基於面部示能性及語意聯想設計之高可控性與記憶性之人臉觸控介面

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ABSTRACT
我們提出了人臉觸控介面，一種提供使用者高度可控性且易於記憶之人體輸入介面。 本篇論文專注於討論如何將觸控介面中常見的操控設計妥善的安置在人臉上，讓使用者可以藉由在臉上進行指觸動作來完成指令輸入。我們主張，人臉豐富的器官與特徵，不但適合放置不同的操控介面，其背後所隱含的語意，更能幫助使用者建立起功能映射(function mapping)，藉由聯想，妥善記憶臉上不同位置代表的功能。我們於實驗一觀察了受測者如何基於操作舒適程度的考量，將按鈕(button)，滑桿(slider)，與平板(pad)放置在臉上。實驗結果顯示使用者依循著面部器官的示能性(affordance)來配置操控介面。實驗二進一步探討使用者臉上的五官是否能幫助使用者記憶放置在人臉上不同位置的指令。實驗結果顯示，受測者能夠藉由五官隱含的語意跟指令進行聯想，因而記住指令的位置，且記憶性在72小時之後，依然能維持在85%的水準。實驗一、二的結果符合我們對於人臉觸控介面的主張，顯示出此介面不但提供豐富的操作，且易於記憶。基於實驗結果，我們於本篇論文中提出了若干人臉觸控介面的設計準則，並根據受測者的實驗訪談，進行分類與討論。我們最後觀察使用者在開車情境下使用人臉觸控介面的表現。實驗結果顯示，人臉觸控介面能有效的幫助使用者專注於開車，在不分心的情況下對其他行動裝置下達指令。本研究提出的設計準則，不但能幫助未來人臉觸控介面的改善與設計，其討論內容更能進一步的被利用在其他部位的人體輸入介面，易於人體輸入介面於人機介面社群的發展。

Categories and Subject Descriptors
H.5.m [**Information Interfaces and Presentation (e.g. HCI)**]: Miscellaneous;

General Terms
Human Factors; Design; Measurement.

1. INTRODUCTION

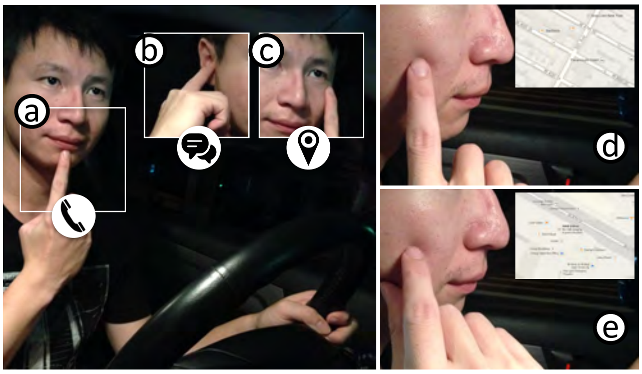

Figure 1: An example of using *Face Interface* in a driving scenario. The user can achieve many tasks eyes-freely and single-handedly while focusing on the major car-driving task.

On-body interface transfers human skin into touch surface, allowing always-available and eyes-free touch input. Despite that different body locations have been explored, previous works provide limited number of functions [4] and require additional mnemonic methods to establish the function-mappings [1].

In this paper, we explore using the whole human face as an on-body touch interface. Compared to extant approaches, face is a compact region offering both richer affordances and semantics. Different facial organs with distinct affordances imply place-holders for various dimensional widgets such as buttons, sliders, and pads, allowing face to support rich yet effective manipulations as an input space. Semantics behind individual organs (*e.g.*, eye, ear, and nose) enables the method of loci, which could help users build mnemonic bindings, allowing them to store and recall multiple applications installed on their faces. The aforementioned properties potentially equip face with *rich input vocabulary* and *memorable command mappings*, which distinguish face from other skin regions and grant face a good nature to work as an input surface. In addition, natural body anatomy allows users to touch any facial feature single-handedly, suggesting that face is suitable for body-constrained scenarios such as driving or holding an umbrella in hand.

More recent research [8] proposed using cheeks as a touch surface and demonstrated its social acceptability and effectiveness for 2D manipulations. However, the aforementioned qualities, *i.e.*, affordances and semantics, were not considered in their studies, and will be further explored in this paper.

