Tangible Interaction with In-Car Smart Intelligence

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Abstract

Interacting with a car was once a tactile experience, which is on the decline with the rise of car assistants, where the dominant form of interaction is through screen displays and voice recognition. These interaction modalities within a car are not the only options available. In this paper, we discuss reintroducing tactility into the automotive experience. This work presents a tactile embodiment of an intelligent car system, different from previous studies, to improve engagement and emotional connection between users and future intelligent cars. A prototype tool was designed to embody an intelligent car system. It was used to investigate how to interact with and control a smart-comfort system to improve user comfort. The tool invited users to interact through touch. Users could use their hands to physically agree or disagree with changes made by the system with the system moving in response, creating a bi-directional interaction symbiosis that re-prioritises tactility.

CCS CONCEPTS • Human-centered computing • Interaction devices • Haptic devices • TUI • Physical Embodiment

Additional Keywords and Phrases: TUI, Tangible Interactions, Data Visualisation, In-Car Assistant, HMI Interactions

1 Introduction

Figure 1 A Bentley concept car depicting a future car, with no screens or digital interfaces. Instead, 3D sculptures are placed in the center of the front and rear of the car for users to tangibly interact with the intelligent cars of the future.

There is an increasing trend in the automotive industry to explore the use of digital assistants in cars. However, the usability and control efficiency of today's Voice User Interfaces (VUI) remains to be enhanced through interaction design. The issue is that VUI assistants do not embody the user's car, and mainly fall under a co-embodiment [10]. This causes dissociation between the car's intelligence and co-shared intelligence in the cloud, reinforcing user perception that the car is merely a vessel for multi-source intelligence. Assistants are currently represented in cars as animations on screen, with users interacting with their assistants via voice recognition or through touch screens when they need to adjust certain functions in the cabin. Interacting with in-car assistants in this way is a cause of driver distraction [5]. For example, using VUI, a user could ask their in-car assistant to increase the radio volume. The assistant would carry out the task but may set the volume higher than the user wanted. To lower the volume to an acceptable level, the user would then have to go through layers of screen interaction, which introduces barriers to their interaction with their assistant, and could also impact other things such as user trust and understanding. In addition, it could be argued that using screens to present digital assistants could contribute to a loss in character of the car [8][9].

A great deal of research has been carried out to investigate and fine tune screen and voice-based interactions, producing a multitude of technological advancements in that area. We use screens and voice recognition software everywhere in the current age, and as such, it can be argued that we are at risk of losing the physical pleasure of car control. Historically, haptic tuning was a crucial part of automotive car development to ensure users have a pleasurable experience when controlling the car. This is something we are losing with the vast increase in screen usage. If we reduce the need for users to control their vehicle physically, the user's connection to the car may also reduce.

In this paper, we investigate how we can combine a novel, 3-dimensional representation of an AI assistant with tangible interaction so users can physically communicate with this intelligent system. Users will be utilizing hand movements to elicit a response within the intelligent system. The study aims to explore the benefits of introducing an alternative physical assistant in the car, focusing on a touch interaction modality. The research also aims to increase understanding of the physical interactions users create with smart control systems to evolve the mechanical interactions users may have with smart control systems in future cars. A prototype was designed and created to depict a form of in-car intelligence interpretation. It included simple physical input techniques for user interaction. Twelve participants were invited to explore and interact with the smart-control prototype tool. We simulated a driving experience around this interaction to make it appear as though the participants were in a driving vehicle as they interacted with this smart assistant. A controlled Wizard-of-Oz study was utilized to evaluate user understanding, control, and trust in the system. Results indicated that user understanding was reduced due to the complexity and novelty of the system. However, there was a clear improvement in machine-to-user communication, and a relationship was subsequently built between the smart system and the users.

