Are You Comfortable Doing That?: Acceptance Studies of Around-Device Gestures in and for Public Settings

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ABSTRACT
Several research groups have demonstrated advantages of extending a mobile device's input vocabulary with in-air gestures. Such gestures show promise but are not yet being integrated onto commercial devices. One reason for this might be the uncertainty about users' perceptions regarding the social acceptance of such around-device gestures. In three studies, performed in public settings, we explore users' and spectators' attitudes about using around-device gestures in public. The results show that people are concerned about others' reactions. They are also sensitive and selective regarding where and in front of whom they would feel comfortable using around-device gestures. However, acceptance and comfort are strongly linked to gesture characteristics, such as, gesture size, duration and in-air position. Based on our findings we present recommendations for around-device input designers and suggest new approaches for evaluating the social acceptability of novel input methods.

Author Keywords
Around-Device Input; User Acceptance; Gesture Design.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

INTRODUCTION
Hardware and software advances in motion sensing technology have compelled researchers to demonstrate the rich potential of interactions that can take place in the air around a mobile device. Such 'Around Device' (AD) interactions has been shown to facilitate input on very small devices such as wristwatches [5], can be used to extend the input vocabulary of mobile phones [8, 10], minimize the likelihood of occluding the screen with the input hand [1] and were shown to be more efficient for search and retrieval tasks in analytic settings [6]. Commercial devices (e.g., Samsung Galaxy S4), inspired by such work, are enabling AD-interactions such as scrolling by swiping the hand above the screen. However, commercial advances are still limited.

While several user studies [1, 6, 7, 10, 19] performed in laboratory settings have shown the potential and benefits of AD-input in a number of tasks, little is known about users' attitudes and comfort levels using these innovative interactions. Particularly when performed in a public setting hand movements and finger gestures around the device may attract by-passers' undesired attention or intrude into areas 'owned' by others (e.g., when sitting on a bus), and thus may evoke feelings such as embarrassment or discomfort. Accordingly, the acceptance and willingness to perform AD-gestures may be limited to certain settings. This speculation is supported by previous studies [13, 14, 17, 18] on device-based gestures (e.g., swinging or tilting the device) and body-based gestures (e.g., a wrist rotation, nods, or foot taps) for mobile phone interaction. These studies have demonstrated that users are indeed very concerned about others' reactions and that users are sensitive and selective regarding where and in front of whom they would use such gestures.

These prior studies, however, classify gestures as either being acceptable or not. In contrast, we hypothesize that gestures and AD-interactions – the focus of this paper – belong to an acceptability-continuum and that various gesture properties influence acceptance differently. Research has not teased out or studied what gesture properties, and specifically AD-features, could lead to higher acceptance and thus lead to quicker adoption of this emerging interaction style. In this paper, we take a first step in this direction. We explore how socially comfortable (we term this as *comfortable* throughout the remainder of the paper) users feel when performing AD-gestures in a public place. We also survey users for which locations and in front of whom they would feel comfortable using AD-interactions. In our first two studies we examine the influence of four fundamental AD-gesture features – the distance from the device, the position relative to the device, gesture size and gesture duration – on users' level of comfort. We further examine whether such perceptions are related to a user's introversion/extroversion personality trait. Finally, in a third study, we elicit opinions from people observing others using AD-gestures in public.

In this work we: i) identify how specific AD-gesture features influence user comfort and acceptance; ii) reveal

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MobileHCI 2014, September 23–26, 2014, Toronto, ON, Canada.
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http://dx.doi.org/10.1145/2628363.2628381

that AD-gestures are perceived as equally acceptable by users with introversion or extroversion traits; and, iii) propose a set of recommendations to assist AD-interaction designers. A minor contribution also consists in proposing methodology improvements for future acceptability studies.

RELATED WORK AND MOTIVATION

Our research is motivated and inspired by the many applications for mobile devices made possible using sensing technology (e.g., magnetic and infrared sensors or cameras-based solutions) to detect in-air finger and hand movements. We first provide a brief overview of this work and then discuss previous studies that have investigated user acceptance of novel mobile interactions.

Previous work has demonstrated that AD-input can be used to facilitate many elementary interactions, such as button selection [5], menu navigation [1], pan and zoom [1, 7], and digit entry [8, 20]. Researchers have also shown how to capitalize on AD-space in more complex tasks or situations, including rotation of on-screen objects [1, 10], the operation of media players [9], for item search and retrieval in analytic settings [6], for cursor control on projector phones [19], and in mobile collaboration scenarios [16]. Most of these projects were focused on hardware solutions. Only a few projects have attended to the human factors involved when designing AD-interactions. Ens et al. [2] modeled user performance in off-screen target acquisition tasks and Jones et al. [7] examined user performance and preferences for multi-scale navigation in AD-space. Hasan et al. [6] proposed a framework consisting of numerous design parameters relevant to AD-interactions, such as the range for user input, suitable in-air target sizes, selection methods and techniques for placing and retrieving content in AD-space.

