Determining Human-Centered Parameters of Ergonomic Micro-Gesture Interaction for Drivers Using the Theater Approach

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ABSTRACT

In this paper, we describe a technique to determine user preferences concerning in-car micro-gesture interaction. The approach is derived from the theater technique [1], and implies a collaborative adjustment of parameters with the experimenter, until the subject has decided about the final settings. We evaluated three systematically selected gestures (*zooming*, *sweeping,* and *circling*) for controlling four exemplary comfort functions of the car (window lifter, air condition, radio volume, and seat heating). The main result of our study is the geometry of a "sweet spot" for micro-gesture recognition close to the steering wheel, which is independent from the underlying technical recognition approach. Additionally, preferred sizes, angles, and pause times for the investigated gestures are provided. We give an indication, which of the gestures is preferred by the users (the *sweeping* gesture). Finally, we provide a more detailed view on the interaction between gesture preferences and function.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Theory and methods, Input devices and strategies*

H1.2 **[Models and Principles]**: User/Machine Systems – *Human factors*

General Terms

Algorithms, Measurement, Performance, Design, Reliability, Experimentation, Human Factors

Keywords

Micro-Gestures, Contact-Free, Modality, Parameters, Usability, Ergonomics, Theater Approach, Steering Wheel, Driving.

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1. INTRODUCTION

During the last decades, the awareness regarding safe driver interfaces has constantly been increasing. With the rising number of functions integrated, traditional knob-based interaction has been enriched with more and more complex displays (sometimes touch screens), with speech interaction, and with tactile feedback. The new technologies have been developed and integrated, in order to use the driver's cognitive capabilities as efficiently as possible. Aiming at further improvement for the driver interacting with the car, several car manufactures are carrying out research on gesture recognition in collaboration with universities and research institutes [2]. Gestures represent a comfortable addition to existing interaction types, without the decline in recognition accuracy under noisy driving conditions that speech still suffers from [3]. Recently, several technologies for touch-free gesture recognition have been identified and gradually been improved: With vision-based systems, one or multiple cameras capture parts of the driver's body, mostly in the center-stack area. There are also a number of systems based on ultrasonic sound [4].

Our approach, called "Geremin", belongs to the category of capacitive systems detecting the presence of a human hand near a conductive object. In a number of studies, this technique has been proven to be unaffected by light and dynamic backgrounds (like the vision-based approach) while having fast response times [5]. The name is derived from the words "Gesture" and "Theremin" (an early capacitive musical instrument named after the Russian inventor Léon Theremin).

The study presented here, adds another piece to the "Geremin puzzle" by addressing the issues of the human-centered parameters. Please note, however, that the delivered insights on sizes, angles, and preferred gesture type are likewise useful for other technical micro-gesture recognition approaches. The only prerequisite that those other approaches need to share with ours is targeting "micro-gestures" – small, one-handed gestures by the driver, controlling the car's comfort functions (or doing other tertiary tasks), without the need to take the hand off the steering wheel.

2. THE THEATER APPROACH

With a user-centric design approach, it is beneficial to let the user actively participate early in the design process. For example, in a "Wizard of Oz" (WoOz) experiment, subjects interact with a computer system that they believe to be autonomous, but which is actually being operated or partially operated by an unseen experimenter (the “wizard”). A subject may think to be communicating with a computer using a speech interface, when the "wizard" in another room is secretly translating the participant’s words into regular computer commands. The Theater-system technique extends the WoOz technique in a way that the experimenter, the so-called "confederate", is visible to the subject. Subject and "confederate" play through different use cases, as if they would play a role in a theater. While the WoOz technique is used for the evaluation of functionality, the theater approach can be used both for evaluation and design. The theater-system technique was proposed by [1] for designing a haptic-multimodal interaction strategy for highly automated vehicles. We adopt the technique here, for determining the human-centered parameters for our proposed micro-gesture interface.