This study makes the following contributions to human-car interaction: (1) An alternative to on-screen visualization and interaction modalities. The study proposes a mechanical interaction method that can become a bi-directional communication tool for not only human to machine but also machine to human. (2) Through a user-elicitation study, guidelines are presented on how to introduce physical interaction designs for novel use cases. (3) Highlighting the benefits of tangible and physical interactions with a smart car assistant.

2 RELATED WORK

This work is motivated by the visible trend seen in the automotive sector around embedding intelligence into the car, and to build on the growing research in this area in a novel direction, to explore different techniques and executions of how users can interact with an intelligent system. We explore this literature here before reporting our study.

2.1 In-car physical assistants and their usability issues

Most research is conducted around VUI and screen assistants in the car domain [3], [11], [12]. Much of this research is focused on interactions with the assistant using voice and focusing mainly on driver interactions to improve the driving experience. An issue with this is that the interactions of users in the car with machines are not only limited to drivers, especially as we move towards autonomous vehicles, making the issues around driver distraction irrelevant. Research such as AIDA [16] has shown that having a physical manifestation of the system resulted in more personal non-verbal cues being used by the occupants in the car, such as expressing emotion through the use of head movement. AIDA's 'Head' moved and used an on-screen face to express human emotion. The study did not explore interactions beyond voice, showing that most research uses voice interaction as a key modality within in-car assistant exploration. In a study that showed a combination of two modalities together (e.g., [5]), where the study showed a mix of touch gestures with a steering wheel with a VUI, it did not mention other modalities that could be explored. These studies do not indicate how users perceive the systems in terms of smart system embodiment. There is a lack of published research around embodied and tactile smart car assistants. However, car companies have demonstrated many future concept cars, such as BMW, Bentley (Figure 1) and Renault that explore the idea of physicality and interaction [1], [2], [14].

2.2 Building user trust and understanding with a new smart system

Research carried out to set guidelines for building trust and understanding between smart systems and users can be used in the design of a prototype tool, ensuring there is a clear opportunity to build a relationship. Before a user interacts with a smart system, the system should present a brand association and lean on its authenticity [15]. The first form of interaction should be such that it ties in with widespread and understandable mental models [13]. After interaction with and continued use of the system, the system should be able to use several forms of communication to give feedback to the user, especially in the context of a car, as the need for different forms of communications is needed for the different use cases and the constantly changing situations when moving in the real world. This could be a combination of movement, noise, information on screen, speech, light, or touching the user, etc. However, the communication should avoid the uncanny valley. The system should prioritize showing the data it is using [15] to ensure that what it is about to do is sound and understandable to the user. Once the output is completed, a confidence marker should be communicated [7]. This combination of factors will ensure the system is transparent to the user [6] and that the quality of trust and the long-standing impression of the system on a user can then be maintained through automation [7].

However, intervention is required whenever the system measures a performance reduction of system performance below a 70% accuracy [17], as this has a strong effect on the smart agent's reliability [4]. Once an error is found, the system should acknowledge that the information is new to the system, allowing the user to intervene if the machine cannot perform. Smart system designers must develop systems that enhance user understanding with all this in mind. In addition, the recommended guideline for designing smart systems involves formats to solve the interpretability problem. This involves systems that are understood by the experts and the end-users [16], [7], [17]. Creating an artificial system that generates a complete and satisfactory explanation of its decisions can positively and substantially impact a person's life. Thus, while maintaining a higher degree of learning performance, developers of artificial intelligence can enhance user understanding in AI systems by considering some approaches such as suitable machine learning techniques, state-of-the-art human-computer interface, question-driven explanations such as the AQUA reasoning model, Fairness, Accountability, and Transparency (FAT) algorithms, Interpretable Machine Learning, and XAI question bank [6], [17], [4].

3 METHODS

In this study we investigate the acceptability and the potential of a tangible interface with a smart AI system that controls the car environment. A Wizard-of-Oz setup was designed to explore initial user interactions with an 'intelligent' comfort system. This study's 'intelligent' system is a rig designed and built with multiple moving components which display patterns of movement in response to human touch or hand movement. Figure 2 shows the hardware rendering of the research tool.

