Gesturing on the Steering Wheel: a User-elicited taxonomy

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ABSTRACT

"Eyes on the road, hands on the wheel" is a crucial principle to be taken into account designing interactions for current in-vehicle interfaces. Gesture interaction is a promising modality that can be implemented following this principle in order to reduce driver distraction and increase safety. We present the results of a user elicitation for gestures performed on the surface of the steering wheel. We asked to 40 participants to elicit 6 gestures, for a total of 240 gestures. Based on the results of this experience, we derived a taxonomy of gestures performed on the steering wheel. The analysis of the results offers useful suggestions for the design of in-vehicle gestural interfaces based on this approach.

Author Keywords

Design; human factors; gestural interaction.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Gestural interaction is considered as a natural interaction means to communicate with computer because it exploits our natural ability to communicate through gestures. Nevertheless, some gestural interfaces have been proven to be rather unnatural [12] because in some contexts the usage of gestures for Human-Computer Interaction (HCI) was unfamiliar to the user. Jacob et al. [6] introduced the concept of Reality-Based Interaction, which suggested that interfaces should use concepts derived from elements of the reality to create more natural interfaces. Recently, Jetter et al. [7] advanced Jacobs et al.'s idea: during digital interaction, users often blend concepts also from other digital systems with which they are already acquainted. In other words, existing systems are part of the reality and often metaphors and associations are constructed also according to this previous knowledge. Indeed, many users prefer to have consistency between interfaces, with similar physical and digital interfaces, functions, designs and gestures, across different devices. The broad diffusion of touchscreen devices has brought new habits for digital interaction and may suggest that users can prefer using gestures typical of these devices even for very different interfaces such as a touch sensitive steering wheel.

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Gestural interaction is raising interest also in the design of in-vehicle interfaces, because they are able to reduce the visual and cognitive load of the driver [16]. In particular, gestures performed on the steering wheel aim also at increasing safety by complying with the paradigm "eyes on the road, hands on the wheel" [5]. A taxonomy of gestures that could be performed while grasping the steering wheel has already been presented by Wolf et al. [19]. While in Wolf et al.'s work only experts elicited gestures mainly considering ergonomics factors, in this paper we would rather elicit gestures through young users. In particular, the user elicitation presented in this paper aims at understanding the influence of popular interfaces, such as those of touch devices, on the user expectation about novel interfaces, such as an interface integrated in the steering wheel based on touch and pressure sensing technologies. Other outcomes of this study consist of understanding the impact of the semantic meaning of the command on the way the gesture is performed and the impact of safety concerns on gesture types, for example if both hands are maintained on the steering wheel while gesturing.

The rest of the paper is structured as follows. Section 2 analyzes existing systems that used gestures on the steering wheel, along with previous gesture elicitation studies. Section 3 describes the methodology of our gesture elicitation experiment and Section 4 presents the results of the gesture elicitation. Section 5 presents the derived taxonomy and discusses the obtained results and the limitations of the study. Finally, we conclude the paper resuming the contributions of this study and presenting expected future work in this field.

RELATED WORK

In 2007, for the first time, González et al. introduced the paradigm "eyes on the road, hands on the wheel" [5]. This paradigm is particularly interesting to increase safety of in-vehicle interfaces; therefore, we will analyze related work according to these two axes: "eyes on the road" and "hands on the steering wheel". Table 1 resumes how existing in-vehicle gestural interfaces have been designed in terms of gesture types, and localization of inputs and outputs. It is worth noting that also other design parameters can affect the driver performance and safety, thus the comparison in Table 1 cannot be used to identify the safest approach among state of the art gestural interfaces.

Previous works have chosen different locations inside the vehicle on which to perform gestures. Many systems explored gestures performed on the steering wheel, either on its surface [1,5,8], in the surrounding space [4] or on a central touchscreen [3,13]. These gestures are performed either while firmly holding the steering wheel [1,3,5,8], or after shifting the hand position [8,13]; touch gestures are often performed also on touchscreens integrated in the dashboard [2] and, finally, some gestures are performed in mid-air [14]. Riener and Wintersberger explored also gestures holding the gear stick [15].