All of the above projects have studied AD-interactions in a lab setting and have focused on hardware solutions or user performance. The acceptance and users' comfort levels when performing these interactions have received very little attention. To our knowledge, only Jones et al. [7] and Kratz et al. [10] have, although only very briefly, considered how users would feel about using AD-interactions in a public setting. Jones et al. who compared various AD-methods for panning and zooming also asked their study participants how comfortable they would feel using the AD-methods in public places. Jones et al. report that although the enlarged interaction space provided by the AD-methods was valued, participants said they were less likely to use these in public settings. Similarly, Kratz et al. who studied AD-techniques for rotating on-screen objects found that participants were split regarding using these in public. These findings, together with recent studies [13, 14, 15, 17, 18] regarding users' concerns and feelings about performing body or device-based gestures in public settings – e.g., tapping the shoulder or shaking the phone to mute a call – warrant caution and further investigations. Probing user perceptions of novel AD-interactions could allow designers to rule out unwanted styles of input before they get implemented. What is needed is an understanding of how such interactions work in ecologically valid settings.

Ronkainen et al. [15] introduced the idea of studying social acceptance of gesture input on mobile devices. In an online survey they used short video clips of people performing different device-based gestures (e.g., swinging and slapping the device) for various tasks and in different settings (café, library, while walking). Participants were asked to decide and comment on whether they would use the featured gestures themselves. As participants were not explicitly instructed to consider the social setting in their responses Ronkainen et al. were surprised to find that roughly half of the participants mentioned context-related and social issues in their rationales when rejecting a gesture.

Rico and Brewster [14] expanded on this finding and studied how the social setting influences the acceptance of device-based and body-based gestures (e.g., tapping the nose, squeezing the forearm). Again, participants watched short video clips showing a person using the examined gestures while being alone in a room. From this, participants were asked to state where and in front of whom they would use the gestures themselves. Rico and Brewster found that participants were very sensitive and selective regarding the usage context: both locations (e.g., at home, on a sidewalk, in a café) and audience (e.g., colleagues, family, strangers) affected participants' willingness to use the gestures. In a follow-up, user reactions were elicited from eleven persons having performed some of the gestures both, in a private room and on a busy sidewalk. Most participants commented on how different they felt when performing the gestures in public, feeling uncomfortable and worrying about what others might think. Several participants also reported having felt somewhat less uncomfortable in later stages of the exercise. These findings demonstrate the potential limits of only letting participants imagine usage without having had a firsthand experience with strangers watching or being cognizant of their own behaviour.

Williamson et al. [17, 18] collected user experiences and insights from real-world usage situations. They asked participants to use a mobile phone application operated though body gestures (nods, rotating and shaking the wrist) as often as possible during a couple of days. The majority of registered usage situations took place in private while at home or in semi-private settings at work or when walking. Only a few participants decided to use the application during public transport. Many worried about what others would think and worked out strategies to appropriate or disguise the gestures in order to avoid attention from potential spectators. Williamson et al. also report that several participants noted a large, and unanticipated, difference between how they felt about 'transitory' and 'sustained' spectatorship (e.g., a person catching a glimpse of the interaction while walking by resp. a fellow passenger on a train that watches the interaction for a longer time).

Montero et al. [13] also used video clip demonstrations of device-based gestures. They asked participants to indicate on a scale from 'embarrassed' to 'comfortable' how they would feel performing the example gestures in a public place. Their results demonstrate that factors, such as gesture category, 'suspenseful' or 'magical', have an impact on the acceptability of device-based gestures. Interestingly, their results also show that early and late technology adopters perceive suspenseful gestures, those with a clear action that is easily seen by bystanders but without a noticeable outcome, as being less acceptable. These results could suggest that AD-gestures, which can be considered to be suspenseful, may not be accepted for public use.

In summary, previous work clearly demonstrates that people are very concerned about what others think and how they will react when observing them perform unusual interactions. Previous studies also show that people are sensitive and selective regarding which gestures they would feel comfortable with in various social settings. However, AD-gestures – as well as many body-based and device-based gestures – possess several attributes, such as area of input and duration that can affect comfort and acceptance. No prior study has explored whether and how user attitudes and acceptance vary depending on such features, a task necessary to refine and propose novel AD-interactions. We are also unaware of any prior work that examines the role of personality traits when investigating acceptance and user perceptions about gesture interfaces. In the next section we present three studies designed to provide initial insights regarding these open questions.

THREE ACCEPTABILITY STUDIES

With our first two studies we aim at clarifying how four elementary gesture-design factors influence users' acceptability of AD-gestures. In Study 1 we explore how users' comfort levels vary when they perform gestures in different regions around the device and at different distances from the device. We also explore whether users' perceptions about AD-gestures are related to extroversion personality traits. In Study 2 we focus on the size and duration of gestures and investigate how these parameters affect users' comfort. In Study 3 we switch to a spectator's point of view and examine peoples' reactions when having observed someone else using AD-gestures.

Compatible with our focus on general gesture-design factors, the involved gestures are simple and consist of 'drawing' one-digit numbers in the air around the device. Such abstract drawing-gestures are easy to perform, are context free and reduce the likelihood that participants' responses are influenced by any uncontrolled factors such as previous experiences, cultural background, and associations to interface tasks or functionality.

In our three studies we elicit participant impressions through questionnaires and use Rico and Brewster's [14] 'audience-and-location' axes to determine levels of "social acceptability". We ask participants to state in front of whom and in what locations they think they would feel comfortable using AD-gestures. To determine the influence of gesture parameters we ask participants to indicate how comfortable ('very comfortable', 'comfortable', 'neutral', 'uncomfortable', 'very uncomfortable') they felt when performing the gestures. We acknowledge that the central usage of the word 'comfort' in our questions may leave room for diverse and individual interpretations. However, we carefully instructed participants of the intended and desired interpretation and we explicitly asked participants to relate 'comfort' to social and mental aspects rather than physical ones. Furthermore, our terminology finds support in previous studies on social acceptance of gestures for mobile use [13, 14, 15, 17, 18] where both, authors and participants have used similar wordings. We also recognize that user acceptance is multifaceted and by far not limited to the perceived or expected levels of confidence and comfort [3].

