaction, smartphone interaction, head-up display.

I. INTRODUCTION

Drivers often perform secondary tasks with their phones while driving. For instance, according to a recent survey, 95% of 62 respondents reported using smartphone applications while driving [1]. The applications provide many types of information, which can distract attention and affect driving safety negatively [2, 3]. Current evidence shows that driver inattention has a role in about 80% of all traffic accidents [4].

The motivation of this study was to explore four different methods of using a smartphone to perform a secondary manual interaction task while driving. In two of the conditions, interaction based on the phone's touch-screen was replaced with wireless buttons or mid-air gestures. Previous research suggests that mid-air pointing gestures *(with haptic feedback)* and wheel buttons are promising schemes for controlling in vehicle-displays [5]. We are not aware of any previous comparisons that have directly compared smartphone, button, and mid-air gesture interaction while driving. Related work includes Harrington et al. [6], who compared touch-screen buttons and gesture interaction for selection tasks. The current research differs from previous work [9, 10, 11] by comparing gestures to

smartphone interaction instead of an in-vehicle touchscreen. The main contribution of this research is to compare and evaluate the four methods using performance measures (LCT [7]) and subjective preferences (NASA-TLX [8]).

II. MID-AIR GESTURES AND ULTRASOUND ACTUATION

Mid-Air ultrasound skin stimulation has been used to provide haptic feedback for non-contact interaction. Even though some in-car setup have utilized mid-air gestures, this type of feedback is still infrequent. As automotive interaction becomes more complex due to the additional information provided by Electrification and Autonomous Systems, new methods of In-vehicle interaction and information presentation are needed to reduce driver distraction.

In this research we utilize the mid-air gesture accompanied by ultrasound actuation cues to relay information for secondary driving tasks. The actuation was provided using a phased array of ultrasound transducers creating focal point of tactile stimulation on the user's palm. As most ultrasound transducers have a resonance frequency of 20-30KHz, utilizing multiple phase shifts was necessary to create a lower resonance frequency (~300Hz) sensible by the human skin. Our internal testing showed that the setup we employed (Ultraleap Stratos device Fig. 1 bottom left corner) was sensible at a distance of 15-18cm. For the purpose of this study, we simple created focal points at center of the palm with no additional tactile effects. To track the user's hand, we utilized the LeapMotion infrared sensor and provided the feedback to palm area during specific task interaction.

III. METHOD

We explored four secondary methods of interaction along with an Lane Change Test (LCT) [7] simulated driving task: smartphone in hand (hand), smartphone in a rack (rack), remote buttons on the wheel + a head-up display (buttons), and mid-air gestures with ultrasound feedback + a head-up display (gestures) [13, 14, 15].

A. Participants

Sixteen university students (13 females, mean age 26, range 19 - 38 years) participated in the experiment. All reported normal or corrected to normal vision. All participants had a driving license, 7.5 years of driving experience on average (range 1 - 19 years), and they drove 6500 kilometres per year (range 0 – 22000 kilometres). Three quarters of them had previous driving simulator experience.

B. Apparatus

We utilized an existing driving simulator setup that housed a 45-degree angled Plexiglas windscreen, Logitech G29 steering wheel and pedals, and a Volvo XC60 motorized driver seat (Figure 1). We used a 49″ Samsung CRG90 widescreen monitor with a 1800R curve to display the Lane Change Test (LCT) simulator (ISO 26022:2010; [6]) software through the Plexiglas windscreen. The secondary interaction task was presented with a Samsung Galaxy S6 phone running Spacedesk software (see Figure 2a and 2b). We used self-implemented software for secondary task presentation, and response time logging. DinoFire presentation device was used to allocate buttons on the steering wheels (see Figure 2c), and Ultraleap device (Figure 1, bottom right corner) was used to recognize hand gestures and provide mid-air haptic feedback.
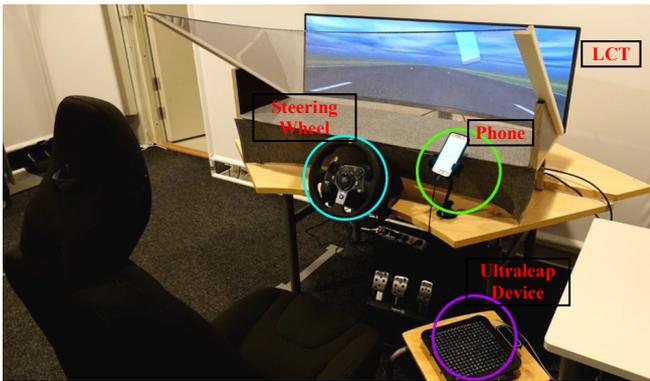