Figure 2 Rendering of research tool, the user interacts with the top surface of the unit, as each diamond shard lifts up and down, pushed and pulled by the servos on the bottom.

The study looks to recognise if a user can understand how the system is 'thinking' by observing and interacting with the tangible representation of its reasoning, which is made of movement and lights. 12 participants were involved the study. Figure 3 shows the expected interaction logic with an in-car comfort system.

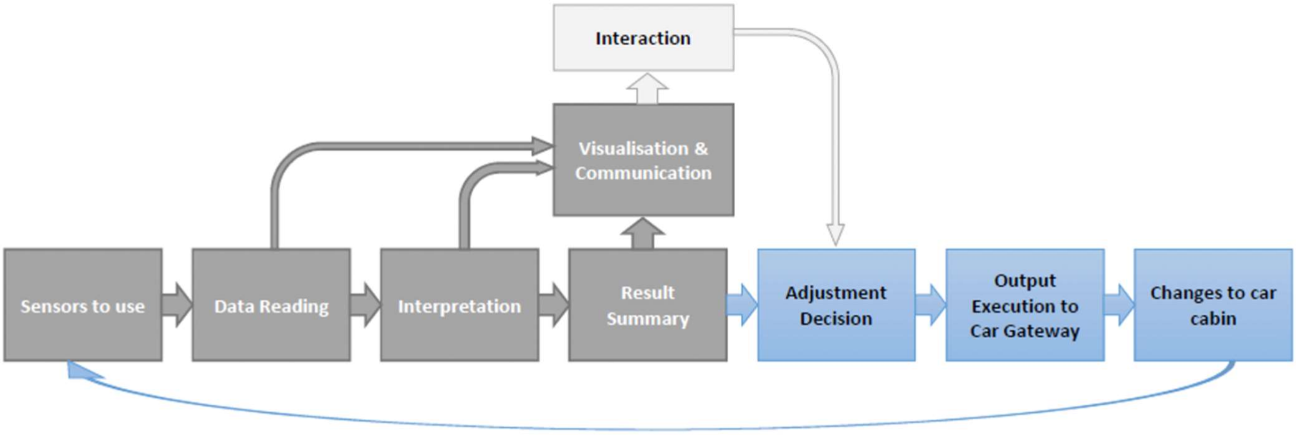

Figure 3: Logic map of how the interaction layer would interface with a smart AI comfort system that could be design for a car. The interaction layer is in grey showing how its input is a visualization of the systems thinking while a user can interact

The experiment consisted of 3 stages totaling a planned 1-hour slot with each participant. However, the average time spent was 83 minutes with a 0.328 standard deviation. This consisted of introducing the participants to the rig, exposing them to a fantasy journey in the car with the comfort assistant and a final interview. Figure 4 shows the structure and activities used in the study.