In contrast to all prior studies on AD-input and the majority of earlier studies on user acceptance of gestures for mobile devices, our studies were conducted in public places. We believe this is important since it provides participants with firsthand usage experiences before making their judgements, unlike in video-based surveys where participants are asked to imagine future use and possible feelings.

Study 1 – Region and Distance

The first study was conducted in a shopping mall. Without being informed about the exact purpose of the study, the participant was asked to perform a set of AD-gestures in a busy entrance zone of the mall. The participant was standing and held the smartphone in the non-dominant hand at a natural viewing distance. A set of 45 images guided the participant through the study task. The images were viewed in full-screen size using the device's default image browser. Each image showed a position in the air around the device and a one-digit number to 'draw' at the indicated in-air position. Figure 1 (a and b) shows two example images.

As illustrated in Figure 1c, five different drawing regions were used: *Above* and *Below* the device, to the *Left* and to the *Right* of the device, and in *Front* of the device. Each region was divided in three distance ranges, measured from the device: *Close*, *Mid*, and *Far*. *Close* corresponds to the area 0 to 15cm away from the device, *Mid* to 15 to 30cm from the device, and *Far* to more than 30cm away from the

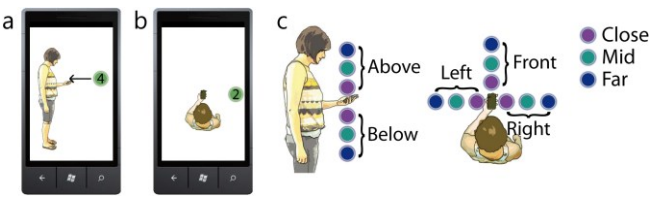

Figure 1. Example task prompts for (a) a gesture in the *Above* region at the *Close* distance and for (b) a gesture in the *Right* region at the *Far* distance. (c) Gesture distances and regions.

device. The furthest distance roughly corresponds to the maximum comfortable reaching range around a handheld device [6], which is also the border area between the 'intimate' and 'personal' space as defined in studies on proxemics [4]. Five regions and three distances yield 15 around-device positions prompted to the participant. In practice trials we explained how to interpret the 15 different gesture positions shown in the task images and to "anchor" the positions in relation to body parts (such as face, chest, shoulder, and beyond shoulder).

The experiment was self-paced and the participant was instructed to work through the images and to draw the prompted numbers at a moderate speed. The next image in the set was loaded with a flick gesture on the touchscreen.

The image set was divided into three sub-sets of 15 images, with one image for each of the 15 gesture positions. The order of gesture positions and the prompted number to draw in the air was randomized within the three sub-sets. All participants used the same image set (and image sequence) in two rounds, for a total of 90 gestures.

After completing the two rounds of gestures the participant was debriefed and asked to answer four questions regarding (Q1) the overall impression/emotion during the task, (Q2) in front of whom and (Q3) in what locations he/she would feel comfortable using AD-gestures, and (Q4) how comfortable he/she felt when performing the gestures in the various in-air positions. Figure 2 shows the used questionnaire. We instructed the participant to answer these questions and to interpret the central word 'comfort' from a social perspective and to ignore issues related to physical comfort and practicability. The participant also completed a Big Five Personality Test [12], which is a standard psychology test that assesses a person's personality on five broad dimensions: conscientiousness, openness, extraversion, agreeableness, and neuroticism. We used the test

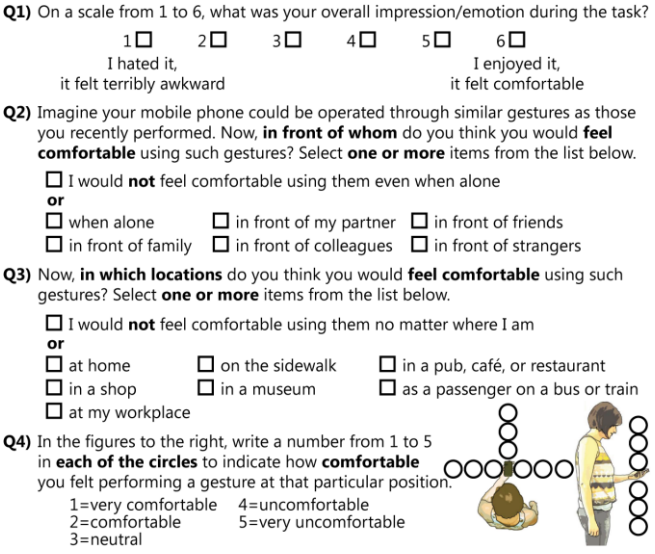

Figure 2. Study 1 questionnaire.

available at http://www.outofservice.com. We were primarily interested in identifying whether scores on extraversion correlated with perceptions of AD-gestures.

Eighteen right-handed smartphone owners (6 female) aged between 24 and 51 years (mean 31.1 years, s.d. 6.6) participated. Participation lasted roughly 30 minutes.[1]

Results

Question 1: Only four participants indicated that their impressions/emotions during the task were more negative than positive by selecting a rating of 3. The other fourteen participants indicated having had more of a positive impression/emotion during the task: ten gave a rating of 4, three gave a rating of 5, and one participant indicated enjoyment/comfort (rating 6).

