Mid-Air Haptic Feedback Improves Implicit Agency and Trust in Gesture-Based Automotive Infotainment Systems: a Driving Simulator Study

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ABSTRACT

Gesture-based interactions for automotive infotainment systems pose advantages over touchscreens such as alleviating the visual field. While the focus of these advantages is on improving the driving task, it is also important that a user feels in control and perceives influence over the in-vehicle system. This is known as the user's sense of agency in psychology, and sensory feedback is a key aspect. The current study involved a dual-task driving (simulator) and gesture-controlled infotainment interaction, accompanied by mid-air haptic or audio feedback. With 30 participants, we utilized an experimental approach with implicit and explicit measures of agency, as well as trust and usability. Results illustrated no difference in explicit judgements of agency, however mid-air haptic feedback improved the implicit feeling. More trust was also reported in the system with mid-air haptics. Our findings provide empirical evidence for mid-air haptics fostering user agency and trust in gesture-based automotive UI.

CCS CONCEPTS

• **Applied computing** → Law, social and behavioral sciences; Psychology; • **Human-centered computing** → Human computer interaction (HCI); Empirical studies in HCI.

KEYWORDS

agency, trust, mid-air haptics, gesture, infotainment, driving simulator

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1 INTRODUCTION

Gesture-based interactions have been explored as an alternative to touchscreens for manipulating infotainment systems while driving [2]. They remove physical constraints and have usability preferences [39, 40]; moreover, they pose advantages such as alleviating the visual field. Visual and cognitive demands required for in-vehicle infotainment systems can distract drivers and increase risk of accident [62]. By reducing eyes-off-the-road time (EOTR), gesture interactions remedy competing visual information to minimize driver workload and decrease crash rates [45, 48]. While much focus appears to be on the driving task, it is important that the user feels in control and perceives causal influence over the gesture-recognition system. This is a psychological variable termed sense of agency (SoA) and is a subjective experience which extends to a plethora of human-computer interactions (HCI) [21].

An important factor for SoA is sensory feedback as confirmation that the user's action has caused the intended change in the system [32]. Auditory displays have been explored to further alleviate visual resources [45, 48, 51]. However, auditory resources are also required while driving and so still risk dual-task demands. An alternative modality is haptics. Mid-air haptics transmits touch sensations directly to the hand by utilizing ultrasound waves to stimulate the mechanoreceptors [20]. Research shows this can provide confirmation feedback via the tactile modality to a variety of touchless hand gesture-based in-vehicle interactions, reducing EOTR times whilst also being robust to road vibrations [23, 46, 47, 60]. As such, mid-air haptics demonstrates promise for maintaining and even increasing SoA over automotive user interfaces (UI) while freeing up resources for the driving task.

The objective of the current study was to empirically investigate SoA with gesture-controlled infotainment interactions accompanied by mid-air haptic or audio feedback, while in a driving simulator. Our primary research question was therefore whether SoA for these interactions are modulated by sensory modality of feedback. We also included other variables pertaining to the interaction such as trust and usability and measured general attitudes towards technology. Our exploratory research questions were therefore whether trust and usability are similarly modulated, and if there is a general relationship between SoA and other HCI factors.

With 30 participants, we implemented a gesture input-feedback interaction task which provided a behavioral measure of SoA of the interface while driving in a simulator. We also took self-report

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measures of SoA, as well as trust and usability. The contributions of this paper are as follows: 1) Our study utilizes a robust, quantitative and implicit measure from cognitive neuroscience to examine SoA with gesture control infotainment while in a driving simulator. This experimental paradigm allowed empirically based evaluation of a user's SoA in a more ecologically valid setting, ultimately providing results applicable to both automotive HCI and psychological theory. 2) We draw attention to both the importance of sensory modality for gesture-based infotainment systems and the use of indirect measures of subjective experience.

2 RELATED WORK

2.1 Sense of agency in HCI

SoA refers to the conscious experience that we bring about change in the environment through our actions [35]. Control over our actions and causal influence over outcomes are considered key factors. As such, experimental paradigms typically involve action and effect events that are manipulatable in some way. A simple capture of SoA is to explicitly ask participants to report their experience. This can be a categorical self/other attribution judgement [52] or a Likert scale rating to what extent they felt in control and had causal influence [17, 19].