Face Interface. We aim to explore the two key qualities of face: affordances and semantics, and therefore conducted two studies to explore the following research questions: (a) What facial regions can be manipulated with sufficient physical comfort? How would users arrange buttons, sliders and pads on a face by utilizing physical affordances? (b) What strategies would users use to help memorizing the layout of functions? Do users apply more semantic bindings on face than other on-body interfaces? (c) Do function-mappings of *Face Interface* are more memorable than other on-body interfaces?

Following a series of guidelines obtained from the aforementioned two studies, we built a prototype and conducted an explorative study with a driving simulation. The user feedbacks reassured the usability of UI on a human face, and suggested that user-defined function-mappings and micro-interactions are vital to the *Face Interface*.

Contribution. This paper offers three major contributions: (a) A set of appropriate arrangements of *Face Interface* covering a variety of modern UI widgets. (b) A proof of capability of memorizing 25 function-mappings on a human face. (c) A validation of utilizing a face as an efficient interface under an eyes-free body-constrained scenario.

2. STUDY 1: EXPLORING UI DESIGN OF FACE INTERFACE

To design an effective *Face Interface*, this study aims to explore (1) operable regions on whole face by evaluating the physical comfort by finger touch and (2) participants' strategies in leveraging facial physical affordances to place different types of widgets. Previous study [8] focused on gesture input on face and excluded the face region covered by an HMD. In contrast, we aim at a variety of dimensional inputs and consider the whole human face as an interface.

2.1 Study Design

This study contains two stages. For the first stage, participants were instructed to rate "physical comfort" across the entire face, where the "physical comfort" is defined as the integrated sensation of the touched area on face and the ergonomic concerns of hand-to-face interactions. For the second stage, participants were then asked to assign some widgets onto their faces, including 2D pads, 1D sliders, and 0D buttons. For 2D pads, we did not limit the number of pad widgets since the whole face is considered as free input regions. For 1D sliders, we asked the participants to identify 10 slider widgets, since the practical amount of list items in current mobile apps is usually no more than 10. For 0D buttons, according to Satistas report[1] based on Google's database, in average 26 applications are installed on a user's smartphone. In order to provide users with sufficient button widgets, we set the number as 30.

Procedure. At the first stage, participants was first asked to watch a sketch (Figure 2a without colors and dots) of a face on a screen. In each trial, a green dot was rendered on the sketch, and the participant was instructed to use the index finger to touch the specified position on his/her face and rate a "comfort" level with seven-point Likert scale. The order of the sample positions was counter-balanced. At the second stage, participants were then asked to install the three kinds of widgets. For each widget assigned, the participant needed to use the index finger to operate the widget on his/her face, such as making strokes on pads, turning volume by sliders, and pressing buttons. This practical manipulations ensure that the participants agreed that the tactile sensation along with the operations on the face. The whole study needs 45 minutes in average.

Participants. 15 participants (3 females) were recruited, with ages ranging from 21 to 32. All participants had used smartphones for more than a year, indicating basic understanding of the GUI widgets on mobile platforms.

2.2 Result

Figure 2a presents the average comfort ratings on face across all participants. The average score (4.25, s=0.88) suggests that most regions on face is acceptable for finger tapping. We further eliminated the regions with lower ratings and sensitive organs, and concluded the rest regions as "operable" for accessing functions. For the second stage, different encoding rules were applied to different widgets. For 2D pads and 1D sliders, the widgets nearby were first grouped together, and the groups less than 5% of overall counts were filtered out. The results are shown in Figure 2b and 2c, respectively. Notably, the appropriate regions of 2D pads reflect the result of [8], and also echo to the comfort regions (Figure 2a). For 0D buttons, we present the raw points in Figure 2d and clustered them in Figure 2e.

2.3 Discussion

For the results of comfort regions, we categorized the following two factors that impact the comfort rating:

Skin Thickness. The flat regions such as cheeks contain higher scores than ridges or hills on face. One possible reason is that according to Ha *et al.* [3], the skin of cheeks is thicker than ridges (*e.g.*, nasal bridge or jaw edges) and hills (*e.g.*, nasal tip). Participants may feel uncomfortable when touching and pressing the areas where less soft tissues cover. The result indicates that we should place widgets which require less pressing strength on the ridges and hills, *e.g.*, sliders. On the other hand, flat regions such as cheek or jaw should be assigned for the widgets which need better controllability, *e.g.*, pads.