Different types of feedback have also been explored in combination with gestures. When touchscreens are used as gesture input, there is quite often a visual feedback on it, although eyes-free gestures on touch-screens can be facilitated by providing also auditory feedback [2]. For mid-air gestures recognized by a Kinect, Rahman et al. exploited both auditory and tactile feedback [14]. Auditory feedback has been explored also by Angelini et al. [1]. Another common approach for "eyes on the road" gestures is providing visual feedback with a Head-Up Display (HUD) [4,8]. HUDs are easy to be integrated into simulated environments but they are also populating many modern cars. Special techniques have been developed to avoid sight refocusing when looking at the projected information.

The types of gestures recognized in existing works in the literature are also quite various. Because of the limited scope of this paper, we will discuss in this section only related work that adopted gestures performed on the surface of the steering wheel. Gestures performed in air such as some of those described in Wolf et al. taxonomy [19] or those recognized by the Geremin system [4] will not be considered in this paper. Nomenclature of surface gestures is often not consistent throughout literature. Indeed, taxonomy of touch gestures for surface computing often differentiates swipe, flick, drag and pan, according to the speed of the movement or the behavior of the GUI. For the sake of simplicity, in this paper all gestures that imply a unidirectional movement on the surface will be considered as "swipes". We will call "strokes" the multidirectional movements and "hands drags" the whole-hand movements around the surface of the steering wheel performed by twisting the wrist as for the "drag fingers around the wheel" gesture defined by Wolf et al. [19]. Moreover, similarly to Wolf et al. [19], in this paper we distinguish between tap and press gestures whether the contact is short or long, respectively. Differently from Wolf et al. [19], we will also consider tap and press gestures performed with the whole hand. Finally, pinch and squeeze are further distinguished from the hand press, according if the hand is grasping the wheel or not. In particular a squeeze is performed also with the palm, while a pinch applies pressure only with fingers.

System or Study	**Eyes on the road (Feedback)**	**Hands on the wheel (Gesture locations)**	**Gesture types**
EdgeWrite, González et al. [5]	++ (Head-up display)	++ (Small pads on the steering wheel)	Thumb strokes on the small pads (while grasping)
WheelSense, Angelini et al. [1]	++ (auditory feedback)	++ "10:10" hand position grasps on the steering wheel	Gestures while grasping: index tap, hand drags, squeeze.
Geremin, Endres et al.[4]	- Feedback behind the wheel or in the dashboard	++ Steering wheel grasp	Index mid-air strokes while grasping
Döring et al.[3]	- (feedback inside the steering wheel)	++ Center of the steering wheel with thumbs	Thumb-swipes while grasping
Bach et al.[2]	+ (auditory but also visual feedback on the dashboard)	- Horizontal touchscreen on the dashboard	Index swipes / double-tap.
Rahman et al.[14]	++ (haptic and auditory feedback)	-- Mid-air	Free-hand mid-air strokes
SpeeT, Pfleging et al.[13]	++ (eyes-free gestures)	- Center of the steering wheel (touch screen)	Index Swipe-Scroll for direct manipulation
Koyama et al.[8]	++ (Head-Up Display)	+ Steering wheel grasp and surface	Hand/thumb swipe, hand/index tap, hand drag
Riener and Wintersberger [15]	-- Screen in the dashboard	-- Gearshift	Index mid-air pointing (while grasping)
Riener et al.[17] (User elicitation)	++ (eyes-free gestures)	-- Mid-air	Free-hand mid-air strokes
Wolf et al. [19] (Taxonomy)	++ (eyes-free gestures)	++ Steering wheel grasp	Fingers tap and swipes, hand drags, mid-air finger strokes (while grasping)

Table 1. Comparison of in-vehicle gestural interfaces

Among the 17 gestures elicited by experts in Wolf et al. taxonomy [19], 2 of them have been adopted by both Angelini et al. [1] and Koyama et al. [8], namely hand drag and index tap. The thumb swipe of Koyama et al. [8] (called "flick" in their nomenclature) was not elicited by experts in Wolf et al. [19], although a similar gesture of "dragging the thumb around the steering wheel" was present. Gestures that imply whole-hand pressure such as squeeze and hand press ("push" in their nomenclature) [1] were not considered in Wolf et al. taxonomy, although single finger pressures were included. Gestures that require leaving the hand from the steering wheel such as "hand swipe" and "hand tap" [8] were not included, because the experts were asked to elicit only gestures that can be performed with a palm grasp.