To measure SoA at the behavioral level, psychological research offers ways to capture the experience without asking the participant. A well-established measure is intentional binding [36]. This stems from an experiment [22] which compared separate button-press and auditory tone (baseline) events to causally related button press-tone (operant) events. Participants reported the time at which they either pressed the button or heard the tone. In the operant condition, they perceived the button press later and the tone earlier as compared to baseline; that is, a perceived compression of time between actions and their causal effects. Notably, when the actions were involuntarily induced via brain stimulation of the motor cortex, the opposite was found – repulsion of time perceived between the two. This perceived compression of time for *voluntary* actions and causal outcomes is termed binding. This effect is widely replicated [1, 3, 26, 57], and simplified efficient paradigms involving directly estimating action-outcome times have also been developed [16, 34].

As actions and effects extend beyond the physical world through the use of technology, so too does SoA [21]. Furthermore, the binding method is a fitting paradigm for ongoing sub-second action-effect loops in human-computer interaction (HCI). With an emphasis on system design that fosters a user's sense of control [43] and an applicable implicit measure, there has been an uptake in research on SoA in HCI [28]. For example, research has shown binding is modulated by computer assistance dynamics such that there is threshold of assistive cursor movement before the user's SoA diminishes [11]. Similarly, there is evidence to suggest that cooperation with robots such as receiving requests from a robot or diffusion of responsibility modulates binding [9, 61]. Together with explicit measures of SoA, the use of an implicit measure expands the potential to understand the user in HCI. Finally, the increased human-computer integration and automation leads to increased shared agency between humans and digital systems, a topic of great interest discussed in a recent review article [10].

2.2 Mid-air input and system feedback

Two early theoretical accounts of SoA suggest a feed forward [42] or a retrospective causal inference mechanism [53]. The former being linked to predictive signals arising from internal motor commands and the latter being linked to feedback from the external world. Recent advances suggest an integration of the two [32, 50] which means both the user commands and how the system responds can modulate SoA. This notion is exemplified in the *Gulf of execution and evaluation* model [38]. The challenge here is that the user carries out their action with the intention to change the system, and in turn the system must respond in a way that the user recognizes as their intended change. This would suggest that input modality and system feedback become important factors. Research supports this, for example showing a diminished SoA for speech input potentially due to competing cognitive resources with working memory [29]. Furthermore, that input-latency weakens SoA [6], and even valence of an outcome retrospectively modulates the experience [55].

There is a recent uptake in the investigation of SoA with mid-air hand-tracking as a relatively newer mode of input. In terms of input, it appears comparable to physical buttons as research has shown the user's experience of SoA does not significantly differ between the two [31]. What is important however, is the feedback received in response. For example, in a virtual environment, mid-air haptics accompanying interactions with objects increases SoA [17], and can mitigate negative impacts of latency [19]. Different sensory modalities have also been investigated for response to mid-air gestures, with mid-air haptics and audio increasing SoA as compared to visual [31]. Evidently, gesture input is viable for the user to maintain SoA, however the feedback in response should be taken into consideration.

2.3 Automotive contexts

Recent literature refers to SoA in automotive environments with a focus on automation and driving assistance [54]. This is due to a close link with ethical and legal concerns of responsibility, particularly as the boundaries of human-machine control are changing. Furthermore, the trade-off between performance and perceived control has been considered. Researchers have investigated how to reduce automated intervention while increasing performance [56]. Essentially, this is to maintain a user's SoA while optimizing driving performance. Proposing a shared intention format, their experiment looked at a lane cut-off situation where participants had to decelerate to maintain appropriate intervehicle distance. Deceleration was either manual or assisted; assistance was in line with cut-off vehicles and only applied when the participant's vehicle speed was faster. Results showed faster and smoother deceleration with assisted breaking and no significant impact on SoA. The authors conclude that shared intention of automated driving intervention may work to eliminate the agency-performance trade-off.