Question 2 and 3: No participant completely rejected the idea of using AD-gestures by stating that he/she would not feel comfortable using gestures even when alone. Only one stated that he would only feel comfortable using the gestures if alone and at home. Sixteen participants indicated they would be comfortable doing the gestures in at least one of the non-private settings (i.e., when not at home and when not alone). One participant thought he would feel comfortable using AD-gestures in all locations and in front of all audiences listed in the questions.

To analyze the answers to Question 2 and 3, we established an acceptance rate for each given audience and location by calculating the percentage of participants who selected each audience/location in their answers. As visible in Figure 3, the more familiar audiences, family, partner, and friends, were accepted by most participants. Only 6 of 18 participants indicated they would comfortably use AD-gestures in front of colleagues and strangers. A Cochran's Q test showed a significant difference between the audiences ($\chi^2_{(5,N=18)} = 46.9$, $p < 0.001$). Post-hoc McNemar tests (Bonferroni: α-levels from 0.05 to 0.003) showed that the acceptance rates for the least familiar audiences, colleagues and strangers, were significantly lower than the rates for the other audiences.

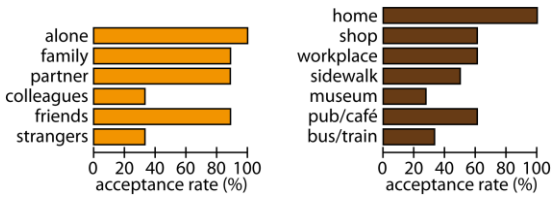

Figure 3. Acceptance rates for audiences and locations.

Also the location influenced the willingness to use AD-gestures (Cochran's Q test: $\chi^2_{(6,N=18)} = 27.2$, $p < 0.001$). However, the results are slightly more controversial with

[1] The anonymous data from our studies can be retrieved at http://ias.aau.at/experiments/.

acceptance rates around 50% for four locations (shop, workplace, sidewalk, and pub/café). All participants indicated they would feel comfortable using AD-gestures at home. Post-hoc pairwise tests McNemar tests (Bonferroni: α-levels from 0.05 to 0.002) showed that the rate for home was significantly higher than for the two most rejected locations, museum and bus/train (with rates of 28% resp. 33%). No other pairwise comparisons were significant.

We also examined whether there was a connection between acceptance rates and participants' extraversion personality trait. On the Big-5 test, nine of the 18 participants had an extraversion percentile score below 50, and nine a score above 50. That is, 50% of our participants were less extraverted than 50% of all persons (over 10,000 persons) that have completed the online Big-5 test service we used. As visible in Figure 4, introverts and extroverts provided similar ratings for most audiences and locations. We did not find any significant differences in the ratings.

Figure 4. Acceptance rates for audiences and locations split by introverted and extroverted users.

We can conclude that the majority of our participants, not only extroverted persons but also persons with a more introverted personality, were quite open to the idea of AD-gestures. Only one participant indicated a strong hesitance to perform AD-gestures in the public or in front of someone else. All other participants responded that they would feel comfortable using AD-gestures outside the privacy of their home: in four of the six non-private locations 50% or more of our participants would feel comfortable using AD-gestures. Overall, our results confirm Rico and Brewster's [14] results, which also showed that both audience and location are important factors that influence the willingness to use gestures.

Given the low acceptance rate for strangers in the audience category, the fairly high acceptance rates for shop, sidewalk, and pub/café – where one would expect to be seen by strangers – are somewhat surprising. However, we assume that participants indeed focused on the various locations and the circumstances that are typical for these. For example, in a pub an AD-gesture could be more easily disguised, e.g., under a table, than in a bus with a passenger sitting close by. We also suspect that acceptance depends on the frequency with which the gestures are used, their size and duration. Particularly for locations such as in a crowded bus or on a busy sidewalk where large or lengthy gestures are likely to be perceived as more inappropriate than small or quick ones. We evaluate these factors in Study 2.

Question 4: Figure 5 shows the mean rating for each of the 15 gesture positions that were rated by participants according to how comfortable they felt when doing gestures in these positions. In all five regions, the position furthest away from the device had the worst rating. Most participants stated they felt either uncomfortable or very uncomfortable doing AD-gestures far away from the device. The majority of participants indicated they felt comfortable or very comfortable when gesturing at a close distance from the device, no matter what region they used.

A Friedman test showed that, across the five regions, the ratings for the far, mid, and close distances (with mean rating of 4.3, 2.8, and 1.5, respectively) differed ($\chi^2_{(2,N=18)} = 36.0$, $p < 0.001$). Post-hoc Wilcoxon tests (Bonferroni: α-levels from 0.05 to 0.016) showed differences for all three pairwise comparisons.

We also found significant differences in the ratings for the five regions ($\chi^2_{(4,N=18)} = 36.0$, $p < 0.0001$). The mean rating for each region was: 2.8 (above), 3.6 (below), 3.1 (left), 2.6 (front), and 2.3 (right). Post-hoc Wilcoxon tests (Bonferroni: α-levels from 0.05 to 0.005) showed significant differences between the left and right region, and between the below region and each of the above, right and front regions. No other comparisons were significant.