Fig. 1. Experimental setup. a) Phone in rack condition (green), b) Steering wheel (blue, see also Figure 2c), c) Ultraleap device (purple, see also Figure 2d).
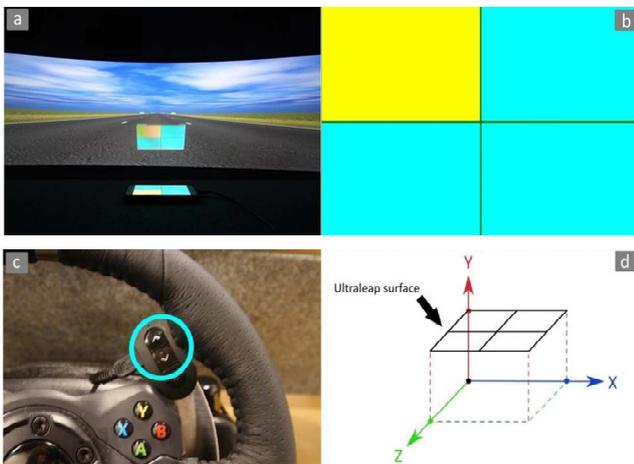

Fig. 2. a) Phone running the secondary task in HUD mode (i.e.., both in buttons and gestures conditions), b) Screenshot of the secondary task, c) DinoFire buttons attached to the wheel (arrow up: browsing, arrow down: confirmation), d) Ultraleap surface with x, y and z axis demonstrated.

C. Procedure

Before the experiment, participants filled in a consent and a short background form and took a practice drive to familiarize themselves with the task. Participants could adjust seat distance to the steering wheel and pedals before the task. They also practiced the secondary interaction tasks before each condition for a minimum of five rounds, or longer if the participant requested (approximately five minutes at maximum were utilized by most participant).

The actual experiment consisted of the primary task of driving the LCT simulator [6] and the secondary task of selecting targets with the four methods presented in a counterbalanced fashion. The driving was done at a full speed of 80 km/h. The secondary task consisted of selecting a yellow-coloured target among four possible targets that appeared in a random sequence (Figure 2b). After a selection, a new target appeared after a 4-10 second interval. This routine repeated for the duration of a single LCT track round. The secondary task was paused for the track part that did not include the LCT turn signs (i.e., the curve). For hand and rack conditions, the selection occurred by pressing the coloured target on the phone screen. For buttons, the participants used two buttons: arrow up to browse the targets and arrow down to make the selection (Figure 2c). For gestures, the browsing was made with left-right (x-axis), and up-down (y-axis) hand movements over the UltraLeap device and selected by a fast, down-up hand gesture along the y-axis (Figure 2d). The gesture condition also provided haptic feedback in the form of a constant haptic wall across the mid-air haptic device to help the participant find the correct interaction volume without looking. The haptic wall pulsed on and off three times to confirm when a selection gesture was detected. We turned off all light sources other than the monitor and phone screen during the driving, to increase the visibility of the smartphone screen.

We measured lane deviation and secondary task response times and used a NASA-TLX questionnaire [7, 8] to evaluate the mental workload after each condition. Finally, we collected user preferences for the different conditions, asking the participants to rank and comment the conditions. On average, the experiments lasted around 45 minutes.