What is seldom considered however, is in-vehicle controls in automotive contexts. For example, interacting with UI elements such as infotainment systems and maps. In this sense, driving is often operating at least a dual-task level, which could be an issue for SoA as research suggests it can decrease under cognitive load [13] due to requiring a shift in attention [54]. While driving then, SoA over in-vehicle commands also becomes important. Research has looked at voice interaction with physical and virtual agents while driving to search for music, change navigation and send text messages [8]. They manipulated anthropomorphism levels and found opposing effects for virtual and physical. Perceived control and trust were stronger for high anthropomorphism of a virtual agent, and the opposite for a physical agent; there were no differences in driving performance. Furthermore, perceived control mediated the relationship between anthropomorphism and trust. It seems SoA may be maintained for in-vehicle controls without impacting driving performance.

However, as mentioned above, SoA at the implicit level may be generally diminished when using speech interfaces [29]. Additionally, speech activation as a requirement may become tricky when there are other passengers in the car. An alternative consideration is gesture-based interactions with mid-air haptic feedback. Gesture-based interactions are a viable way of reducing eyes-off-the-road time and can be utilized with audio [48] or haptic [46] feedback. Previous research has shown a comparable SoA for both types of feedback for mid-air interactions [31], albeit not in the context of driving. We aim to build on this by looking at gesture-based interactions with mid-air haptic and audio feedback, and using robust, quantitative and implicit measures of SoA in a driving simulator.

3 METHODS

3.1 Study design

In the current study, we aim to investigate SoA for a gesture-based automotive infotainment system during a driving simulation exercise. Participants carried out a dual task which required driving around a track in a simulator while selecting different icons (seat temperature or fan speed) using mid-air gestures – different hand-poses detected using machine vision cameras. Participants either received mid-air haptic or audio feedback.

We utilized an interval estimation paradigm to measure implicit SoA [16] where time delays were introduced between the gesture pose and the feedback received. Participants estimated the delays, and differences in the perceived time between their actions and effects are considered differences in the magnitude of their subjective experience [11, 19, 55, 59]. We also used a passive control condition often seen in binding studies [5, 12], where they would estimate the time between two unrelated tones – this was also while driving. Self-report questions of control and causality were adapted from previous studies [17] as an explicit measure of SoA. Questions of trust and usability were also asked, and general HCI factors of computer anxiety and technology readiness were also taken. Average speed throughout was taken as a measure to account for driving performance.

A repeated measures design was used with all participants taking part in all conditions: haptic, audio and passive (Figure 1). The Latin square method was used to ensure a clean counterbalanced design and account for any order effects. With 24 interval estimation trials per block, each interval was presented 8 times in random fashion. For the active blocks, a trial consisted of selecting the requested icon while driving and receiving feedback (haptic/audio) after a short delay and estimating the delay. For the passive block, a trial consisted of listening to two tones with a short delay between them and estimating the delay.

3.1.1 *Research hypotheses.*

- **H1.** Interval estimations will be shorter in the active conditions than in the passive, indicating SoA.
- **H2.** Interval estimations will be shorter in the haptic condition compared to audio, indicating an increase in SoA.
- **H3.** Self-reported SoA, trust, and usability will be higher in the haptic condition as compared to audio.
- **H4.** There will be a relationship between SoA and general attitudes toward technology and HCI

H1 was to verify SoA in the active conditions and H2 to then compare the magnitude. H3 was to look at explicit agency and explore other HCI factors of the user's experience. H4 was to explore where SoA in this context is associated with individual differences in attitudes toward HCI.

3.2 Participants

30 participants (17 female, 2 prefer not to say) were recruited via posters and word of mouth and received £10 compensation. Ages ranged from 19-40 (*M*=27.8; *SD*=4.7). Participants were screened for handedness and driving experience as potentially confounding variables. All participants had normal or corrected-to-normal vision and no reported somatosensory impairments.