Many of the systems found in literature have been designed following a technology-driven approach for the gesture design. Including end-users in the design phase of gestures can bring benefits in terms of guessability of the adopted gestures, as demonstrated by Wobbrock et al. [18] for a tabletop touch interface. Indeed, Morris et al. [11] stated that user-elicited gestures are generally preferred because they are easier to perform and understand, especially if gestures were performed with one hand or one finger. Lahey et al. [9] conducted a user elicitation for bending gestures on a flexible phone. The particularity of this study was the approach for the elicitation, based on gesture pairs, i.e., users had to define symmetric gestures for specular actions in the interfaces. We adopted a similar approach for the first group of our gesture elicitation. A recent user elicitation has been conducted by Valdes et al. [20] for gestures with active tokens. In their study, they noticed a strong influence of the user habits with mobile touch devices in the gesture elicited for the active tokens. Our hypothesis is that similar evidence can be found with gestures performed on a steering wheel.

In the domain of in-vehicle gestural interfaces, only few user elicitations have been conducted. Pfleging et al. [13] investigated touchscreen gestures for the control of different elements of the vehicle, which were selected by voice commands. The study showed that the 78% of the gestures were 4 simple directional swipes. Recently Riener et al. [17] conducted a user elicitation for hand gestures performed in mid-air. Interestingly, there were few consistencies among the gestures performed by the different participants, except for the most frequent locations and the hand used for the gestures (mostly the right hand).

Within this context, our study aims at providing additional information about possible gestures that users are likely to perform in the car, specifically, on the whole surface of the steering wheel.

Figure 1. Setup for the pre-elicitation phase.

METHODOLOGY

Elicitation setup

In a pre-elicitation phase, all the users participated to an experience where they had to drive for about 30 minutes in a simulated environment. The setup was composed of a driving simulator running in a three-monitor configuration and a Logitech G27 steering wheel (see Figure 1). During this phase, participants were asked to perform several interactions with a responsive In-Vehicle Information System (IVIS): handling the music (select songs and regulating the volume), traffic alerts, incoming calls, etc. We separated the participants in two groups. Group 1 interacted with an IVIS based on vocal interaction and a HUD. Group 2 interacted with a touch dashboard with UI buttons. Both interfaces implemented a similar menu-based structure. In both interfaces, the current item was in the center of the screen, next and previous items were respectively on the right and on the left of the current item and volume information was displayed just over the current item.

For the elicitation phase, participants were instructed through a video and were asked to elicit gestures in a given time (30 seconds for each gesture) while thinking aloud. Participants were recorded with two cameras (see Figure 2) and two people annotated the elicited gestures, according to the gesture definitions mentioned in the previous section.

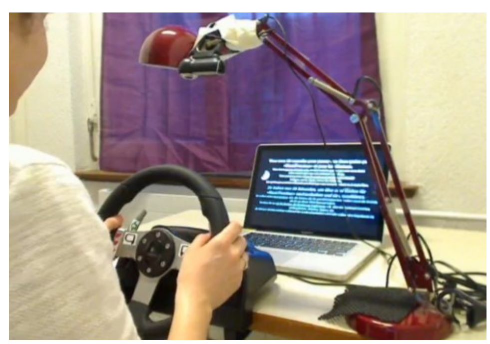

Figure 2. Setup of the gesture elicitation seen from the second camera.

Participants were sitting in front of a Logitech G27 steering wheel; a laptop was used to show the instruction video. Since our study aims at analyzing gestures on the steering wheel, we fixed some constraints to the interaction. Only gestures that implied contact with the steering wheel, including the external ring and the spokes, were allowed (either implying pressure, movements of the fingers or of the hands). On the contrary, the usage of paddles and buttons as well as mid-air gestures was forbidden. In order to allow the participants to focus only on gestures, the elicitation study was not conducted while driving. In this manner, participants had more cognitive resources at their disposal for the gesture elicitation.

Group 1 was asked to elicit gestures for three given pairs of commands of a menu-based interface in a HUD. The command pairs were: select/back, next/previous, volume up/volume down. The same command set was used in the vocal interface during the pre-elicitation phase.