3. TECHNICAL IMPLEMENTATION OF MICROGESTURE RECOGNITION

The objective of the experiment described in this paper, was to specify parameters necessary for building an in-car micro-gesture recognition device. In order to provide a better understanding of the context, we shortly introduce our *Geremin* device here [5]. The empiric results presented, however, are generic in nature and are not depending on any specific, underlying recognition technology.

The *Geremin* is a recognizer for micro-gestures in an in-car environment – particularly for the driver. Its aim is to provide an additional modality to control (comfort) functions of the car, without the need for taking the eyes off the road or the hands off the wheel. It is based on electric field sensing and attached in close proximity to the right (and/or left) hand of the driver at the "2 o’clock" position (respectively “10 o’clock” position) of the steering wheel. *Geremin’s* ancient ancestor is an early electronic music instrument, invented and patented by Léon Theremin in the 1920ies. Like the “Theremin”, our system uses the combination of antenna and hand as a capacitor, and detects changes in the distance of the hand. However, it does not oscillate and generate sound, but directly converts changes in voltage into numbers to be transmitted via a USB interface. The resulting data is thereupon processed on the computer using state-of-the-art machine learning algorithms, e.g. Dynamic Time Warping (DTW), or most recently with custom developed geometric analysis methods. Furthermore, the *Geremin* is capable of using several antennae, i.e. three in the most recent prototype.

4. RELATED WORK

In addition to the assessment of micro-gesture settings and the proof of concept of a new technology, drivers’ acceptance of the new technology needs to be considered. Would micro-gestures be an accepted additional input modality? [3] compared a traditional 2D in-car interface with an innovative 3D Virtual Reality (VR) interface in a user study in order to evaluate performance and general acceptance. Both interfaces could be used with traditional controls (switches, buttons) as well as with gestures and speech commands. 15.5% of the users of the traditional interface and 11.6% of the VR users used interaction with hand gestures. Based on that study, we claim that gestures as input modality are a suitable extension of the standard in-car interaction. This is also supported by [6], who state, "a gesture interface is a viable alternative for completing secondary tasks in the car". According to [2], gestures are originally not self-revealing and therefore need explanation and visual reminders. At the same time, the authors acknowledge that providing visual reminders would necessarily neutralize any potential safety benefit. Nevertheless, [7] expects numerous automotive applications by 2020.

According to [2], three different application domains for mapping automotive hand gestures have been addressed:

1. Direct mapping of gestures to the complete functionality of in-vehicle devices (e.g. radio, CD, navigation system). Although this approach could lead to a very consistent interface, the authors conclude that too many gestures would be needed and thus many of them would not be natural.

2. Mapping to in-vehicle controls, mimicking each individual control type (push button switch, push and hold button switch, rotary position selector, etc.). This type is not recommended as well by [2], because creating natural mimic gestures for each control type has substantial limitations like transferability between different cars.

3. According to the authors, the third category, selective mapping to theme or function, "appears to have the most realistic practical possibilities". With this approach, a relatively small selection of gestures is mapped consistently to a (again relatively small) number of functions. [8] provides examples belonging to this category: a) waving-off incoming calls; b) using one's index finger with a clockwise/counterclockwise rotation to raise respectively lower the stereo volume. [9] proposes skipping between music titles, albums, radio stations or enabling/disabling audio sources.

As indicated above, we envision testing the selective mapping of a limited set of "micro-gestures" performed in the immediate area of the steering wheel without taking a hand off. The question, which different kinds of micro-gestures can still be performed in an ergonomic way while holding the steering wheel, has recently been investigated [10]. Independent of any technical solutions, the authors present 17 gestures that can be performed with varying effort, while the palm is grasping something with moderate pressure. This was a rich basis for the selection of micro-gestures for our study.