3.3 Materials and apparatus

The driving simulator setup (Figure 2) included a car shell which provided separate in-vehicle sound for the gesture selection task. Separate speakers outside of the vehicle played the in-game sounds and the projector displayed this on an outer screen. BeamNG.drive (v0.29.1) [4] was used for the driving simulation, using the time trial mode on the Italy Mixed Circuit map which used mixed terrain including gravel and dirt roads. This version provided 12 checkpoints in the form of red beams of light to give a clear path and allowed data collection of average speed. The vehicle type was automatic, and participants were not required to use a gearstick at all, only two pedals – accelerate and brake – with their right foot. NB holding the brake pedal down when the vehicle is at a stop would put the car in reverse and there were buttons on the steering wheel for mechanics such as rear-view, but this were never used.

An Ultraleap STRATOS Explore development kit was set up inside the vehicle, positioned to track the user's hand when moved left of the steering wheel (Figure 2). This device consists of a Leap Motion camera (v5 Gemini SDK) and an ultrasound transducer array, enabling a touchless interaction with gesture recognition and haptic feedback by stimulating the mechanoreceptors on the hand to transmit tactile sensation [20]. An infotainment system interaction was setup in Unity engine (v2020.3.27f1), consisting of a fan speed and seat temperature icon. Gestures required to activate these were a 4-finger pose and 3-finger pose, respectively (Figure 1), with a mid-air haptic scan down the hand for fan and up the hand for seat for a duration of 1s. These hand poses and haptic feedback were chosen as they are distinctly different as also discussed in [60]. The audio feedback version was a high pitch tone for fan and a low pitch tone for seat. These also lasted a duration of 1s to ensure consistency with the haptic condition and were played through separate in-vehicle speakers. The gesture recognition was

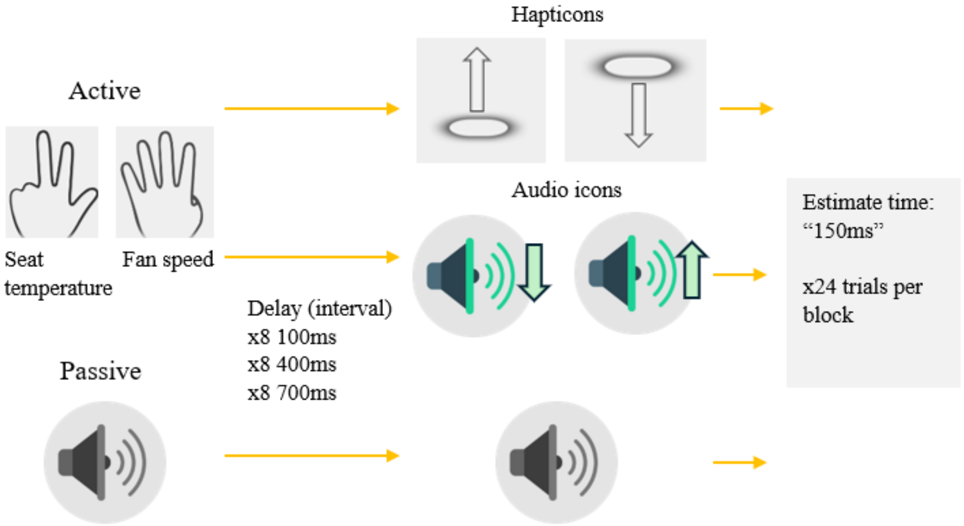

Figure 1: Experimental procedure schematic and trial structure. NB hapticon images representing mid-air haptic scan up and down; audio icons representing high and low pitches; passive involved no active gesture and both tones were a middle pitch dissimilar to the audio icons.

Figure 2: Driving simulator setup, internal and external.

generally accurate and on rare occasions trials where participants felt it inadvertently selected the icon were rendered void (<1% trials).

3.4 Tasks and measures

3.4.1 Driving. For the driving task, participants were specifically asked to drive carefully and more realistically rather than race, simply following the checkpoints. They were particularly instructed to avoid crashing/damaging the in-game car to an extent that it alters the driving mechanics. This was due to having to reset the car which meant losing the in-game average speed check data. We took this data for exploratory measures however, and so it did not mean losing the main SoA data with the gesture interaction.