In contrast, the second group was asked to elicit 6 gestures with no predefined commands associated and the participants had to define the system behavior (the associated commands) for each gesture. This second approach was chosen to give more freedom to the users for the definition of gestures. By dividing participants in these two groups, we aimed at investigating whether specific assigned functions have an impact on the elicited gestures or not.

Participants

40 participants, 34 females and 6 males, aged 19-38 (average 22, SD: 3.3) composed the population of the study. All the participants have a driving license and previous experience in interacting with touch interfaces such as smartphones or tablets. 87.5% of our participants were right-handed.

RESULTS

Gesture locations

The steering wheel has been divided in 44 zones and unfolded in Figure 3 to show in a planar view also the posterior and lateral zones. Zones have been defined through the visual and tactile cues that the Logitech G27 offered to the users. It is worth noting that a gesture may be performed on more than one zone: in this case all the touched zones for that gesture have been counted for the generation of a heat-map. In Figure 4, we present the heat-maps obtained for the gestures elicited by Group 1 and Group 2. The two heat-maps show that few zones of the steering wheel are left untouched, especially for Group 2, where only one zone was left untouched. Both left and right spokes have been used for more than 10 gestures for each group. The heat-map of Group 1 is more symmetric, probably because we asked for pairs of specular commands. Group 2 participants, who were free to define their own commands, performed more gestures on the right side than on the left side, probably because most of them were right-handed. The preferred side of the steering wheel for Group 2 was the front side with 86 occurrences (without spokes), followed by the external side (65 occurrences), while the Group 1 preferred the external side (74 occurrences) over the front side (44 occurrences, without spokes). It is worth noting that in order to reach some locations, users had to temporarily detach the hand from the steering wheel, which was quite natural for some participants, while others

Figure 3. Steering wheel unfolded to show the four sides and divided into 44 zones

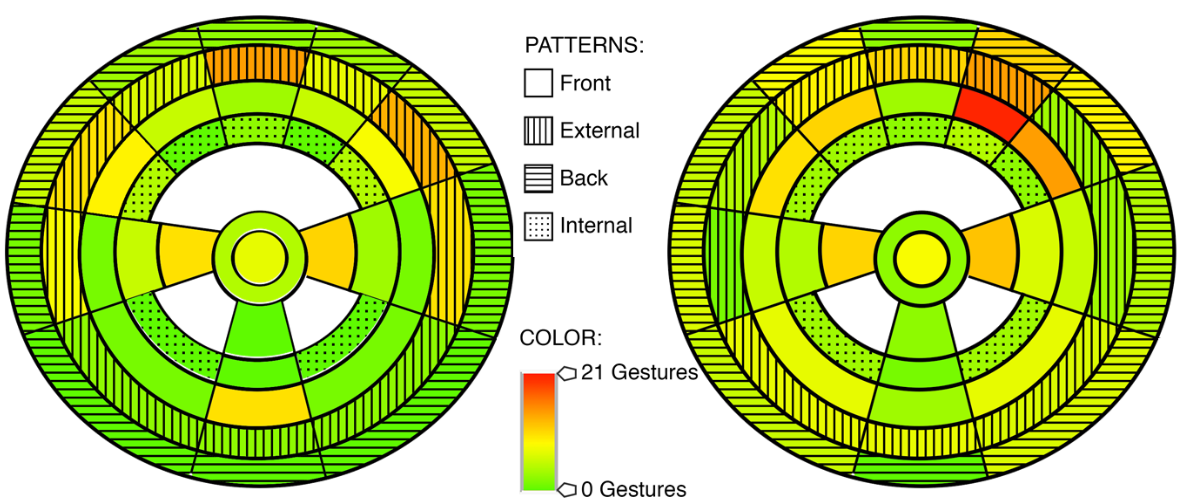

Figure 4. Heat-maps for gesture locations for Group 1 (left) and Group 2 (right).