IV. RESULTS

A. Lane deviation & Response Times

We used one-way repeated measures ANOVA and Bonferroni-corrected post-hoc pairwise t-tests to analyze lane deviation in the LCT task, as well as response times in the secondary task (Figure 3). We also estimated the effect size. ANOVA showed statistically significant effect of the condition ($F_{3,13} = 11.329$, $p = 0.000012$, $\eta p2 = 0.72$). Pairwise comparisons showed that lane deviation was more frequent with gestures than with hand ($t15 = 4.05$, $p = 0.006294$, $dav = 0.95$), rack ($t15 = 4.34$, $p = 0.003513$, $dav = 1.0800$), or buttons ($t15 = 3.11$, $p = 0.042789$, $dav = 0.78$).
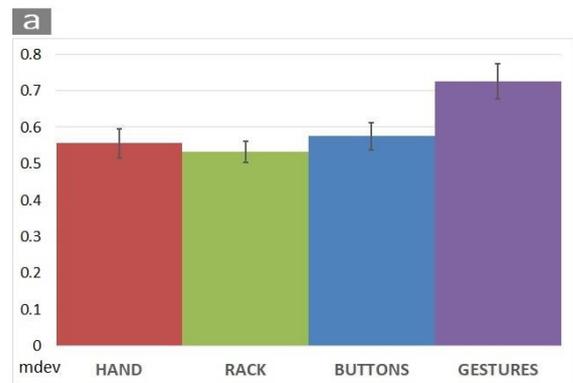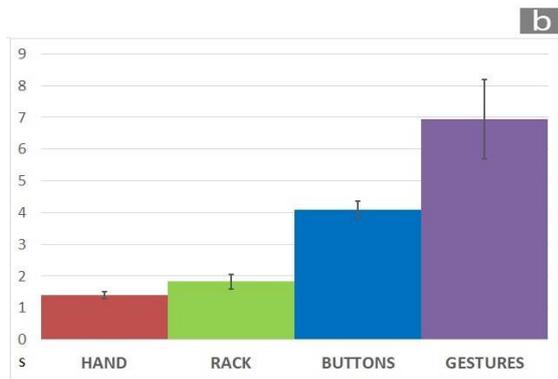
Fig. 3. (a) Mean lane deviation, a higher score means a larger deviation from the optimal driving lane; (b) Response time in the secondary selection task (seconds). Errors bars show the standard error of the mean (SEM).

For response times, ANOVA showed a statistically significant effect of condition ($F_{3,13}$ = 19.670, p = 0.000000027071, ηp^2 =0.82). The hand condition resulted in faster response times than buttons (t_{15} = 11.28, p = 0.000000060253, d_{av} = 3.24) or gestures (t_{15} = 4.59, p = 0.002117, d_{av} = 1.57), and rack had faster response times than buttons (t_{15} = 12.16, p = 0.000000021734, d_{av} = 2.22) or gestures (t_{15} = 4.73, p = 0.001623, d_{av} = 1.43).

B. NASA-TLX scores, preference ranks and comments

We used Friedman tests to analyze NASA-TLX questionnaire data and preference ranks (Figure 4). Friedman tests showed statistically significant effect of condition for NASA-TLX total score (p = 0.00000028872, $\chi^2(3)$ = 33.225). Wilcoxon tests showed that perceived workload was higher for buttons than hand (p = 0.009677) or rack (p = 0.000528). Further, perceived workload was higher for gestures than hand (p = 0.000437), rack (p = 0.000438), or buttons (p = 0.003772).

Friedman tests showed statistically significant effect of condition for preference ranks (p = 0.00000069173, $\chi^2(3)$ = 31.425). Wilcoxon tests showed that buttons were ranked lower than hand (p = 0.026830) or rack (p = 0.004729). Also, gestures were ranked lower than hand (p = 0.000352), rack (p = 0.000352), or buttons (p = 0.002775). As the most preferred method, 50% of the participants preferred the hand, 37.5% chose the rack, 12.5% preferred the buttons, and no one preferred the gestures (see Figure 4b). Furthermore, 87.5% commented that the gestures were the worst method; 12.5% commented that the buttons were the worst.