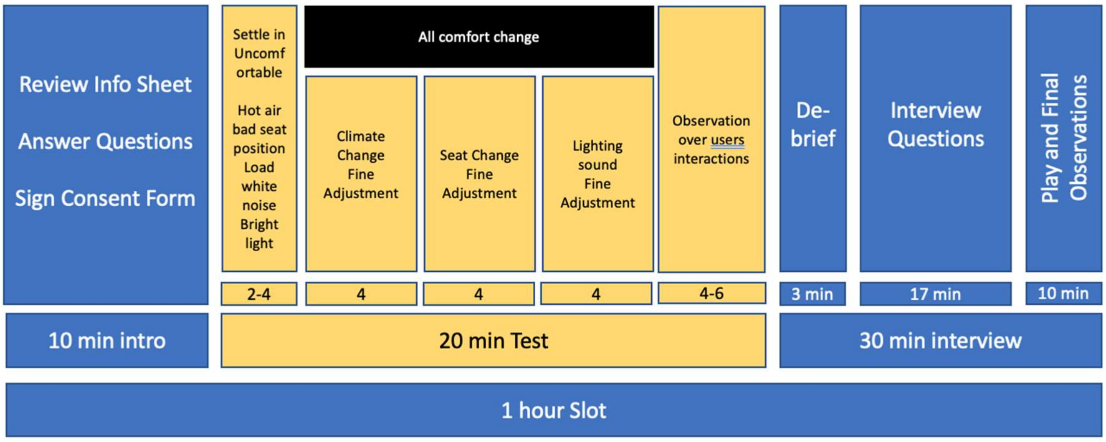

Figure 4 Testing methodology and the time taken for each stage.

The first stage was a short 10-minute discussion to review the experiment and interview, explain the local ethics committee's approval (RA040154/2), and obtain written consent to be interviewed and observed. The second stage was the Wizard-of-Oz experience of using the comfort system. Here there was an expectation that the users would start interacting with the system, and they were encouraged to voice their thoughts about what they were doing throughout and why. The experiment had a way to remotely control all settings and changes behind the user to maintain the illusion of a fully functional system. This stage lasted 20 minutes. At the end of the journey in the experiment, each participant was first debriefed on what was involved in the experiment and then interviewed to understand why they reacted to the system at certain times, and why they didn't react at other times. They were also encouraged to talk about what they experienced in the interim of comfort with the system and if they understood what was happening. However, they were not told that it was a Wizard-of-Oz setup, as this was a pivotal point to observe during the interview to understand better their thoughts about the AI and their interaction with an AI/smart system in the car.

For the data analysis, all interviews and user thoughts during the experiment were transcribed. Thematic analysis using NVIVO 1.6 was used to analyze the transcripts. The thematic analysis was complemented by an analysis of video footage aimed to capture the critical hand and gesture interactions between the participants and the system. Video timestamps were used to calculate the gesture frequency and duration. This was added and compiled together to generate a table of frequency and time, as seen in Table 1.

Table 1 Table capturing the frequency and time in seconds of the gestures observed of participants in the study from their interactions with the system. G# refer to the gesture ID.

Key F = Frequency of Interaction T = Time Spent Seconds % = Prese

Participants	G1 Resting Hand			G2 Hovering Hands			G3 Stroking & Swiping			G4 Pressing Down			G5 Moving out of the way		
	F	T	%	F	T	%	F	T	%	F	T	%	F	T	%
P01	7	61	5%	10	131	16%	15	151	19%	5	32	4%	0	0	0%
P02	18	163	14%	12	62	5%	2	11	1%	9	33	3%	4	12	1%
P03	2	62	5%	11	108	9%	17	117	10%	39	84	7%	10	157	13%
P04	13	582	49%	4	67	6%	0	0	0%	16	72	6%	1	11	1%
P05	1	31	3%	3	8	1%	2	9	1%	15	46	4%	2	13	1%
P06	6	288	24%	3	11	1%	4	16	1%	7	25	2%	3	12	1%
P07	8	103	9%	1	5	0%	1	3	0%	4	11	1%	4	37	3%
P08	9	708	59%	1	7	1%	6	52	4%	3	17	1%	7	33	3%
P09	3	158	13%	2	17	1%	0	0	0%	2	13	1%	1	6	1%
P10	12	128	11%	3	33	3%	3	16	1%	6	19	2%	7	32	3%
P12	4	817	68%	0	0	0%	0	0	0%	4	14	1%	2	12	1%
All	**83**	**3101**	**23%**	**50**	**449**	**4%**	**50**	**375**	**3.4%**	**110**	**366**	**2.9%**	**41**	**325**	**2.5%**

4 Observed Physical Interactions

Table 1 shows the recorded user interactions with an intelligent physical system, and it breaks down how frequent each interaction was by the user and the length of the engagement with that interaction. The physical interaction gestures identified from the video analysis were 9 (G1 to G9) interactions. Figure 5 shows examples of hand positions and movements used to determine and label the nine interactions.