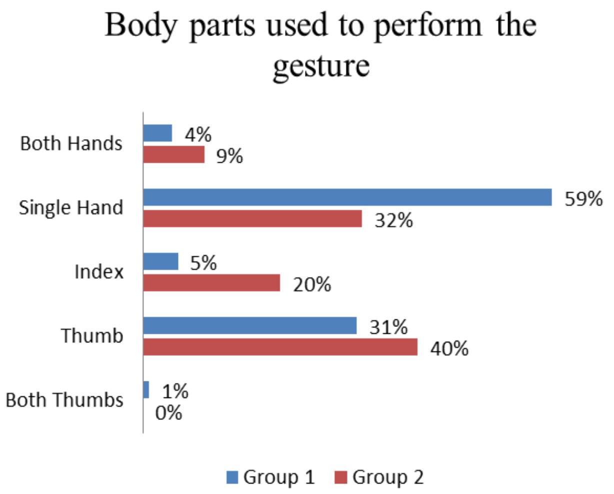

Figure 6. The bar chart summarizes the proportion of the body parts used by the participants to perform the various gestures.

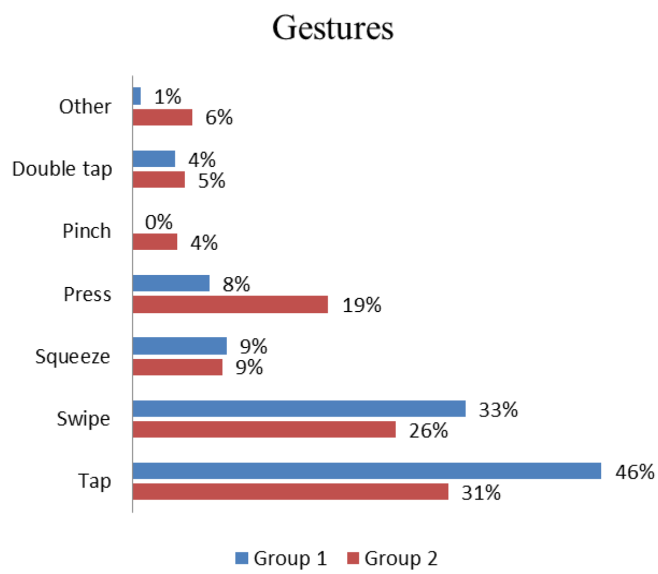

Figure 5. The bar chart summarizes the gesture adopted by the participants

preferred to focus on zones next to the normal holding position for security concerns.

Gesture types

In this section, we present the analysis of body parts and gesture types chosen by the participants during the elicitation.

There is no significant difference between the two groups for the body parts used to perform the gesture on the steering wheel. Figure 5 shows a clear preference in both groups for gestures performed with a single hand and the thumb. This result could suggest that the preferred part of the body for performing gestures does not depend on the associated function. However, between the two groups there is a statistically significant difference between gestures performed with "single hand" and "index" (considering a 95% confidence interval). Indeed, single hand gestures have been chosen by the first group 27±12% more often than the second group. Conversely, there is an opposite trend for gestures performed with the index finger. This probably means that gestures performed with the single hand were more suitable for the proposed command set (select/back, next/previous and volume up/volume down). Furthermore, we report that, in average, each participant tended to use a limited number of different body parts for all the gestures. In particular, participants in Group 1 used 1.65±0.13 body parts while members of Group 2 used 2.4±0.15 body parts. The difference in terms of different adopted body parts can be explained by a larger freedom in the choice of gestures for Group 2.

The analysis of gesture types (Figure 6) reveals that the two groups have a similar trend with an evident preference for the "tap" and "swipe" gestures (especially in Group 1). As already seen in the analysis of body parts, the gestures not related to a specific command set, performed by Group 2, show a larger variability among gestures, with more occurrences in the class "other". This empirical observation is statistically confirmed: the members of Group 1 completed the task using in average 2.45±0.15 gestures while member of Group 2 (without a command set to take into account) used a more varied set of gestures resulting in 3.3±0.23 gestures proposed per participants. Furthermore, there is a statistically significant difference between the two groups for the adoption of the "tap" and the "press" gestures.

In order to understand if the different assigned commands can influence the chosen body parts or gesture types, we analyzed more in depth the gestures elicited by Group 1. Since the collected data are not enough to perform a chi-square analysis (the sample size condition is not verified), we used an inference via simulation approach for proportion, comparing the results of the simulation with the data actually collected to see if there were statistically significant differences (with a significance level, α=5%).