Ergonomics. The regions of the dominant-hand side were rated higher than those in the opposite side, and the regions on lower face were rated higher than those on upper face. Based on the interviews, the tendency suggests that the path of finger tapping impacts the comfort while operating, since upper regions require more physical efforts during the interactions. Therefore, for general system control, the widgets should be placed on the lower or dominant-hand-sided regions on face.

As for the strategies of assigning widgets, we recognized the following two design guidelines from the above results:

Affordance-Based Strategy. According to Figure 2c, the sliders are more frequently placed at facial ridges (*e.g.*, brow ridges, jaw edges, and nasal bridges), and less on the flat (*e.g.*, cheeks) or sensitive (*e.g.*, mouth) regions. Participants reported two strategies for implementing sliders. First, sliders are placed at where the affordances reveal constraints for 1D movement, such as the nasal bridges and facial edges. Second, when more sliders are required, participants would place sliders on flat regions such as cheeks and forehead. Based on Figure 2e and the interviews, we identified two

[1] http://www.statista.com/chart/1435/top-10-countries-by-app-usage/

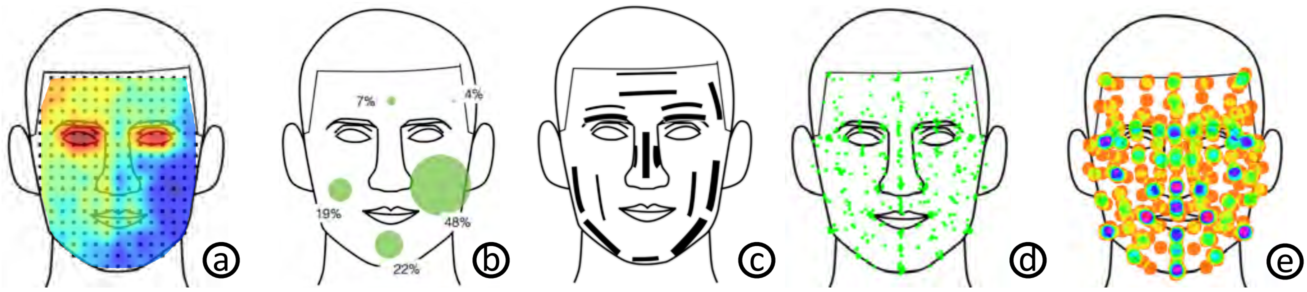

Figure 2: Main locations of preferences and widgets assigned by participants. (a) The heat map of "physical comfort". The blue and red colors present comfortable (score ≥ 5) and uncomfortable (score ≤ 3) regions, respectively. The rest regions colored from green to yellow present the scores during $5 \sim 3$. (b) The most frequently assigned regions of 2D pads. (c) The most frequently assigned locations of 1D sliders. The thickness of lines represents the agreements of assignments. (d) The assigned locations of 0D buttons. (e) The heat map of (d).

strategies for button widgets: landmark and interpolation strategies. For the landmark strategy, heat regions appeared either on or near the facial landmarks, suggesting that the participants utilized the caves or hills on face as the pivots to place button widgets. Remarkably, although sensitive organs were concerned discomfort mainly for hygiene concerns, landmarks on these organs were still considered as good candidates for placing button widgets. However, to avoid the hygiene problem, participants also reported that they would place buttons nearby the sensitive landmarks as if these buttons are offset proxies to the landmarks. With interpolation strategy, when participants needed more buttons, they started placing buttons at the mid-point of two nearby landmarks.

Flat UI Arrangement. Recent studies have proposed that flat UI arrangement performs better than hierarchical menu organization on fast command selection, since the flattening reduces the traversal process [2, 7]. However, many studies of on-body input provide less number of functions, since the number is related to evident body landmarks. For example, PUB [4] provided six buttons between wrist and elbow. Earput [5] also enabled up to six buttons between the top of ear helix and the lobe.

Summary. Our result points out that rich facial landmarks also enable participants to install many commands, allowing flat UI arrangement and effective on-body shortcuts. However, it is still unknown if the *Face Interface* provides memorable command mappings to the users. We will explore this in the next study.

3. STUDY 2: UNDERSTANDING MEMORABILITY

This study addresses the quality of rich semantics of human face, and investigates how the quality supports users to recall the applications installed on face. We argue that rich semantics on face allows stronger memory links between the applications and their locations, comparing to other on-body input methods.