5. PREDEFINITION OF GESTURE TYPES

In the beginning, the micro-gestures and tasks for our study had to be chosen from a variety of possibilities. To start with the selection of the micro-gestures, there were a number of aspects to considered. On the one hand we considered the ergonomic aspects of the context that the driver should still be able to hold the steering wheel at least with the palm and the remaining fingers. On the other hand gesture selection is limited by the ease of performance: The driver would perform the gesture from time to time and should not feel uncomfortable or even painful applying the gesture. Some gestures one could think of would also be too hard to apply like for example moving the ring and index fingers simultaneously. Without any training a gesture like this is hard to perform for most people [10]. Drivers should furthermore be able to a) learn the gesture easily and b) recall the learned gesture when needed. Also the risk of gestures being mixed up with natural or accidental movements should be kept to a minimum.

To sum up, together with some technological considerations these are the reasons why we decided to engage a maximum of two fingers for the gestures for a start. Moreover, we wanted to make use of analogies to well-known gestures like the ones used for the iPhone interaction and transfer them to this new context. In an informal brainstorming session (4 researchers familiar with the field) we resumed former ideas for micro-gestures, generated new ones and rated all of them. Finally we chose the most promising three gestures for our study: the *zooming* gesture, the *sweeping* gesture, and the *circling* gesture.

The aim of the experiment presented here was to answer the following questions: 1. Do users find such a system useful? 2. Which gesture is preferential to the users for +/- kind of controls: *circle*, *sweep*, or *zoom*? 3. What is the set of parameters for finding a mapping between the (recognized) motion of the subject's finger and the status of a device?

6. EXPERIMENT

6.1 Subjects

24 subjects participated in this experiment, 12 men and 12 women. Their age varied between 21 years and 67 years (mean = 37.0, SD = 15.1). All of them possessed a valid driver's license for at least two years, and 86 percent of them were driving regularly. We just allowed right- or two-handed people to our study, as our setup had so far been implemented in the right-handed version only. We measured subject's hand and body size, to check for any correlation with gesture preferences. Body size varied between 1.59 and 1.85 meters (mean = 1.70, SD = 0.08), gesture span measured as maximal distance from the tip of the index finger to the tip of the thumb varied between 12 and 20 centimeters (mean = 15.4, SD = 2.2). We furthermore determined subjects' length of the index finger only. It varied between 6 and 8 centimeters (mean 7.2, SD = 0.7). All subjects were native German speakers. They were paid 8 Euros for approximately 1 hour of time.

6.2 Apparatus

The experiment setup consisted of a steering wheel attached to a desk in a way that resembles the ergonomic condition of a driver in a car (cf. Figure 1). During the experiment the subject was holding the steering wheel with both hands at the 10/2 o'clock position.

Figure 1: Setup

A computer flat screen (size 19 inch, resolution 1280 x 1024 pixel) was set up behind the steering wheel in a distance of about 8 centimeters to the position where the subject's right hand was holding the wheel. The distance between the steering wheel and the screen was individually adjusted to index finger length plus about 1 centimeter. Accordingly, subjects were close to the screen, but did not touch it. On the screen our experimental gesture-program displayed a moving red dot that indicated the position of the subject's right index finger (sometimes in combination with the thumb) and hence the gesture to be performed. The subject should follow the red dot as exactly as possible. A screenshot of this interface for the example of a *sweeping* gesture can be seen in Figure 2.

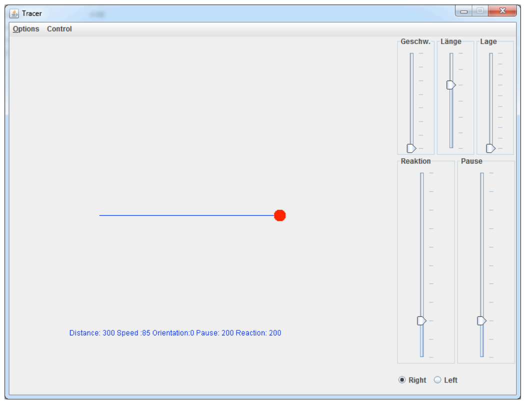

Figure 2: Screenshot of the program, which presented the micro-gestures to be performed (the example shows the *sweeping* gesture). The right index finger should follow the position of the red dot moving along the line. With the help of the sliders on the right hand side the gesture parameters could be adapted.