The first evident result is that "symmetric" commands implied symmetric gestures, i.e., the paired gestures select/back, next/previous and volume up/volume down resulted having almost identical (pairwise) results for the chosen body parts and gesture types (Figure 7 and Figure 8).

The analysis of Figure 7 shows that the choice of the body part used to perform the gesture is almost unrelated to the associated command. The users showed a constant preference for gestures performed with a single hand, followed by gestures performed with the thumb. Other body

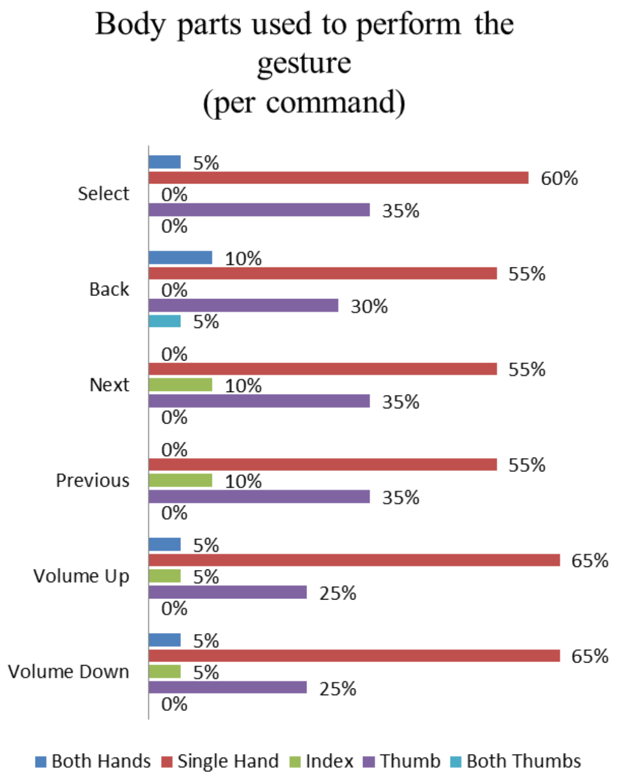

Figure 8. Body parts used to perform the gestures in relationship with the asked command set

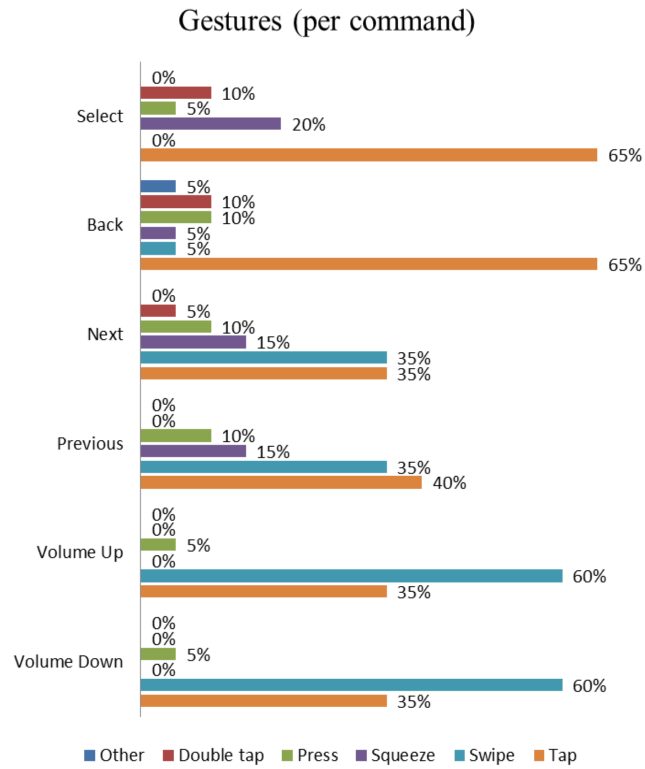

Figure 7. Gestures proposed by the participants in relationship with the asked command set

parts (both hands, index, both thumbs) were less employed by the users.