3.1 Study Design

To evaluate the memorability allowed by human face, we compared face interface with palm interface. Palm allows an input space with rich affordances but few semantics. Therefore, comparing the memorability of the two enables us to know if semantics on face are useful for memorization, and if the memorability of *Face Interface* outperforms other on-body interfaces with less semantics. Figure 3 illustrates the layouts for *Face* and *Palm*, respectively. For *Face*, we

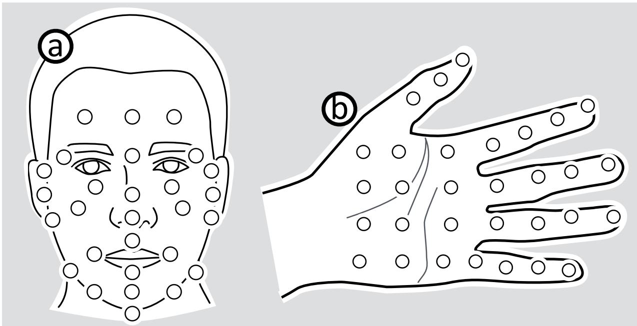

Figure 3: Participants were given two body-based layouts, which are (a) *Face* and (b) *Palm*. The black circles stand for the candidate locations for applications.

created a face layout for button widgets, *i.e.*, icons, based on the results of Study 1. For *Palm*, we referred to the layout defined in previous research [1].

The study design on memorability is inspired by the studies of gesture memorability [6, 9], which is a three-phase cycle: learning, reinforcing, and testing (after a period of time) to evaluate memorability on each gesture set. Our procedure followed the same structure, requiring participants to join a seven-days study going through the two interfaces. On the first day, the participant was introduced to the concept of on-body input, and asked to select the most frequently-used 25 apps from his/her smartphone and placed onto his/her face or palm. Games were asked to be excluded because the genre itself is highly diverse. If the participant had less than 25 apps, he/she would be instructed to pick up some other apps from a predefined list. However, such cases never happened in our study. Participants then learned the usage of one of the interfaces, reinforced the learning immediately, and then were examined after 72 hours. The cycle were then repeated once for the other interface. Afterward, we compared the recall rates of the two interfaces across all participants. Based on our arguments, we propose the following hypotheses:

(H1): Participants tend to use more semantic bindings on *Face* than on *Palm*.
(H2): Applications placed on *Face* is more memorable than on *Palm*.

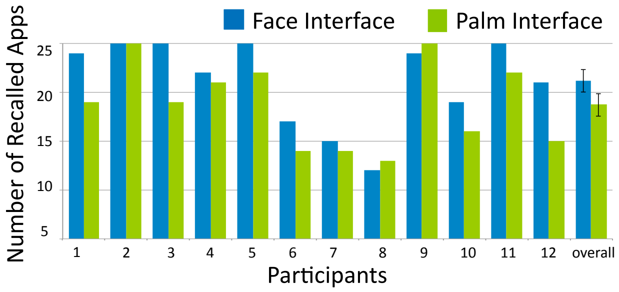

Figure 4: The correct memorization in testing phase between each participant after 72 hours. The rightmost histogram is the average results with $\pm$ 1 standard error.

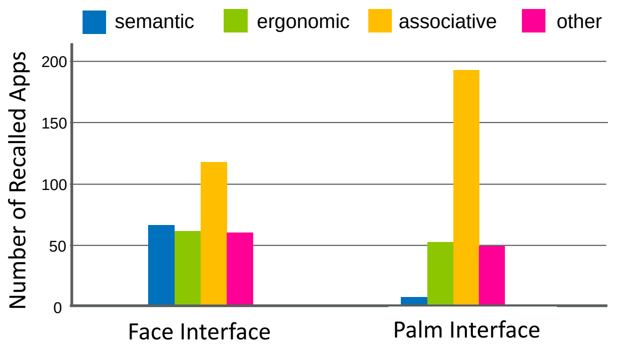

Figure 5: An overview of strategies of function-mappings. Participants tend to use more semantic strategies on *Face Interface*.

Procedure. In the learning phase, each participant was presented with one of the interfaces, and was given time to get familiar with it. Afterward, the experimenter instructed the participant to write down the mapping of the apps and their locations on the interface. During the procedure, the participant needed to assign the mapping one-by-one, and provided their explanations to the experimenter. The participant received 5 minutes to review the mappings and then proceeded to the reinforcing phase.