In most cases, users first were very observant and cautious not to interact (G9) immediately with the system. It took an average of 3 minutes and 17seconds for the first interaction gesture. The first gesture used varied between (G1), (G3) and (G4), with the user's hands being very slow and cautious. Once there was physical contact and the system moved physically, users in most instances moved their hands out of the way (G5). The reasons for this vary massively. For some users, it was a shock to experience the system responding to them and for others, it was due to curiosity about how the physical system moved under their hands. This caused the users to spend a significant time hovering their hands over the system (G2) signifying their intentions to reengage with and explore the system. Towards the midway mark, users appeared more familiar with the system and started resting their hands (G1) on the system for longer and more frequent periods of time.

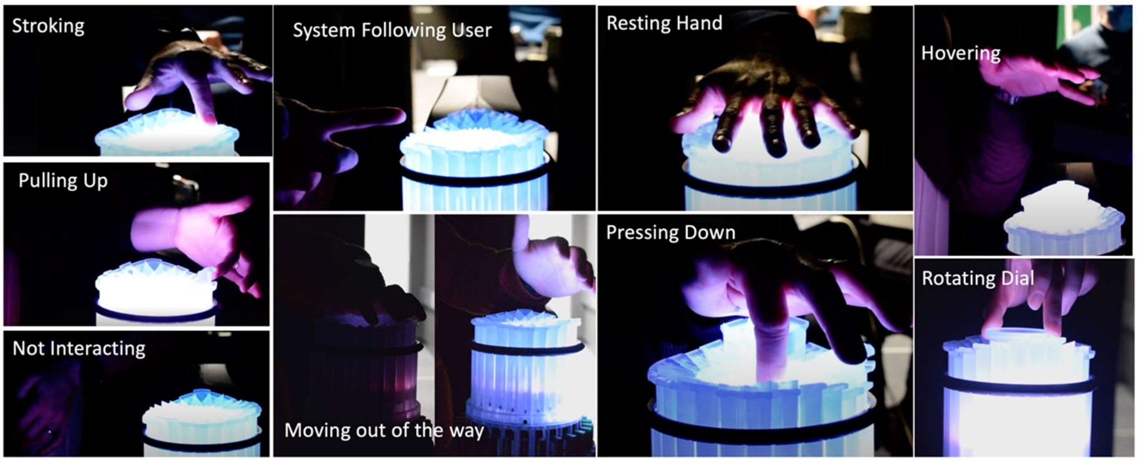

Figure 5 The 9 gestures used by the participants, showing the classified Interaction labels

4.1 G1: Resting Hand

This gesture was used the most as user left their hands on the system for long periods of time, as seen in Figure 6, however as shown in Table 1 and in Figure 7, it was the second most frequently used interaction gesture after G4, as G4 was a relatively quick press down gesture. All participants used the resting hand interaction. Participants rested their hands on the system after they understood its movement limitations, whereby the system would not jump higher or faster than a certain amount. They were then happy to “feel” the system, and its movement and flow of information, some expressing how it felt like a “hand massage” P11 or how it was “relaxing” P04. Due to this, it was the longest-used gesture as seen in Figure 6.