On the right upper side there were sliders with which each of the gestures could be configured in various ways (size, location, speed, etc.). A detailed description of the settings for each gesture can be found in Section 6.4. By using a mouse the experimenter adapted the settings according to the demands of the subject. The effect of the gesture performed with the selected settings for a special task was shown on a second screen located on the subject's right hand side.

6.3 Exemplary Interaction Tasks

As we chose to refer to the "selective mapping" [2] (see above), our goal was to select one suitable micro-gesture for a larger number of tasks even though they are performed and observed in a completely different fashion. As a result, we wanted to choose a specific set of tasks for the experiment that is as representative as possible for a big variety of in-car comfort functions. First of all the majority of in-car (comfort) tasks comprises an increasing or decreasing of an actual state of a device to a desired level, whereas the number of levels that can be selected is an important factor that – so far – usually becomes obvious in the specific design of buttons and knobs with their labels and tactile feedback. Accordingly, we selected four exemplary in-car devices to be controlled by the subjects via micro-gestures: The window lifter, the air condition, the radio volume, and the seat heating (cf. Figure 3).

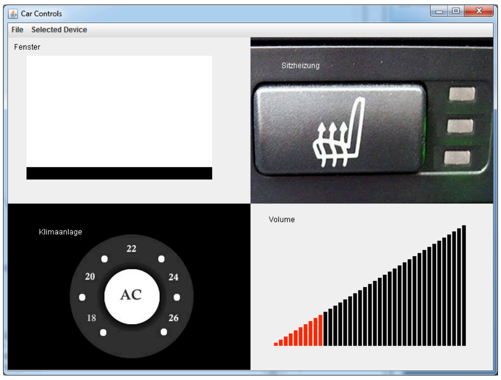

Figure 3: Animated controlled devices as gesture feedback to the subject.

Table 1: Specifications of the selected tasks.

device	number of levels	speed
window lifter	∞	fixed
air condition	~10	controllable
radio volume	~40	controllable
seat heating	3	controllable

Table 1 provides an overview of the functions with their respective number of levels from minimum to the maximum. In order to simulate more realistic interactions, and to find parameters that are valid not only for performing tasks from the minimum to the maximum or vice versa, the subject's task was to use the whole range, but to fulfill also partial tasks using about 1/3 of the range.

6.4 Investigated Gesture Types

The trace displayed on the screen behind the wheel (cf. Figure 2) could demonstrate three different micro-gestures, in two different directions each (for increasing and decreasing respectively). The three gestures were a two finger zoom gesture (*zoom*), a index finger sweeping gesture (*sweep*) and a circular movement of the index finger (*circle*). For a better understanding confer the exemplary demonstration of the *zoom* gesture in Figure 4.

First, the animated *zoom* gesture was configurable on the screen in terms of direction (minimizing or maximizing), size, speed, tilting/orientation, pause between two executions, and "transmission rate". Second, the animated *sweeping* gesture used the same parameters as the latter with the only difference that the direction is left or right. Third, the animated *circle* gesture could be configured in direction (clockwise or counterclockwise), size, speed, and "transmission rate". The next section will provide a description of the collaborative parameter adjustment and the overall experimental procedure.

6.5 Procedure: Setting Parameters with the help of the Theater Approach

After filling out the first questionnaire with demographic questions the experimenter explained the procedure to the subject, demonstrated the setting parameters for the gestures and had her get familiar with the setup.