In the reinforcing phase, the purpose is to build up the participants' memory about the mappings. The experimenter would ask each participant to recall each app-location mapping in a random order. If the participant could not correctly answer, the experimenter would tell the answer to reinforce his/her memory. The testing phase was held after 72 hours of reinforcing. Similar to the previous phase, each participant was examined by going through all apps in a random order, except that he/she would not be told whether he/she made mistakes. With the end of the first interface, the participant started a new learn-reinforce-test cycle for the other interface. After the participant finished both interfaces (*i.e.*, on the seventh day), the experimenter interviewed the participant to understand his/her concerns on the two interfaces.

Participants. 12 participants (7 females) were recruited, with the ages ranging from 20 to 26, and all right-handed. All participants had used smartphones for more than a year.

3.2 Result and Discussion

Memorability. The average accuracy of reinforcing was 99% for *Face* and 95% for *Palm*. However, the average accuracy of testing were 85% on *Face* and 75% on *Palm*. The overall recall rates and individual recall rates are shown in Figure 4. The paired t-test suggests that there is significant difference on memorability between *Face* and *Palm* ($t(11) = 3.39$, $p < 0.01$) after 72 hours. The result failed to reject *H2*, indicating memory of app-location mapping on *Face* is more retainable than on *Palm*.

Encoding. As shown in Table 1, the strategies of app-location mapping are summarized into three categories: *Semantic*, *Ergonomic*, and *Associative*. The category of an assignment is determined based on the users' own explanation. For example, for assigning Messenger to the right corner of mouth, it can be explained as either of Semantic: *"Messenger is related to talk."*, Ergonomic: *"Right corner of mouth is convenient to tap."*, or Associative: *"Messenger is simliar to Line, so I put them together."*. The assignments that do not fit any of the three strategies, like *"Messenger on the right corner of mouth... no specific reason"*, were labeled as *Other*.

Strategy	Criterion	Example
Semantic	semantic features of body part	*"Camera capture images... like eyes, so around my left eye."*
Ergonomic	human factor reasons	*"I can touch my thumb tip easily so I assigned (frequently-used) Facebook on it."*
Associative	relations with other apps	*"I would like to put Line nearby Messenger."*

Table 1: Three categories of strategies.

Semantics-based Strategy. We ran a CHI-squared test between strategies and interfaces. The results show that significant differences exist on strategies between face and palm ($\chi^2(3) = 104.42$, $p < 0.001$). This suggests that the participants used more *Semantic* strategy on *Face* and more *Associative* strategy on *Palm* (failed to reject *H1*). From the results, both our hypotheses are supported.

Layout Arrangement. With the interviews, we found that the participants tended to use *"divide-and-conquer"* [P1] process to arrange the app layout. For *Face Interface*, participants described that they tend to *"use landmarks to divide the layout into several sub-regions for different purposes, and then assign related apps into the same sub-regions"* [P1, P3, P12]. Some participants noted that palm contains less semantic landmarks, so they used more *Associative* strategies to memorize the locations of apps.

Patterns of Error. During the studies, the experimenters observed certain patterns of errors in testing phases. For errors of *Face Interface*, symmetrical locations were easily confused. As for errors of palm, the participants tend to tap the locations that are *nearby* the correct locations. The errors on palm is not surprizing, because the participants tend to use *Associatiive* strategy that involves less directional information. Our argument was also supported from the interviews. Participants described that *"I don't remember whether Line is on the left side or the right side of Whatsapp"* [P1]. and *"Apps for chatting are all on my index finger, but I forget which joint the FB Messenger locates"* [P8].

On the other hand, the errors on *Face Interface* was not expected in our study design. From the video log, we found that some of the participants used their dominant hand and the other hand *in-*

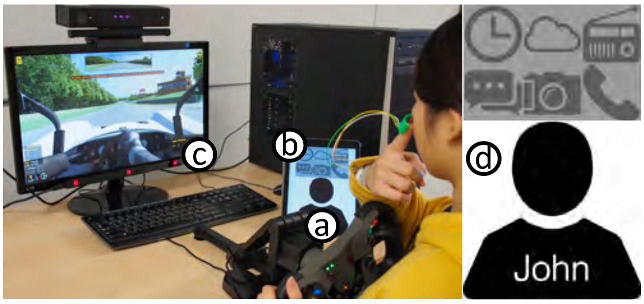

Figure 6: In the explorative study, participants used the (a) steering wheel to control the driving simulator, and triggered the apps on (b) the iPad by *Face Interface* or touchscreen. (c) A gaze tracker placed on the monitor for evaluating participants' attention. (d) The displayed arrangement on the iPad. The upper-half part is the icons of the apps, and the lower-half part shows the content of the *Phone* app.