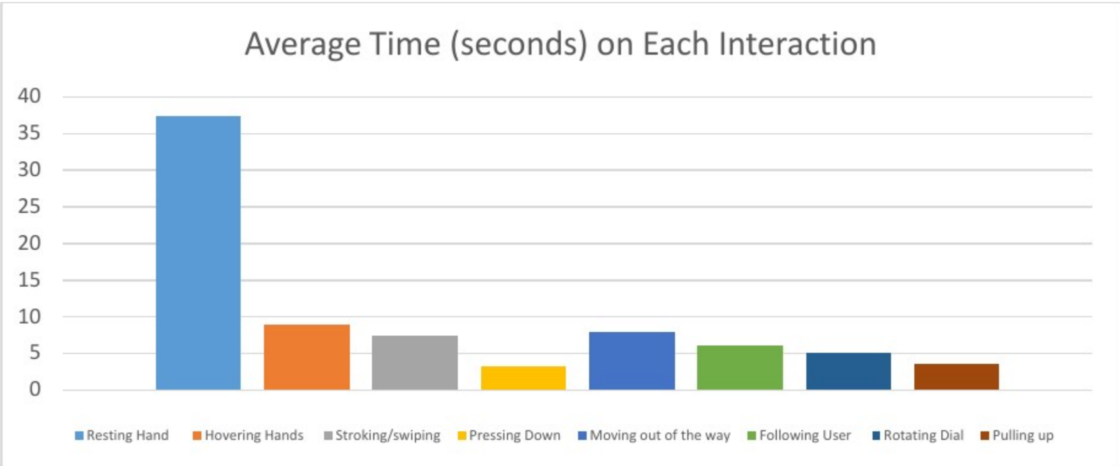

Figure 6 Graph showing how long in seconds, on average, each interaction took

4.2 G2: Hovering Hands

In the instances where users were unsure of touching or exploring the physical system, it was determined that they were unsure of the system's capabilities. This hesitation normally followed an instance of the system moving. This gesture happened significantly as seen in Figure 7, due to the prototype moving significantly and frequently throughout the experiment.

4.3 G3: Stroking

Some users stroked the shards and identified that they responded to them stroking them. One described it like petting a "*dog*" P02, while others likened the system to a variety of "*creatures*", ranging from "*alien*" to "*sea creature*". However, they did not use their full hand when interacting with the system, preferring to utilize their fingers, giving the reason that the system felt "*sharp*", and they thought it could cut them or "*take their finger*" P04. Therefore, this interaction was observed to be slow with a light touch skimming the surface of the prototype tool.

4.4 G4: Pressing Down

The most common and frequent interaction as seen in Figure 7 was the press of the central dial, also illustrated in Figure 5, with the use of one or many fingers.

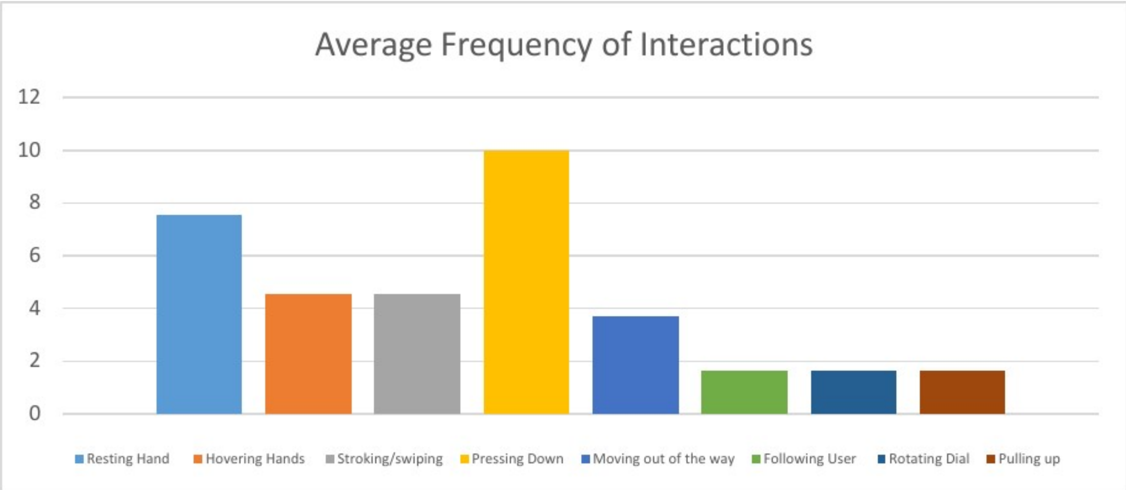

Figure 7 Graph showing the average frequency of interactions (count).