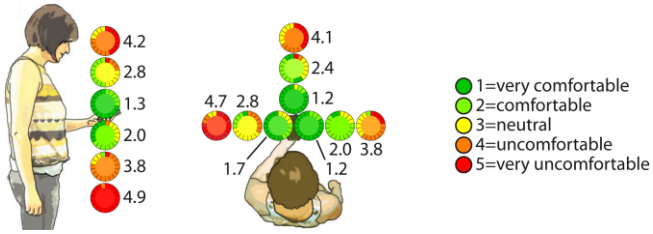

Figure 5. Comfort-ratings of the 15 gesture positions (segments around each middle circle show individual ratings, best viewed in color).

Again, as with acceptance rates for audiences and locations, we did not find any differences in the distance ratings or region ratings between introverted and extroverted persons.

We can conclude that the distance between the device and the region in which AD-gestures are made strongly influence how comfortable users feel performing AD-gestures in a public setting. The level of comfort depends on the position of the gestures: gestures below the device evoke feelings of discomfort (more so the further away they are from the device) and gestures to the right of the device are preferable (we note that all our participants were right-handed, we assume the results regarding the left and right regions should be mirrored for left-handed users).

Summary

Our results suggest that we could expect the majority of future around-device gesture users to have a neutral feeling when they use AD-gestures in the public (Q1), but that how comfortable they feel using the gestures will depend on

where and in front of whom the gestures are used (Q2 and Q3). The results also suggest that most users think that AD-gestures are compatible with many public settings, but that the acceptance for some settings is quite divergent. The results do not show that acceptance is related to the extraversion personality trait. Furthermore, our results (Q4) show that, generally, users feel more comfortable when gesturing within 30cm from the device (i.e., distances corresponding to the Close and Mid distances in the study).

Study 2 – Size and Duration

With the knowledge that most of the participants in our first study showed a neutral attitude towards using AD-gestures in public and that none completely rejected the idea of doing so, we conducted our second study to investigate how the size and duration of AD-gestures affect users' attitudes. Since Study 1 showed that there was no relationship between users' extraversion personality trait and how they perceived using AD-gestures in public, we decided not to use the Big-5 test.

For Study 2 we used the busy main entrance hall of the local university. The task and materials were similar to those used in Study 1. A set of images guided the participant through the task. As in Study 1, the images prompted one-digit numbers to be 'drawn' in the air at a specific in-air position around the device. A Silverlight Windows Phone application displayed the task images and randomized the image sequences for each new participant. One task image is shown in Figure 6. A task counter was shown in the top right corner, and a label in the top left corner indicated to the participant for how long he/she was required to draw the prompted number. When the 'start' button was pressed, the timer in the bottom right corner of the screen started. The participant was asked to re-draw the digit in the indicated location as long as the current task screen was shown. The next task screen was loaded when the timer reached the prompted duration.

We used small and large gestures. Small gestures were required to cover an area of about 15×15cm, large gestures 30×30cm. These sizes roughly correspond to half respectively the full distance of the preferred gesture distances defined by Study 1 results (Close and Mid). Two small gestures were prompted in each of the *Left*, *Front*, and *Right* regions (corresponding to distance *Close* and *Mid* in Study 1) and one large gesture was prompted in each of the three regions. We used three gesture durations: 3, 6, and 9 seconds (typical AD-gesture durations reported in the literature [6, 7, 9]). In total 27 task images were used. The used combinations of gesture size, duration and location are shown in Figure 6. Each combination was repeated twice, for a total of 54 images. After completing the 54 gestures the participant was debriefed and asked to complete the questionnaire shown in Figure 6. As in Study 1, we instructed the participant to answer these questions and to interpret the central word 'comfort' from a social perspective and to ignore issues related to physical comfort and practicability. Participation lasted around 25 min. Eighteen right-handed smartphone owners (3 female), aged 21 to 32 years (mean 26.1, s.d. 3.6) participated. Five had participated in Study 1.

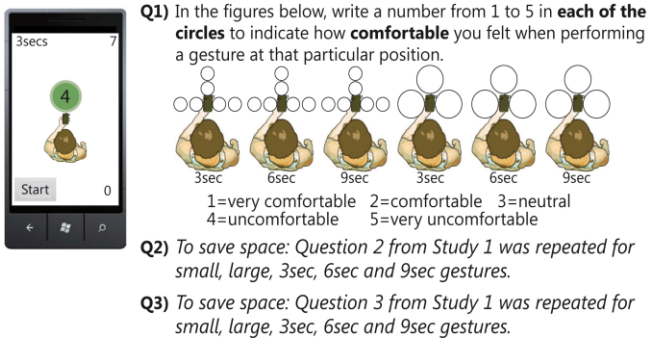

Figure 6. Left: task screen. Right: Study 2 questionnaire.

Results

Question 1: Figure 7 shows the mean rating for each of the 27 size/duration/location combinations rated by participants according to how comfortable they felt when performing these gestures. Although participants were asked to provide twice as many ratings for small than for large gestures (small gestures were performed twice in each region), we chose to make a comparison for guidance. The mean comfort-rating was 3.0 for small gestures and 3.5 for large gestures. A Wilcoxon test showed a significant difference ($Z = -2.9$, $p < 0.01$). Understandably, smaller gestures felt more comfortable as these are likely to attract less attention.