terchangeably in the learning and reinforcing phases. One factor of the spatial memory is the length of the hand-to-face path. The interchanging behavior duplicates a hand-to-face path for its opposite side and weakens the spatial memory. Therefore, we draw this as a limitation: system designers should implement fool-proofing mechanisms, or even utilize the characteristics to design different UI layouts for each hand.

Summary. Our results show that the strategies of app assignments vary with the richness of semantics. Participants tend to use more *Semantic* strategies if semantic landmarks are affordable. We also examined the memorability between face and palm interfaces. Recall rate of *Face* maintains at 85% after 72 hours, implying that the qualities of face can work as strong memory connections. Also, the memorability of *Face* performs better than palm even after 72 hours. The results in this study confirmed that the *Face Interface* is memorizable, and has a lower rate of memory decay than palm interface. Two notable findings are concluded from the interviews. To avoid the confusion caused by facial symmetry, designers should ensure users to assign and recall apps with the same hand. To understand the potential effect of visual feedback on face, we could allow users to review it via mirrors or HMDs on the go.

4. BODY-CONSTRAINED EYES-FREE INTERACTION

Previous study suggests that haptic feedback and proprioception of on-body interfaces aid users to locate their input positions, allowing eyes-free peripheral input while focusing on their primary tasks [4]. However, under some body-constrained scenarios, such as driving or riding a bike, users only have limited physical degrees of freedom to perform some other minor tasks, since they need to concentrate on the primary tasks. In this respect, human anatomy allows us to acquire facial targets single-handedly, implying that *Face Interface* might allow reliable peripheral control with less physical demand. We finally conducted an explorative study to test if users are able to focus on primary tasks while performing some other minor tasks with *Face Interface*.

4.1 Study Design

We chose car-driving as our testing scenario, since drivers need to focus on the traffic conditions while performing some peripheral controls in a steady sitting posture. In this study, users were asked to focus on controlling a driving simulator as a primary task and simultaneously open some apps on a mobile device as the minor tasks. Six commonly used apps of Study 2 were selected, including Clock, Weather, Music, Message, Camera, and Phone. Participants were asked to perform corresponding tasks after opening the apps, for example, turning down the Music volume, sending a canned Message, or reading out the contents (*e.g.*"*Arial calls me.*" or "*It's sunny in Taipei city.*"). The eyes movements of the participants were recorded for estimating the participants' attention during the tasks.

Study Setting. Figure 6 shows the study setup. A steering wheel and pedals were placed in front of our prototype system. An Apple iPad was placed nearby the steering wheel as if the participants' own mobile devices or the screen in a car. We assumed that when a participant's gaze is out of the computer monitor, he/she lacks attention from driving. A Tobii EyeX gaze tracker was installed to measure the participants' attention during the trials. Figure 6d is the software interface on the iPad. Six apps were flatly arranged on the upper region of the iPad, and the content of the activated app is displayed on the lower part.

Interfaces for Comparison. To evaluate the capability of *Face Interface*, we considered touchscreen and arm-based interface [4] for comparison. Touchscreen is the basic approach for interacting with mobile devices, and arm-based interaction is an applicable eyes-free single-handed approach.

We first performed a preliminary study using the arm-based interface. 7 participants were asked to keep the simulated driving while tapping the six buttons on their arms in an eyes-free manner. We first examined whether the participants could distinguish the six buttons without function-mappings. In each trial, each participant was asked to tap one of the six buttons on his/her arm, and every participant needed to take 30 trials in a counterbalanced order of buttons. In consequence, among the 210 trials, there were 42 times that participants cannot correctly tap the buttons, causing an error rate of 20%. The error rate even deteriorated to 29% when the function-mappings were requested.

Participants reported that the arm movements interfered with the tactile feedback, and it is thus intractable to precisely locate the buttons. The randomly listed apps linked to nothing memorable on their arms, which may further increase the difficulty of memory retrieval. Briefly, with the combination of physical and cognitive loads, arm-based interface could not bear a sufficient accuracy for our study. We therefore excluded the arm-based interface from the candidates, and only compared touchscreen with *Face Interface*.