Figure 4: Demonstration of the "zoom**" gesture.**

In the main experimental block subjects completed one of the four interaction tasks after the other (order was counterbalanced between subjects). For every interaction task subjects investigated each of the three gesture types (order also balanced between subjects). For each gesture the subject had the experimenter adapt the parameters (with the help of a mouse) until she was satisfied with the result. Each task was performed from the minimum to the maximum, the maximum to the minimum and also for a partial range of about one third in order to achieve results that are valid for the complete range but also for fine tuning of functions. After the subject had decided about her final settings, the experimenter recorded the final parameters for this gesture and task. The program furthermore delivered the number of gesture iterations performed and the total task time. Additionally the subject indicated on a 5-point rating scale, whether she had personally liked using the gesture for this specific task.

After having completed the practical part of the experiment, the participants filled out a final questionnaire about her summative rating of the three gesture types (liking, ergonomic aspect) and a ranking of them. We also asked, if they would like to use micro-gestures in general and if they would be willing to pay extra for them.

7. RESULTS

7.1 Parameter Settings

For a start, we want to present the descriptive results for some parameters like gesture size, orientation, and pause. The latter applied to the *zooming* and *sweeping* gesture only, as the *circling* gesture was intended to be continuous. For almost all of the general parameters (size, orientation, pause) people turned out to stick with the settings they had once selected for one gesture type across the different tasks. This is why we present the results aggregated over the different interaction tasks. Figure 5 shows, that the size for the *circling* gesture was the smallest and about half of the average size of the *sweeping* gesture. The *zooming* gesture with the combined usage of two fingers turned out to be the largest of all gesture types with the greatest variance. For this gesture type, any recognition technology would have to be the least sensitive. The measured average angles show, how *zoom* and *sweep* would be used in an ergonomic and natural fashion, when holding the steering wheel, and how detection areas should be adjusted. Whenever a rest period between the gestures is desired or necessary, a pause of about 500 ms seems to be suitable.