4.5 G5: Moving out of the way

Many participants moved their hands out of the way from the system to observe what was happening, as they did not understand the system fully and what it was trying to achieve.

4.6 G6: System following user

Other participants placed their fingers near the system, causing the system to react and move in the direction of their finger. In one case, the participant then gestured and waved his hand over the system, causing the system to wave with the same frequency as the participant as seen in Figure 5, which amazed the user.

4.7 G7: Rotating dial

Almost all participants attempted to use the central part as a dial, as it looked like one and is a typical interaction in many cars. They realized they couldn't turn it, so they pushed down on it. It was infrequent that the participant would pull up on the system.

4.8 G8: Pulling up

As part of the original intent, it was extremely rare for participants to pull upwards on the shards. Participants reported it was not apparent for them to do so. In addition, the very few that did felt like they were breaking the system as it showed a level of resistance.

4.9 G9: Not interacting with the system

Other participants rested their hands away from the system, watched it, and reported it was calming and pleasant to watch.

5 Findings

As the project was an explorative investigation of how users interacted with an intelligent system within a car, the findings did agree in most parts with previous research, however due to the context and the specific application some novel findings were recorded from both the gestural observations and the qualitative investigations. The findings highlight recommendations to improve user to machine relationship bonding beyond voice or screen technologies.

5.1 Tangible Interactions

Users were not ready to interact with a mechanical object due to its novelty in the first instance. They had no vocabulary and language understanding of interaction with tools like the prototype tool used. Users reported that their perception of the tool was not "*like using a mouse or using an iPad you know you flick, or you drag, and that's what I think I was anticipating, I didn't realize it was going to be so mechanica*l" (P11). This view explains how it took several minutes for almost all participants to interact with the system physically. Once users had spent some time with the system, they did feel compelled to interact with it more. They attributed this need to physically interact with it due to its movement, "*you want to interact with it because you see this surface moving*" (P07), and "*its moving makes you want to play with it… I still feel like you need some physical interaction with it because of its movement… kind of felt safe to touch it.*" (P02). Where if it were designed with no movement, it would be more appropriate for a non-interactive system, "*I feel like it should be represented differently if you weren't going to interact with it because there are moving parts*" (P02) and this could be switched on and off based on context and circumstances as discussed in the understanding chapter, e.g. "*I don't want something moving all the time when I'm trying to relax*" (P02). This shows that the amount and type of movement could have the opposite effect by reducing interactions, as users have reported in some instances that they didn't want to interfere or intervene with the system. "*It doesn't feel like there's something to press because it's so interactive, and it's going in ripples that I'm just letting it do its ripples. They don't feel like switches because there's so much interaction*." (P08) and "*I felt like it was sort of thinking or like processing information or doing something, and then it was steady. I felt like that was the time in which I could then interact with it.*" (P02). In addition, the type of movement could give the wrong impression, as in the example, "*I think you want to touch it, and it's pushing you back.*" (P07).

A two-way physical engagement was observed between the system and humans, where physical interaction from participants was used to elicit a reaction back from the system. P04 was observed to have removed his hand, placing it on his lap, while the system was still moving. Once the system switched off, the user then placed his hand immediately back onto the device to get it to react again. Other users explored if the system recognized their physical movements and the position of their hands and fingers. P05 hovered his hand over the system to see if it followed his hand, and P08 waved his hand around the system as the system followed his hand.

5.2 Physical AI system design

All participants were taken back by the design and presence of the system; "*I've never seen a feature like this before, interested in the capability of it*" (P01), and "*I'm just intrigued… it looked pretty, that was a nice thing*" (P03). Another participant said "*it was aesthetically very interesting … if it were a work of art sitting in a room I'd quite happily watch*" (P06), and another, "*Whoa look at this! the fact that it had either woken up or oh my goodness…This is amazing…blows your mind… it looks like it means business*" (P08), and "*Looks really cool*" (P11). After they took some time to digest what they were seeing, they mentioned that the system was quite approachable, "*it seems quite friendly on approach like you know it seems quite elegant quite approachable it doesn't seem too scary. Which is obviously quite a thing*" (P02).