3.4.2 Sense of agency. To measure implicit SoA, we used an interval estimation paradigm where participants are asked to estimate the time interval between actions and effects [16]. To do this, we introduced a time delay between when they make the gesture pose and when they received the feedback, to which they were told varied from 1-1000ms. In reality there were only 3 intervals – 100ms, 400ms, 700ms – which is a standard format to give the perception of complete variation [37]. As this task was done amidst the driving, participants were required to verbalize their estimate aloud. Shorter time estimates are considered to reflect a stronger experience of agency. We also included a passive control (no agency) condition whereby no gesture actions were made, instead they simply estimated the time interval (same variation) between two tones played through the in-vehicle speakers (different pitch to that of the active condition). Comparisons between active and passive conditions provide further insight into a categorical presence of SoA [5, 12].

For the explicit measure of agency, we used a more straightforward self-report style. With respect to control and causation as key factors of SoA [35], we adapted two questions from a previous study [17] and tailored them to the task by asking: "*How much control did you feel in terms of going to make the gesture action?*" and "*How much do you feel the (haptic/audio) feedback was caused by your gesture command?*". These were asked on a Likert scale of 1-7 and taken once at the end of each block.

3.4.3 User experience. For exploratory reasons, we also took other HCI factors via self-report for each condition (haptic and audio). These were: "*How in control did you feel over the driving?*" (driving), "*How much did you trust the gesture recognition system when selecting your icon?*" (trust), "*How efficient did you find the gesture recognition system?*" (efficiency), and "*How innovative did you find the gesture recognition system?*" (innovativeness). This allowed us to examine whether there were any differences in perceived trust and usability between haptic and audio feedback, and whether they felt there were any altering effects on their driving. These were taken on a 1-7 Likert scale.

As a post-hoc measure of general trust and experience with the gesture control infotainment system, we adapted HCI scales to be utilized in context. The Trust Between People and Automation scale [25] consisted of questions such as "*The gesture control system behaves in an underhanded manner*" and was measured on a Likert slider scale from 1-7. The UEQ-S [44] was used to measure both pragmatic (e.g. complicated/easy) and hedonic (e.g. conventional/inventive) usability on a slider scale which ultimately scored from 1-5.

3.4.4 HCI factors. For more exploratory factors, we took general measures of computer anxiety and technology readiness. We used the 19-time CARS [24] which consisted of questions of fear such as "*I hesitate to use a computer for fear of making mistakes that I cannot correct.*", and anticipation such as "*The challenge of learning about computers is exciting.*". This uses a 1-5 Likert scale and totals a score from 19 (low anxiety) to 99 (high anxiety). The 16-item TRI 2.0 [41] was used which is a streamlined version of technology readiness, consisting of items such as "*In general, I am among the first in my circle of friends to acquire new technology when it appears.*" These also use a 1-5 Likert scale, and a final mean score then ranges from 1 (low readiness) to 5 (high readiness).

3.5 Design and procedure

Participants completed the CARS and TRI 2.0 prior to the experimental session. They were told that they will be carrying out a dual-task involving driving in a simulator and using a gesture control system to select in-vehicle features. A practice lap was completed to become familiar with the mechanics and the track. The focus then turned to the interval estimation task, where they completed a practice phase without driving to understand the task. The infotainment screen was presented to them, informing them of the poses and icons, and we physically demonstrated this. 6 practice trials were conducted with both haptic and audio feedback, where they were also received feedback of the exact interval to give a sense of the millisecond timescale. All participants experienced the same 6 intervals in a random order (in milliseconds): 50, 200, 350, 500, 750, 900. Practice trials were also conducted with the passive condition where they would simply estimate the interval between two tones.