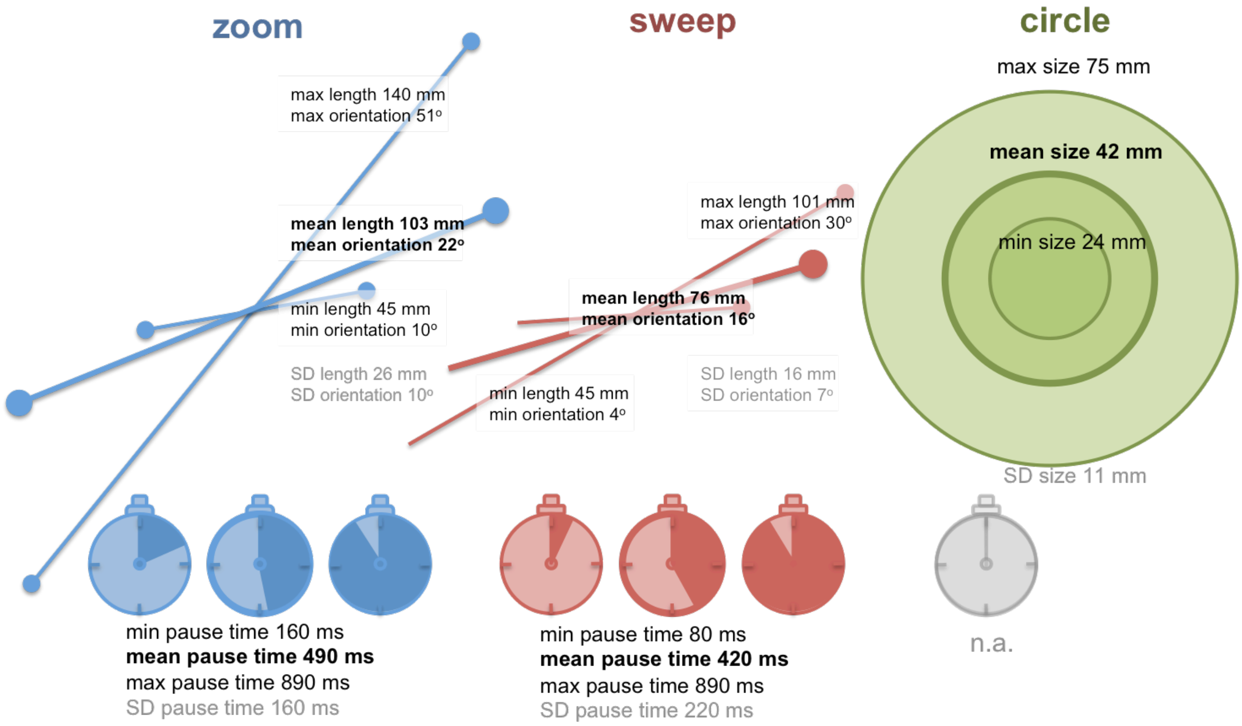

Figure 5: Descriptive statistics for the three gestures and the parameters size, orientation and pause.

The only exception to the uniform parameter settings mentioned above was the transmission rate and also the speed of the red dot (resulting in the relation of number of gestures an overall task time). These parameters turned out to be adapted by subjects according to the task and gesture type.

7.2 Relation of Interaction Task and Gesture Type in Terms of Iterations and Task Time

Beyond the parameters already mentioned there are parameters resulting from the subjects' gesture speed and iterations until a task was conducted from the minimum to the maximum (complete range). First, we want to take a look at the number of gestures applied (Figure 6).

A Repeated Measures Analysis of Variance (RM ANOVA) revealed a significant main effect of interaction task ($F(3,21) = 4.97$, $p < .01$), indicating that mainly the different tasks result in different numbers of gestures and a significant main effect of gesture type ($F(2,22) = 4.49$, $p < .05$), which indicates, that the average number of gestures also depends on the gesture type applied. The interaction between task and gesture type was also significant ($F(6,18) = 3.80$, $p < .05$). This is a result of single combinations being unlike the usual pattern, like the relatively low number of gestures for the *zooming* gesture belonging to the window lifter task or the relatively low number of gestures for the *circling* gesture in the air condition task. The results in Figure 6 show furthermore, that parameters cannot simply be derived from the inherent number of task levels (independent of the implementation, cf. Table 1) or the traditional switches and controls in the car.

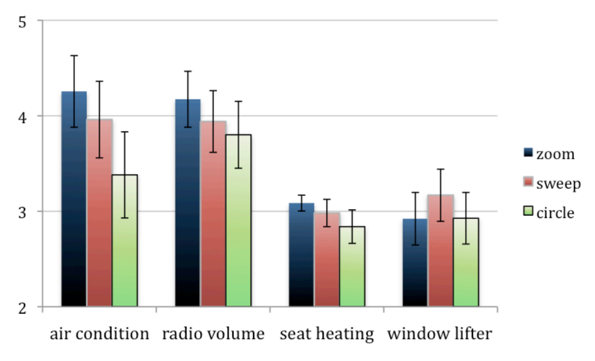

Figure 6: Average number of gestures selected by the subjects for the three different gesture types (for task completion).

Even though this might apply for some interaction tasks like the seat heating or the radio volume or might break through in special mappings (like the *circling* gesture and the traditional air condition device), the window lifter for example includes a large number of different levels, but people still want to adjust quickly and with fewer gestures than the air condition, which originally has fewer different levels. Basically, our methodology can help the human machine interface researcher to determine the perceived number of (useful) levels for a given task.

As a dependent variable we furthermore recorded the completion time for each task with each gesture. As expected, the time for task completion was closely related with the number of gestures performed.