On the contrary, the choice of gesture type resulted strongly related to the associated command. The adoption of "swipe" significantly changed among the different commands: it was almost not used for the select/back commands, has been used often for next/previous commands, and much more appreciated for volume up/volume down commands (60% of these commands were performed as a "swipe" gesture). On the contrary, the "tap" gesture was appreciated for the select/back commands (65% of preferences), decreasing to around 35% for the other commands.

Finally, in order to understand how many users were concerned by safety, we considered the number of gestures proposed by the participants that were performed holding firmly the steering wheel against the gestures that required the participants to leave one hand from the correct driving position. Only 41% of the gestures proposed by Group 1 were performed in the holding position, against the 54% of Group 2. This is coherent with the previous results; in fact, in the first group there is a higher use of gestures performed with the whole hand, which typically required shifting or temporarily removing the hand from the correct driving position.

Spatial references

The function associated to a gesture is clearly linked in our dataset to a spatial reference in the gesture execution. Indeed, 100% of users have used the right hand, the right part of the steering wheel or gestures towards the right to perform the gesture associated to the "Next" command. Conversely, the "Previous" command is associated to movements to the left or gestures on the left side of the steering wheel. We measured very similar results with the "Volume Up" and the "Volume Down" gestures and the related parts of the steering wheel or direction of the gesture ("Volume Up": 92.9% in the top part of the steering wheel or in the up direction. "Volume Down": 95.2% in the bottom part of the steering wheel or in the down direction). While the spatial reference for next and previous commands can be easily linked to the behavior of the menu in the head-up display, "Volume Up" and "Volume Down" spatial references can find their roots in the behavior of most common interfaces, as well as in the name of the command. Interestingly, comparing only the left and right components of the interaction, we noticed also that "Volume Up" gestures are performed for the 86.6% in the right part of the steering wheel and the 71.4% of the "Volume Down" gestures are in the left part of the steering wheel, showing a strong correlation between up and right, and down and left.

GESTURE TAXONOMY

In order to derive a taxonomy of user elicited gestures on the steering wheel, we collected the most popular gestures elicited by the two groups. By summarizing the previous analysis, it is possible to classify gestures according to the body parts used to perform the gesture and the gesture type. Figure 9 shows the most popular gestures and their occurrences classified according to our taxonomy. Three macro-categories can be identified: tapping, swiping and applying pressure. We excluded from the taxonomy less popular gestures, i.e., gestures with less than 4 occurrences. It is worth noting that gestures presented in Figure 9 can be executed in different zones of the steering wheel, either on the external ring or on the spokes. The location where these gestures can be effectuated is likely to depend on the type of command associated and/or how feedback is displayed. Moreover, some gestures of Figure 9 can be performed either while firmly holding the steering wheel or releasing the hand from it, depending on if the gesture will be performed next to the driver's hands position or not (e.g., index tap, thumb tap or hand squeeze).

DISCUSSION

Observing people during gestural elicitation, we found different behaviors among users. Some people were concerned about safety and were looking for gestures to perform without releasing the hand from the steering wheel. Other people, instead, were looking for very simple gestures and were not concerned by this safety issue. In few cases, gestures even required leaving both hands from the steering wheel, such as, both-hand swipes, or both-hand squeezes in particular locations. While these gestures could seem particular unsafe to be performed while driving in current vehicles, semiautonomous cars of the future could allow for such "unsafe" but simple gestures when the car is undertaking the driving task from the user.

Furthermore, we noticed an important correlation between the gesture location and visual cues on the steering wheel. The spokes but also the center of the G27 Logitech steering wheel offered both tactile and visual cues that stimulated in few cases particular gestures, such as circling around the central bezel. Moreover, since the G27 steering wheel has a small diameter (27cm), some participants tried to reach the center without leaving the hand from the correct holding position. An obvious implication of these observations is that an appropriate design of the steering wheel could be used to enhance safety for in-vehicle gestural interaction.