For the experimental phase, participants were told that the time intervals would now vary randomly between 1-1000ms. At the start of each block, they were familiarized with the condition (haptic, audio or passive) by starting the drive and running two interval estimation trials. A full block would be completing 2 laps of the course while selecting the icons at times as instructed by the experimenter, giving their time estimates verbally aloud. These instructions were given at each checkpoint to ensure consistency across participants. With respect to avoiding a crash, we informed them that they are entitled to slow down where necessary when doing so. This resulted in 24 interval estimation trials per block, and they would answer the self-reported agency, trust and usability questions at the end of each *active* block respectively.

At the end of the experimental tasks, participants completed the Trust Between People and Automation scale and the UEQ-S. This was tailored to the task that they just completed. Finally, they were asked if they had any questions and debriefed on the experiment. The whole session would typically last up to 1.5hrs.

4 RESULTS

Checks were first carried out whether driving experience or any demographic factors affected SoA. No differences were found in implicit nor explicit agency as per which side of the road participants had driven on before (all p>.05), nor any association with driving experience (all p>.05). Age and sex were also not influential factors (all p>.05).

Preliminary checks found no difference in average speed between any of the conditions (Figure 3). Additionally, that SoA over the in-vehicle task did was not correlated with average driving speed (all p>.05). Together, this suggests both actively using mid-air gestures while driving does not impact average speed and that results discussed below were not confounded by differences in this driving behavior

4.1 Sensory feedback on interval estimations

A repeated measures ANOVA was carried out comparing interval estimations between the haptic, audio and passive conditions (sphericity assumed, Mauchly's W, p = .580). There was a significant effect (Figure 4), $F(2, 58) = 13.71$, p<.001, $\eta_p{}^2 = .32$, with interval estimations being shortest in the haptic condition (M=306.3; SE=17.8). Bonferroni correct paired-comparisons found large significant differences between haptic and audio conditions, $M_{\text{Difference}} = -81.98$, SE = 17.58, $t(29) = -4.66$, p<.001, d=-0.85, 95% CIs [-117.9,-46.0], haptic and passive conditions, $M_{\text{Difference}} = -73.22$, SE = 15.5, $t(29) = -4.72$, p<.001, d=-0.86, 95% CIs [-104.9,-41.5], but not audio and passive conditions, $M_{\text{Difference}} = 8.76$, SE = 18.37, $t(29) = -0.48$, p = .637, d=-0.09, 95% CIs [-28.8,46.3]. Overall, this shows implicit SoA was much stronger in the haptic condition. Additionally, with comparable effects between audio and passive conditions, this suggests a potentially diminishing implicit SoA in the audio condition.

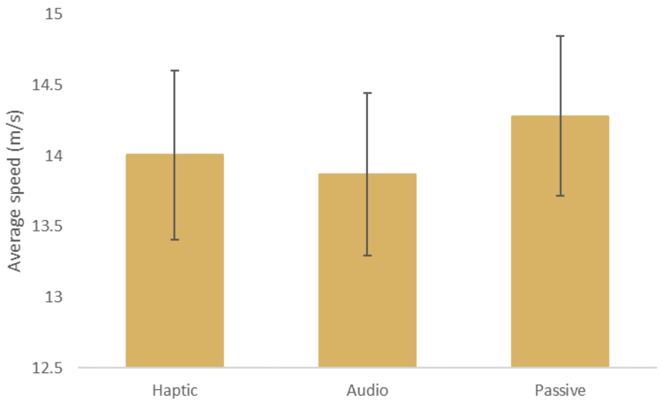

Figure 3: Average speed per condition in meters per second (m/s). Error bars represent standard error across participants.

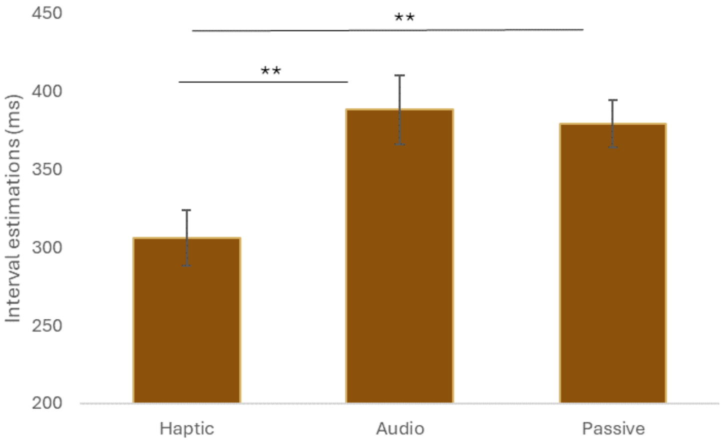

Figure 4: Mean interval estimations in milliseconds (ms) per condition. Lower scores indicate greater agency. Error bars represent standard error across participants. **p<.001