Table 2: Correlations of task time and number of gestures

		gesture		
	CORRELATIONS (#gestures x time)	*zoom*	*sweep*	*circle*
task	air condition	.73 ***	.80 ***	.78 ***
	radio volume	.75 ***	.67 ***	.73 ***
	seat heating	.22 (ns.)	.59 **	.79 ***
	window lifter	.78 ***	.83 ***	.65 **

Table 2 shows the 12 correlations for each gesture and task type. Except for the *zooming* gesture in the seat heating adjustment task, high and significant correlations can be found between gesture number and time. For the *zooming* gesture the explanation can be easily found: there was almost no variance in the number of desired gesture iterations (exactly three) but quite some variance in the desired task time (1.6 – 5.2 sec). With very little variance correlations can hardly occur. To sum up, this investigation of task time and number of gestures implies, that the basic speed of subjects' performing a gesture for a specific task is quite consistent as the different task times correlate highly with the chosen number of performed gesture iterations. This might be another important finding for engineers implementing any new gesture recognition technology.

7.3 User Preferences: Questionnaire

Finally, we evaluated several subjective ratings of the three gesture types. The first rating was supposed to be rather fine-grained at the end of each interaction task and consisted of a rating of the three gestures applied to the specific task. Figure 7 shows the respective results.

As expected there was no main effect of interaction task ($F(3,21) < 1$, ns.) on ratings and only a marginally significant difference of gestures ($F(2,22) = 2.78$, $p < .08$). When taking a closer look and comparing the gesture ratings with Helmert contrasts, we found that the *zooming* gesture was rated significantly lower than the other two gesture types ($p < .05$). Furthermore we found a significant interaction ($F(6,18) = 2.76$, $p < .05$), revealing, that the rating of gestures significantly depended on the tasks performed. As you can see in Figure 7 the *circling* task was rated highest for air condition and the window lifter on the one hand. On the other hand the *sweeping* gesture was rated highest for the radio volume and the seat heating task. When taking a look at Figure 3 it becomes plausible, that the graphical feedback of buttons and switches on the display might have influenced the users' experience of the gestures. When the movement or direction of the gesture and the graphical feedback is rather consistent, the gesture seems to be more suitable. Also people mentioned that the *circling* gesture matched quite well with the movement of the out-dated manual window crank lever.

After the completion of all tasks at the very end of the experiment, we asked subjects to indicate much they liked every single gesture and how much physical demand they experienced in each case merged over all tasks. We found a marginal overall difference in the ratings of the three gestures ($F(2,22) = 3.31$, $p < .06$), and when comparing the *sweeping* gesture with the other two via Helmert contrasts, we found that this gesture is significantly preferred ($p < .05$). The *zoom* and the *circle* gesture did not differ significantly. Hence, in the overall rating, the immediate rating results after the task, with the *circle* and the *sweep* gesture being rated higher than the *zoom*, change slightly.

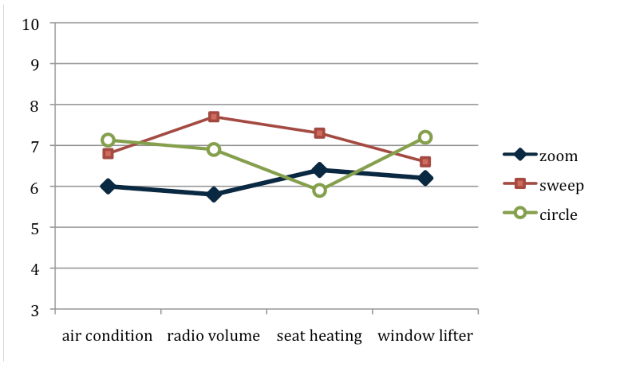

Figure 7: Detailed ratings of the gestures after each task completion (scale from 0="did not like at all" to 10="perfectly liked").