While ranking the methods, the participants could also comment on each of the methods. Regarding the hand, participants commented that it "*was the easiest*" (4 mentions), "*familiar*" (3), and "*allowed you to choose your hand position*" (3), but it "*also occupied the hand*" (2). Concerning the rack, participants commented that "*it made possible keeping both hands on the wheel most of the time*" (4) and "*was the easiest to use*" (2). Regarding the buttons, participants commented that "*it was the easiest*" (2) "*but also slow*" (4). Regarding the gestures, participants commented that they "*found it difficult*" (16), "*could not operate it properly*" (4), "*required concentration*" (3), and that "*it was frustrating*" (2).
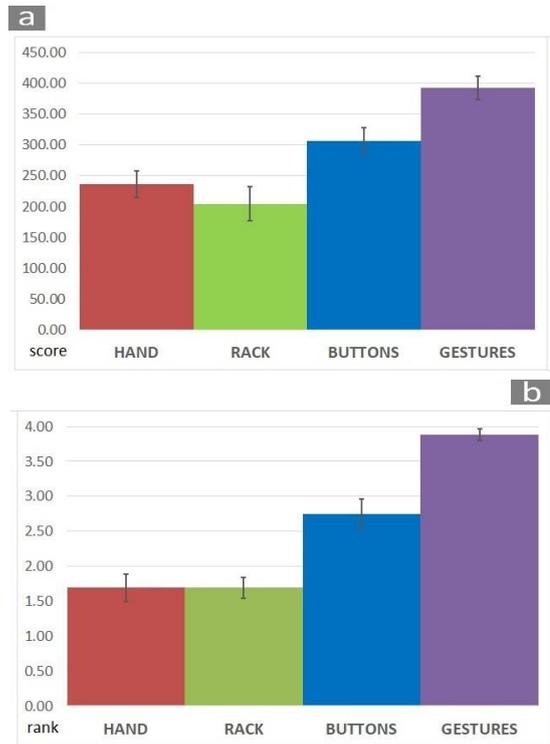

Fig. 4. (a) NASA-TLX total score, a higher score means a higher perceived workload; (b) User preferences, average preference rank from 1 (best) to 4 (worst). Errors bars show SEMs.

V. CONCLUSION

We demonstrated that typical methods for smartphone interaction performed better than wireless wheel buttons or mid-air gestures in a secondary target selection task while driving [12, 13]. To our knowledge, this is the first experiment that directly compares in-car, mid-air gestural interaction, steering wheel buttons, and conventional smartphone interaction [14, 15]. The results point out that mid-air gestures and wheel buttons performed worse than conventional methods in a simple selection task and raise caution in bringing new modalities into in-vehicle infotainment systems without thorough user testing. For future research, we highlight the importance of including contextually appropriate control conditions (i.e., smartphone usage) when studying novel interactions in secondary in-vehicle tasks. The study's limitations include that the participants were relatively young and inexperienced drivers and that they had a limited time to learn and practice the new methods. Furthermore, we only studied one task type, thus the results may not apply to other types of interaction. More research with different target populations, and interaction schemes are required to assess the performance of wheel buttons and mid-air gestures for various driving scenarios

REFERENCES

[1] R. Häuslschmid, D. Ren, F. Alt, A. Butz, & T. Höllerer. Personalizing Content Presentation on Large 3D Head-Up Displays. PRESENCE: Virtual and Augmented Reality, 27(1), 80-106, 2019.

[2] S. G. Hosking, K. L. Young, & M. A. Regan. The effects of text messaging on young drivers. Human factors, 51(4), 582-592.E Publications, 2015.