4.2 Sensory feedback on self-reported agency and user experience

Due to significant departures from normality across the self-report measures (Shapiro-Wilk, p<.05), non-parametric, Wilcoxon signed-rank tests were used.

There was no significant difference in self-reported control over actions (W(29) = 91, p = .885) nor causal influence over feedback (W(29) = 103.5, p = .742) between haptic and audio conditions. There was also no difference in feelings of control over the driving, W(29) = 67, p = .422. Overall, this shows that explicit judgements of agency for both in-vehicle and driving controls did not differ as a factor of sensory feedback.

There was a significant difference in trust between the haptic and audio conditions (Figure 5), W(29) = 134, p = .028, r_b=-0.57, 95% CIs [0.00,1.5], such that participants reported more trust in the system when there was haptic feedback compared to audio. There was however, no significant differences in reported efficiency (W(29) = 107, p = .145) nor innovativeness (W(29) = 81, p = .063), between haptic and audio feedback. Overall, this suggests participants generally find the gesture-based system innovative and efficient but appear to trust the mid-air haptic feedback more.

4.3 Relationship between agency and other HCI factors

No significant correlations were found between SoA measures and general trust and usability with the gesture control system (all p>.05). This suggests SoA is a potentially independent psychological factor for the user with gesture-based interactions.

No significant correlations were found between SoA measures and general computer anxiety and technology readiness with HCI (all p>.05). This suggests user SoA with gesture-based interactions may be separate from their general anxiety and familiarity with technology.

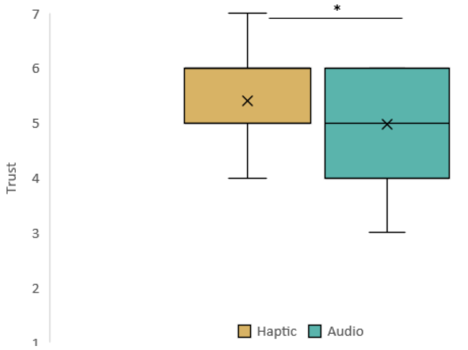

Figure 5: Trust ratings plotted as a function of feedback. The middle lines of the boxplot indicate the median; upper and lower limits indicate the first and third quartile. The error bars represent 1.5 X interquartile range or minimum or maximum. *p<.05

5 DISCUSSION

The current study aimed to investigate the user's SoA with gesture-based in-vehicle infotainment systems in a driving simulator dual task. The focus was particularly on the effects of mid-air haptics, and other HCI factors were explored. Though no differences in SoA were explicitly reported by participants, there were large significant differences in interval estimations. That is, the implicit feeling of SoA was much stronger with mid-air haptic feedback as compared to audio. Furthermore, interval estimations for audio feedback were comparable to the passive condition which suggests a potentially diminished SoA. These differences were independent of age, driving experience and driving speed. Finally, participants also reported more trust in the gesture-based system with mid-air haptics compared to audio.

To our knowledge, this is the first study to measure both explicit and implicit SoA in a driving simulator, utilizing a robust, quantitative psychological research method. Previous research has looked at mid-air gestures with implicit measures and shown a comparable SoA to physical interactions, suggesting it as a viable input modality [31]. However, this may depend on the sensory feedback received. More specifically, visual feedback may not provide as strong a cue for SoA as compared to mid-air haptics and audio, to which the two are comparable. Here, we have combined mid-air interactions for an infotainment system in a driving simulator for a more ecologically valid, dual automotive task. We find that mid-air haptic and audio cues are not comparable here, and mid-air haptic feedback significantly increases SoA where it potentially diminishes for audio feedback.