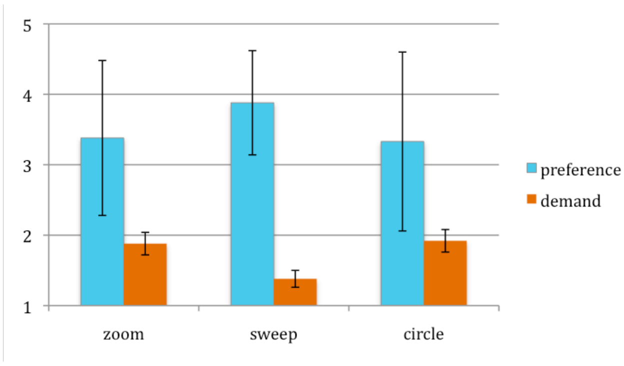

Figure 8: Overall subjective ratings of gesture preference on 5-point scale (from 1="did not like" to 5="liked a lot") and experienced demand on a 4-point scale (1="no demand at all", 4="very high demand").

In terms of overall physical demand estimation, we found once more a significant difference between conditions ($F(2,22) = 7.00$, $p < .01$). The *sweeping* gesture was rated significantly less demanding than the other two ($p < .05$), whereas the latter ones, again, did not differ significant from each other (ns.). For the correlation of the preference and the physical demand for every gesture, we found medium negative correlations (.44 - .50, $p < .05$), demonstrating that the less demanding gestures a preferred in comparison to the more ergonomically demanding ones. 92 % of our subjects would like to use the micro-gesture interaction in their car, and so far 23 % would pay an unspecified surcharge for a system like this.

8. CONCLUSION AND FUTURE WORK

According to our overall findings, micro-gestures are an interaction modality, which is quite promising for the users as well as for the researchers, who are encouraged to dig deeper into the special challenges of (contract-free) micro-gesture interactions. For a start, we have provided concrete parameters like average sizes (42 up to 103 mm), average timing for breaks (about 500ms between iterations), and mean number of iterations (3 to 4) for example, that can be used as benchmarks for tuning the existing technologies. Furthermore, we revealed insights about the users subjective evaluation of the gestures for adjusting the level of in-car comfort functions in terms of preference and perceived physical demand, indicating that all in all the *sweeping* gesture is better than the other two evaluated gesture types. But also an interesting dependency of the preferred gesture on the performed task and its visualization has been revealed. Since our results support that the visual feedback, belonging to a gesture or function, influences the perception of interaction intuitiveness and the preferred gesture type, we provide a take-away message for designers: Be especially aware of this issue, when implementing micro-gesture interactions and try to aim for a suitable visualization! Furthermore, future studies need to consider potential impact of micro-gestures on steering performance particularly in demanding traffic situations, before this technology is applied on the road.

Taken as a whole, our new approach derived from the theater technique has been affirmed by our detailed results, consisting of quite divers metrics with meaningful differences for the micro-gesture types investigated, and revealing sophisticated insights into this new interaction modality in general. Some subjects even stated that they liked the procedure and the fact of being able to influence parameter settings in the way they wanted. Of course, a validation of the determined parameters in a working system with direct feedback is one future issue to be addressed.

Obviously, this paper does not provide a solution for an entire interaction with all systems available in the car and further research needs to be conducted for a complete concept. Gestures for navigation through menu levels still need to be selected and worked out in interplay with the gestures selected for magnitude adjustment. But fortunately, the interactions for adjusting comfort functions are partially transferrable to other task types like for example selecting an item out of a list. The reason is, that this could be considered to be analogue to selecting one instance out of many ordered ones. As we investigated interaction tasks with very few levels (seat heating), some levels (air condition), many levels (radio volume), and even with a theoretically endless number of levels (window lifter) we covered the whole range of possible list lengths. However, besides the air condition our levels are not labeled like for example in the list of an address book – thus further solutions how our approach could in detail be transferred here, are needed.

Another challenging and demanding follow up issue, is the combination of micro-gesture interaction with other modalities, like speech or touch-based interaction. As each of them has its specific benefits and drawbacks that are depending on user, situation, and interaction context, it seems to be advantageous to use several modalities in any supplementary combination. Overall, micro-gestures represent a promising complement for this approach that needs further investigation.

9. ACKNOWLEDGMENTS

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