The think aloud protocol used during the elicitation study revealed that most gestures have been suggested just because they seemed intuitive and easy to perform, similarly to what Morris et al. found out [11]. Nevertheless, four users explicated that they performed gestures similar to those of smartphones or tablets. Another participant, proposed tap gestures to replicate the same interface of a common MP3 player (iPod). This insight confirms Valdes et al.'s user elicitation results [20] and Jetter et al.'s [7]

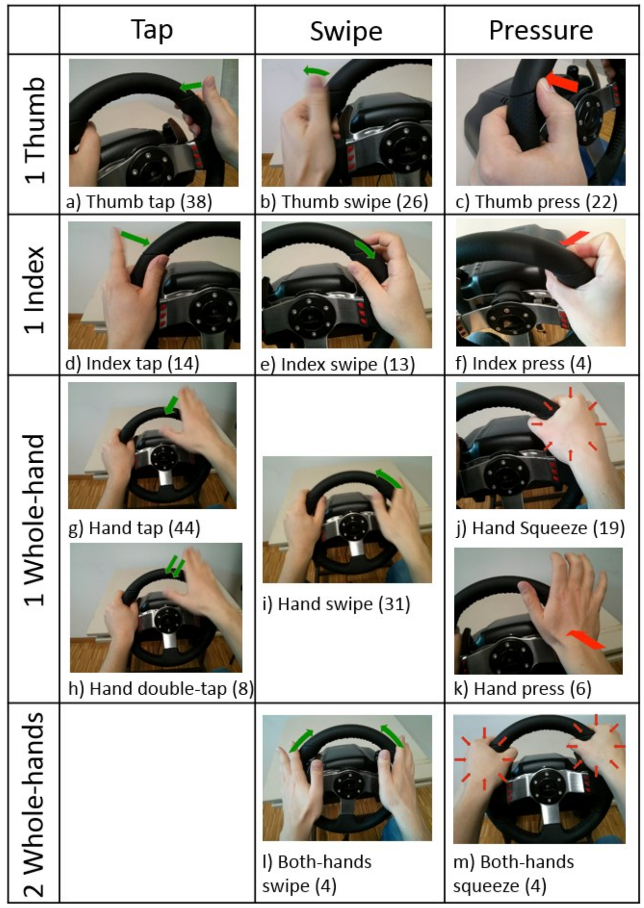

Figure 9. Taxonomy of gestures on the steering wheel

blended interaction theory, where the knowledge about existing interfaces can have a strong influence on the expected behavior of new interfaces. Another insight obtained from the think aloud protocol is the users' need of direct manipulation gestures. Indeed, for commands like controlling the volume, several participants proposed the possibility to fine-tune the volume with one gesture, instead of doing it with repeated commands. This means that some of the gestures that in our taxonomy we classified as swipes are actually more controlled "drags" that require a higher sensor resolution in order to be accurately recognized. Manipulation gestures have been elicited by the participants of Pfleging et al.'s study [13].

Limitations

We are aware of some limitations of our study. First, users elicited gestures in front of a steering wheel but not while driving. This could have lowered the awareness that some gestures could be dangerous to be performed during the drive, because many of them require leaving one or both hands from the steering wheel. Nevertheless, users participated to a preliminary experience where they had to drive for about 30 minutes and they had also to interact with the IVIS at the same time. This pre-elicitation experience should have mitigated the fact that there was no feedback during the gesture elicitation. The absence of feedback could have an impact on the way gestures have been performed, especially if feedback is directly coupled to the gesture, such as feedback displayed on a smartphone when scrolling a list of items. For example, all participants in Group 1 swiped from left to right to go to the next song (displayed in the Head-Up Display of the pre-elicitation phase on the right side), while a participant of Group 2 proposed opposite directions for a similar command, namely, to simulate the aforementioned behavior of a touchscreen device.

CONCLUSION

This paper presented a user elicitation study for gestures performed on the surface of the steering wheel. The study provided useful information about gestures that users are likely to expect in an in-vehicle gestural interface. This information could help in the design of steering wheels that are able to detect gestures on its surface. Thus, technologies based on proximity, capacitive or pressure sensors can be used to provide an interaction compliant with the "eyes on the road, hands on the wheel" paradigm, if coupled with a proper feedback such as a HUD. Nevertheless, the study showed that some of the most popular gestures were performed releasing one hand from the steering wheel, without worrying about safety risk.

As future work, we will implement a system based on gestures elicited by Group 1 and we will assess if the designed gestures are easy to perform and to understand by other users. We will also assess if gestures performed by releasing one hand from the steering wheel can have an impact on the driving performance.

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