This difference in SoA, while not picked up at the explicit level, was revealed at the implicit level. Divergence of the two measures is common in SoA research [27, 33], extending to HCI contexts too [17, 18, 59]. It has been suggested that there is a separation in the subjective experience, potentially at the level of awareness. That is, that there is a judgement and a feeling of agency [14, 49]. Here, in the dual task, it may be that participants appropriately judged themselves to be the agent over the mid-air infotainment system, but the implicit feeling was affected by differences in feedback. This further illustrates the importance of utilizing robust methods which capture potentially different components of a complex psychological experience.

5.1 Implications for gesture-based infotainment systems

Mid-air interactions for automotive UI are considered to offer several benefits for the user over more commonly used touchscreens. These include removing physical constraints and general usability preferences [39, 40]. Of particular importance though, is the decrease in risk of accident due to reduction in visual and cognitive demands [62]. Research shows these interactions do minimize competing visual information and indeed reduce eyes-off-the-road time [48]. The question then turns to ensuring the user feels SoA over the in-vehicle system. While auditory displays have been shown as viable for the interaction in terms of eyes-free information [45, 51], our findings show that they may not be sufficient for the user's SoA. In contrast, mid-air haptic feedback as confirmation for gesture recognition could quite significantly foster user SoA, as well as increase their trust in the system.

These findings provide exciting grounds for more nuanced mid-air haptic research in automotive. For example, Brown et al [7] explored whether the semantic value of features being actuated in an in-vehicle Human-Machine-Interface (HMI) could be translated through the mid-air haptic medium. The intention being that while a driver maintains visual and cognitive attention to the road, not only could they understand when their action has been detected but also if the correct action has been detected. Findings revealed that semantics can be conveyed through "Hapticons" which aligns with similar work in the vibrotactile medium [30]. With SoA being closely tied to action and detection, there is potential for added value of semantically informed mid-air haptics.

5.2 Limitations and future directions

One limitation we consider here is that the passive control condition used audio feedback which, although using a different pitch tone, was the same sensory modality as one of the active conditions. As interval estimations in both were comparable, it does leave question whether this is just an effect of sensory modality. Although much previous research would suggest this is not the case [12, 58], including using a passive haptic-audio condition [1], a control with a passive haptics condition would ensure this in future research.

Another limitation here we consider is a lack of extra informative data such as eye tracking and more detailed driving performance. Previous research suggests gesture-based systems with audio or haptic feedback do reduce eyes-off-the-road time [46, 51]. Without the use of eye-tracking here however, we are unable to show that here nor further extend this by looking at any relationship with SoA.

We also consider the limited scope the current experiment offers in terms of a very simplified gesture interaction task. Due to the use of a rigorous psychological paradigm, we were confined to having participants just make a gesture pose and be notified of the selection. Of course, in an automotive environment these interactions are ongoing and longer lasting, involving altering the settings of the icon selected and more. There are a multitude of gesture input techniques being explored for these including, pinching, sliding and pointing [15, 46]. We appreciate that the foundations set by the current study may offer future research grounds for extending the investigation of SoA to these interactive causal chains.

6 CONCLUSION

In sum, the current research looked at mid-air haptic and audio feedback for gesture-based infotainment interactions in a driving simulator exercise. We looked at the user's SoA using a robust, implicit and quantitative measure adapted from neurocognitive research. Other HCI factors were also considered. Results showed that mid-air haptics significantly increased implicit SoA as compared to audio feedback where it potentially diminished. Participants also reported more trust in the system with haptic feedback as compared to audio. Implications of these findings suggest mid-air haptic feedback as confirmation for icon selection may not only be key but could largely improve the implicit SoA of the user. Further, it may also foster the user's trust in gesture-based in-vehicle systems. In view of the increasing autonomy functions of modern cars, our findings and approach could transfer over to benefit other UI research aspects in cars to support a shared human-car SoA. Finally, this research demonstrates the importance of interdisciplinary research where HCI can benefit from the use of both computer science and psychological research methods.

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