Many participants associated the system's design with a living organism and were quite convinced of this fact, "*If I didn't see all of this and I didn't see you behind me, I could quite happily be convinced it was alive*" (P06). They gave the system an extensive range of example similarities as, "*This thing is alive!*" (P07), "*it's like an organ… it was like a heart… is a sensory receptor*" (P08), "*it has a sense of being alive…it shows quite humanistic qualities…like a child who's babbling away…It's the butler…it's every animal like it's like an intelligent dog…intelligence from an alien planet…an octopus on the beach… like a jellyfish*" (P06).

6 Discussion

In this section, we discuss the meanings of the findings, limitations and future work of the study.

6.1 Impacts of mechanical and light movements:

The two types of movements that were identified were mechanical and light-based movements. Both created the senses of intelligence, emotions, lifelikeness, and engagement. However, they both had different roles. Physical movement and movement using light in an in-car intelligent embodiment was noted to have affected the perceived intelligence of the system, as it introduced a dimension of emotions to the system in an abstract sense. This perceived emotional communication gave the digital system the ability to appear living, which ultimately offers users the humanistic pull to interact with the system. It was the key driving factor for users to want to spend time with a new system and learn how to communicate with it, ultimately leading to the user 'bonding' with the machine.

Mechanical movement should be used less frequently as excessive movement can cause extra confusion and reduces the impact of information importance. What can also be added is well-designed physical animations improve physical engagement. Light movements have a more effortless ability to communicate abstract states, such as thinking, process and doing. This balance and design strategy of when to use mechanical and light-based movements will enhance engagement and improve users' understanding and interaction language, as it will be more apparent when to interact and when not to.

6.2 The future design and interaction should be based around familiarity and ergonomics:

For future studies, the design of new prototype research tools must include the evolution of what is familiar to users. This can be taken from traditional interaction objects found in cars. This ultimately boils down to familiarity, which tools are users most familiar with. As we observed from the study, users turned the center large plunger into a dial and pulling upwards was not used as frequently as the pushing "buttons" interaction choice. In addition, better ergonomic and tactility materials are required for future research tool prototyping. This includes making the material choices warmer and more welcoming in feeling. The system parts need to be softer and shaped more ergonomically.

6.3 Importance of Understandability:

The biggest issue with the system was the user's lack of understanding of what the system was doing and how it was doing it. This was the ultimate cause of frustration seen and made people feel 'stupid'. One of the concepts that will be added to future studies is for the system to give clear and simple feedback to the user after an interaction. However, more research is needed about what kind of feedback should be given to users and how much detail and information should be used.

6.4 How beauty and novelty can momentarily trump the need for understandability:

This study showed how the novelty and beauty of the prototype tool were enough to engage the participants even though there was almost no understanding of what was happening. This created a sense of AI embodiment linked to a car and became its 'soul', and this fascination took precedent in this experiment. An additional step was to ensure that the system could track a user's hand to improve its perceived intelligence. This will allow for a further investigation into the human-to-machine relationship for both parties to learn from each other.

7 Conclusion

In-car smart systems or AI systems that require user interactions are likely to encourage user engagement and are vital for long-term system training. The use of physical embodiment and physical hand interaction can enhance this requirement with users. A lot more subtle and nuanced information can be communicated using physical and light-based movements. More research should investigate this physical interaction modality and not only focus on on-screen and voice interactions. Building back character for every individual car may maintain the traditional desirable attribute of users loving and bonding with their cars for years, improving sustainability and reducing the throwaway culture.

ACKNOWLEDGMENTS

This study is part of a funded PHD by Bentley Motors.

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