The average comfort-rating was 2.4 for 3sec gestures and 3.1 and 3.8 for 6sec and 9sec gestures, respectively. A Friedman test showed differences between the three gesture durations ($\chi^2_{(2,N=18)} = 34.5$, $p < 0.0001$) and post-hoc Wilcoxon tests (Bonferroni: α-levels from 0.05 to 0.016) showed differences for all pairwise comparisons. We also found significant differences among the three regions (Friedman: $\chi^2_{(2,N=18)} = 24.4$, $p < 0.0001$) with post-hoc Wilcoxon tests (Bonferroni: α-levels from 0.05 to 0.016) showing that the right region, with a mean rating of 2.6, was significantly different from both the front (mean 3.1)

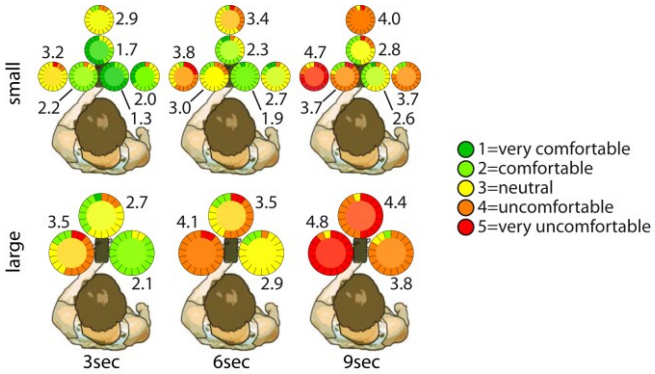

Figure 7. Comfort-ratings for all gesture size-duration combinations (segments around each middle circle show individual ratings, best viewed in color).

and the left (mean 3.7). Also left and front differed. Again we note that all participants were right-handed and assume the results would be mirrored for left-handed users.

In Figure 7 we also see an interesting interplay between position, size and duration indicating that the drawbacks of large gestures can be compensated if they are done in a favourable location and if they are quick (e.g., to the right/3sec). Likewise, a small 3sec gesture in a less favourable region (e.g., far away in the left or front region) is rated similarly to a large 6sec gesture in the preferred right region. We also note how small 3sec gestures are consistently rated about 0.5 points higher than in Study 1 at the corresponding gesture positions (close and mid distance, compare middle part of Figure 5). Since small 3sec gestures take longer than the gestures in Study 1, where participants only had to draw one quick digit, the higher ratings in Study 2 are reasonable and confirm the robustness of our rating-based approach. We can conclude that both gesture size and duration have a significant influence on how comfortable users feel when performing AD-gestures in public. Most users indicated that they felt comfortable or neutral using small gestures and were less comfortable with large ones.

Questions 2 and 3: We analyzed acceptance rates for audiences and locations aggregated across gesture sizes and durations. The results are shown in the left part of Figure 8. A Friedman test showed a significant difference between audiences ($\chi^2_{(5,N=18)} = 59.8$, $p < 0.001$) and post-hoc Wilcoxon tests (Bonferroni: α-level 0.05 to 0.003) showed that the least desired audiences – colleagues and strangers – differed from all other audiences, as in Study 1. The rates for the audiences were similar to those in Study 1 (±10%).

A Friedman test showed differences among locations ($\chi^2_{(5,N=18)} = 40.1$, $p < 0.001$) and post-hoc Wilcoxon tests (Bonferroni: α-level 0.05 to 0.002) showed that home differed from all other locations. In Study 1, home only differed from museum and bus/train.

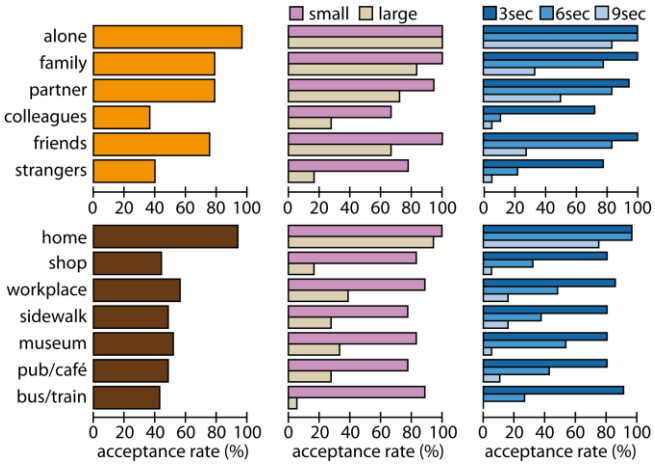

Figure 8. Acceptance rates for audiences (top) and locations (bottom). Rates aggregated across size and duration (left), split by size (middle), and split by duration (right).

The ratings for gesture sizes and gesture durations are shown in the middle and right parts of Figure 8. Clearly, for private settings (alone and home) size and duration had little or no effect. For familiar audiences (family, partner and friends) size and duration were more important. For the least familiar audiences, colleagues and strangers, we see pronounced differences with the rates for large, 6sec and 9sec gestures around 25% or below. We also see such pronounced differences for all non-private locations. In particular we note the great difference between 3sec and 9sec gestures in the location ratings: 3sec gestures have an acceptance rate close to, or above, 80% for all locations whereas 9sec gestures have rates below 10% (ignoring the private home setting). We conclude that, indeed, both gesture size and gesture duration have a great influence on how comfortable users feel about performing AD-gestures in public places (and to some extent even at home).