Procedure. Every participant was first instructed to practice with the same car type and the same track until becoming familiar with the driving simulator. We restricted the car speed in first gear, making all participants able to master the simulated driving within five minutes. The participants were then educated to open the apps by using our prototype or touchscreen, and had a five-minute practice for each interface.

During the trial, the participants were asked to pay their full attention on driving. For every thirty seconds, a beep sound with a recorded task description will be played, and the participants were asked to complete the corresponding task after successfully activating the app. The order of the two interfaces were counterbalanced, and each participant was required to complete all six tasks in a random

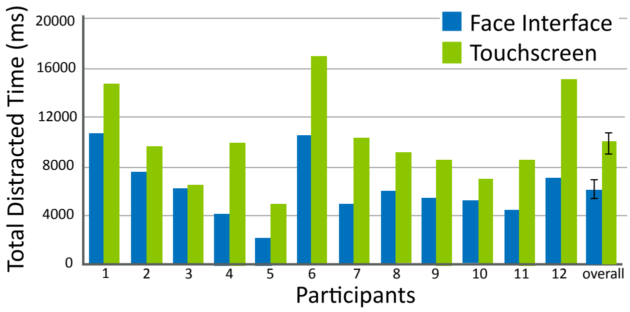

Figure 7: The results of our explorative study. The rightmost histogram is the average with $\pm$ 1 standard error.

order with each interface. The arrangement of the apps on both *Face Interface* and touchscreen were predefined by the experimenters. For *Face Interface*, the layout is defined based on the result of Study 2, in order to eliminate the differences of personal abilities on associating semantics to the apps. The gaze movements of every participant were recorded. After all six tasks in both interfaces were finished, an interview was conducted.

Participants. 12 participants (5 females) were recruited, with ages ranging from 24 to 28, and all right-handed. All participants had used smartphones for more than a year.

4.2 Result and Discussion

All participants could drive safely and completed the secondary tasks successfully with both interfaces. Figure 7 lists the results of accumulated time length of lacking attention. In average, the accumulated time of being distracted is 6.16 seconds with *Face Interface* and is 10.04 seconds with touchscreen. From the paired t-test, significant difference on the accumulated time ($t(11) = 6.48$, $p < 0.001$) is observed. The results suggest that, by using a human face as an input surface, visual attention on the primary tasks is less required with *Face Interface* than with touchscreen.

Overall, the participants felt positive about using our prototype. They could still keep sufficient cognitive resources on the main task, *i.e.*, driving simulation in this case, and operate several secondary tasks with peripheral sensation. We summarized the interviews with the following two points.

User-defined Function-mappings. The layout of the apps in the study is predefined based on Study 2. Thus, unsurprisingly, some participants mentioned that some of the bindings between the organs and the apps were not straightforward to them, costing them more efforts on remembering the mappings. As Nacenta *et al.* [6] suggested, self-defined gestures are easier to remember, the conclusion should also be applicable to the interface arrangement of *Face Interface*. Designers should provide capacity for users to define the UI on their own faces. From the user feedbacks, we also reconfirm that leveraging the rich semantics on face to associate functions and locations is a natural design.

Micro-interactions. Our study successfully proved that *Face Interface* provides an efficient approach for completing secondary tasks in an eyes-free body-constrained scenario. This property guarantees *Face Interface* as an powerful input space for supportive functions. Furthermore, participants reported higher preference on quick and light contact on their faces. Long-lasting gestures are considered less physically and socially comfortable. This echoes to the conclusion of Serrano *et al.* [8] that subtle gestures (*i.e.*, flick and panning) is more acceptable than lasting ones (*i.e.*, *cyclo*). With the two aforementioned observations, we suggest that micro-interactions are both sufficient and necessary for using a face as an input device.

5. CONCLUSION AND FUTURE WORK

In this paper, we explored *Face Interface*, a novel on-body interface enabling users to install more than 20 functions while remaining efficient memorization. The two qualities of human face, *i.e.*, rich affordances and semantics, grant it the excellent nature as an input space. We also learned that, with user-defined function-mappings and micro-interactions, input gestures on face are considered reliable and acceptable in general scenarios. In our explorative study, participants could concentrate on the main task, *i.e.*, safety driving, and meanwhile successfully completed the secondary tasks.

6. 致謝

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