[3] Virginia Tech Transportation Institute. New data from VTTI provides insight into cell phone use and driving distraction. Blacksburg, VA: Virginia Tech Transportation Institute. Retrieved from www.vtnews.vt.edu/articles/2009 /07/2009-571.html (2009).

[4] Virginia Tech Transportation Institute. 100-car naturalistic study fact sheet. Blacksburg, VA: Virginia Tech Transportation Institute. Retrieved from www.vtnews.vt.edu /articles/2005/06/2005-834.html (2005).

[5] B. I. Ahmad, C. Hare, H. Singh, A. Shabani, B. Lindsay, L. Skrypchuk, ... & S. Godsill. Selection facilitation schemes for predictive touch with mid-air pointing gestures in automotive displays. In Proceedings of the 10th international conference on automotive user interfaces and interactive vehicular applications (pp. 21-32), 2018.

[6] K. Harrington, D. R. Large, G. Burnett, & O. Georgiou. Exploring the use of mid-air ultrasonic feedback to enhance automotive user interfaces. In Proceedings of the 10th international conference on automotive user interfaces and interactive vehicular applications (pp. 11-20), 2018.

[7] S. Mattes. The lane-change-task as a tool for driver distraction evaluation. Quality of Work and Products in Enterprises of the Future, 57, 60, 2003.

[8] S. G. Hart, & L. E. Staveland. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In Advances in psychology (Vol. 52, pp. 139-183), 1988.

[9] A. Farooq, G. Evreinov, R. Raisamo. Reducing Driver Distraction by Improving Secondary Task Performance through Multimodal Interaction. ACM Special Issue Journal on Multimodal User Interfaces, 2018, ISSN: 1783-7677 (print version) ISSN: 1783-8738 (electronic version)

[10] A. Farooq, G. Evreinov, R. Raisamo, E. Makinen, A. Majeed. Developing novel multimodal interaction techniques for touchscreen in-vehicle infotainment systems. In Proceedings of IEEE International Conference on Open Source Systems and Technologies (ICOSST 2014, Lahore, Pakistan), 32-42, ISBN: 978-1-4799-2054-9, IEEE New Jersy, USA ©2016. https://doi.org/10.1109/ICOSST.2014.7029317

[11] A. Farooq, G. Evreinov, R. Raisamo, A. Hippula. Developing Intelligent Multimodal IVI Systems to Reduce Driver Distraction. In: Karwowski W., Ahram T. (eds) Intelligent Human Systems Integration 2019. IHSI 2019. Advances in Intelligent Systems and Computing, vol 903. Springer, Cham. https://doi.org/10.1007/978-3-030-11051-2_14

[12] K. Salminen, A. Farooq, J. Rantala, R. Raisamo, V. Surakka. Unimodal and Multimodal Signals to Support Control Transitions in Semiautonomous Vehicles. In Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI 2019). Association for Computing Machinery, New York, NY, USA, 308–318. DOI: https://doi.org/10.1145/3342197.3344522

[13] J. M. Owens, T. A. Dingus, F. Guo, Y. Fang, M. Perez, & J. McClafferty. Crash Risk of Cell Phone Use While Driving: A Case – Crossover Analysis of Naturalistic Driving Data (Technical Report). Washington, D.C.: AAA Foundation for Traffic Safety, 2018.

[14] D. L. Strayer, J. M. Cooper, J. Turrill, J. R. Coleman, & R. J. Hopman. The Smartphone and the Driver's Cognitive Workload: A Comparison of Apple, Google, and Microsoft's Intelligent Personal Assistants (Technical Report). Washington, D.C.: AAA Foundation for Traffic Safety, 2015.

[15] R. D. Large, G. Burnett, E. Crundall, G. Lawson, and L. Skrypchuk. Twist It, Touch It, Push It, Swipe It: Evaluating Secondary Input Devices for Use with an Automotive Touchscreen HMI. In Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (Automotive'UI 16), 2016. Association for Computing Machinery, New York, NY, USA, 161–168. DOI:https://doi.org/10.1145/3003715.3005459