Summary

To our knowledge, considering unique gesture features has not been explored in prior acceptability studies. The results of Study 2 further confirm the need to examine the acceptability of gesture features separately. Gesture size and duration, both impact the acceptability of AD-interactions. We notice that acceptance drops rapidly after the 6-second mark. Furthermore, for all locations and audiences (except home and alone), larger gestures are seen as being less acceptable.

Study 3 – Spectators

After Study 2 and 3 where we investigated users' attitudes about the acceptability of AD-gestures we were also interested in the reactions of persons who have watched someone else using this type of input modality. We call these persons "spectators". We are unaware of any previous work on mobile gestures that investigates spectators' reactions by probing people in public. Another important aim with the study was to compare the effect of having participants perform interactions themselves – as in Study 1 and 2 – to the effect of only letting participants watch another person and then ask them to imagine their own future usage without having had the opportunity to try out the interaction themselves (as in previous video-based acceptance assessments of mobile gestures [13, 14, 15]).

One of the authors acted as an AD-gesture user in five different locations: in a commuter train, in a café, in a library, in a restaurant, and at a birthday party. The author worked through the same image set as was used in Study 1 until noticing having caught someone's attention. This spectator was then asked to answer the questions shown in Figure 9. Answers were collected from 24 spectators aged between 17 and 43 years (mean 26.7, s.d. 9.6). Eleven were female and all but one owned a smartphone.

Results

Question 1: In Question 1 spectators were asked to select one or more statements to describe his/her thoughts when

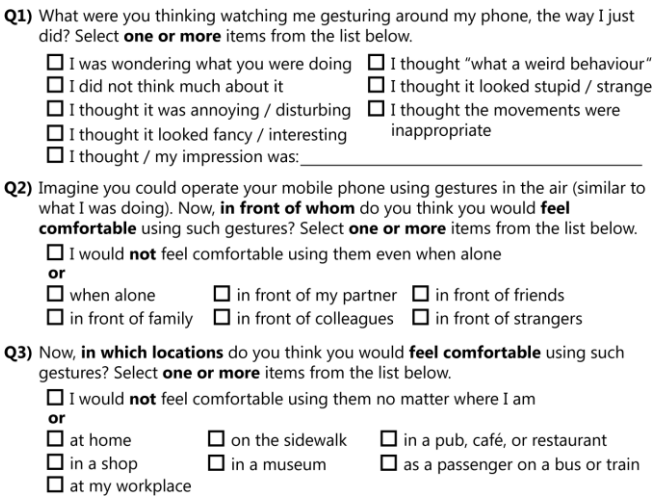

Figure 9. Study 3 questionnaire.

watching the AD-gestures. Twelve spectators (50%) indicated that they became curious, wondering what the user was doing. Twelve indicated that they did not think much about what they had seen and two commented that it looked "cool". One thought that it looked "fancy". Only five spectators thought it was a weird behaviour and one thought it looked stupid or strange. No one thought it was annoying or disturbing. These initial reactions were given by the spectators before they were informed about the idea of AD-gestures and before they knew what the user actually did. This suggests that most spectators perceived the gestures in a neutral or curious way. Very few perceived the gestures as something negative or disturbing.

Question 2 and 3: Spectators' acceptance rates, generated from answers to Question 2 and 3 (in front of whom and in what locations they thought they would feel comfortable using AD-gestures), are shown in Figure 10. As the users in Study 1, all spectators answered that they would comfortably use AD-gestures when alone and 92% said they would feel comfortable using the gestures in front of their partner and friends. The acceptance rate for family, colleagues, and strangers amount to 83%, 79%, and 67%, respectively. We found a significant difference between the audiences (Cochran's Q test: $\chi^2_{(5,N=24)} = 15.4$, $p < 0.01$). But post-hoc pairwise McNemar tests with the conservative Bonferroni correction (α-level 0.05 to 0.003) showed no significant differences among pairs of audiences.

When compared to the acceptance rates in Study 1 (Figure 3) where Question 2 was answered after a firsthand

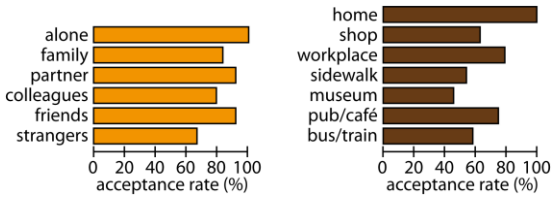

Figure 10. Acceptance rates for audiences and locations.

experience of performing AD-gestures in a public setting, we see markedly higher rates in Study 3 for the least familiar and most critical audiences, colleagues (79% vs. 33%) and strangers (67% vs. 33%). The results for the more familiar audiences are similar in the two studies. We also find higher acceptance rates in Study 3 for most locations. Rates for home and shop were the same in both studies, for the other locations we find higher rates in Study 3. The differences vary between four percent points (sidewalk) and 25 percent points (bus/train). A Cochran's Q test showed a significant overall difference among locations ($\chi^2_{(6,N=24)} = 28.3$, $p < 0.0001$). Post-hoc McNemar tests (Bonferroni: α-level 0.05 to 0.002) showed that the acceptance rate for home was significantly higher than for shop, sidewalk, museum, and bus/train (no other pairwise comparison was significant).

In conclusion, the results from our spectator study indicate that AD-gestures are not likely to be perceived as obtrusive (Q1). None of the spectators we asked thought the gestures were inappropriate or annoying. Indeed, many did not think much about the gesturing they had watched, 50% got interested and curious. Furthermore, as most users in Study 1 and 2, most spectators were quite open to the idea of AD-gestures and thought they would feel comfortable using them in public locations and in front of strangers. However, acceptance rates were generally much higher in Study 3 than in Study 1, indicating an over-estimation. A likely reason for this is the absence of an actual usage experience to relate to when providing the answers.

DISCUSSION

In this section, we discuss the lessons we learned and insights we gained from our studies. We also demonstrate how our findings can be applied to existing around-device interactions, reflect on limitations in our approach, and point at directions for future work.

AD-Input Design Considerations & Recommendations

Intuition may provide initial guidance regarding AD-input design, suggesting general directions such that a small or quick gesture is more likely to be acceptable than a large or lengthy one. However, without experience or empirical data it is difficult to estimate what size is small enough; when does a gesture start to feel too lengthy; and to correctly predict the consequences of changes regarding such gesture parameters. With our results we can provide opening design considerations and recommendations.

It is evident from our results that AD-gestures belong to an acceptability-continuum where a combination of several gesture properties influences user perceptions and how comfortable users feel about performing the gestures in a social setting. Our results demonstrate that users are sensitive to the parameterization of the examined properties – distance from the device, input region, gesture size and gesture duration – and that rather small differences in

parameter settings may result in large shifts on the acceptability-continuum.

The following considerations and design recommendations emerge from our exploration of AD-gesture acceptability:

• *Distance*: AD-gestures that are closer to the device are more acceptable. Our results suggest a critical point approximately 30cm away from the device. Input beyond this distance is likely to be considered as "socially awkward" and thus should be avoided if possible (the region from the device extending to this point is slightly smaller than the intimate space defined in studies on proxemics [4]). The critical distance is applicable for all tested regions: to the left and right, in front, above, and below the device.

• *Input region*: Our results reveal a strong preference for gestures to the right of the device for AD-gestures, then the front region (for right-handed users, and the reverse otherwise). This suggests that AD-input designers need to consider user handedness (which should be reflected in the operation of the system) and that they should design for input to the right and in the front of the device. However, also the regions above, below and to the left of the device are acceptable given that the critical distance is attended to.

• *Size*: When in public, users indicated a strong preference for small gestures. Our results indicate that caution is warranted when the gesture size approaches 15×15cm, larger gestures should be avoided.

• *Duration*: Gesture duration strongly affects users' comfort levels, even after a few seconds of AD-input users are likely to start feeling uncomfortable. Acceptance drops rapidly after the 6-second mark.

• *Gesture property interplays*: The strong interplays we found between gesture properties suggest that AD-interaction designers can achieve socially acceptable designs even when their interactions require less favourable property characteristics. For example, the negative effects of an over-sized gesture can be reduced if input is allowed very close to the device or in a favourable region. Thus, designers are good advised to carefully consider such interplays and to examine possibilities to encounter critical features by making changes to other gesture properties.

Adaptations to AD-Interactions

Our findings can be directly applied to several existing AD-input techniques. For example, Hoverflow [9] uses a small space (5-7cm) above the device for simple interactions such as to sweep or to rotate an image. Similarly, SideSight [1] uses proximity sensors that are capable of detecting limited space (8cm) along each side of the device. In contrast, our results suggest that socially acceptable AD-input space could be larger (30cm) and could be used for complex 3D gestures such as Cyclo [11] for continuous zooming. Such gestures could extend up to 6 seconds in length without impairing users' perception of comfort.

Few AD-techniques utilize the valuable – and acceptable – space below the device. For example, the AD-Binning technique [6] relies on a large 2D space, extending up to 40cm away from the device, to allow users to store, browse and retrieve contents through gestures issued within storage bins that are positioned in AD-space. Our results revealed that people feel uncomfortable using far distances for AD-input. This finding diminishes the potential value of AD-Binning. However, our results can suggest alternatives and still allow users to benefit from AD-Binning. Using the space above and below the device, we could reorganize bins in a layered structure into a small 3D space. This avoids large reaching distances and thus likely improves the acceptance of the technique.

Improved Methods for Acceptance Studies

Our studies included two new approaches to collecting user opinions related to social acceptance. The first consisted of teasing apart specific gesture features. Whereas in prior work results would indicate whether a gesture is viewed as either acceptable or not, our approach is to examine unique elements of gestures. This may not be possible with all types of gestural input. However, when the interaction modality affords this, such as with AD-input, we recommend that studies tease these apart. In our case we found that rather small changes on the studied variables had a large influence on user perception. Furthermore, teasing apart gesture features may reveal new opportunities to improve the acceptability though intelligent combinations or adjustments to the individual parameters.

The second adjustment we included was to ask participants to rate their view of a gesture after having experienced using this in a public setting. Prior work has relied on visual demonstrations of the studied gestures and on participants' imagination of a future usage situation. In our case, we found that having a person rate gestures without having had a firsthand usage experience resulted in much higher acceptance rates. Overly positive responses in early design phases may allude to sub-optimal designs that future users may avoid in public settings. However, more targeted methodological research endeavours are needed to systematically disentangle the effects of firsthand usage experiences in acceptability related matters.

We also introduced a new dimension to social acceptability studies by exploring possible linkages between personality traits and user perception. Our results did not reveal any relations between the extroversion trait and user perceptions. One explanation might be that people are starting to get familiar with mid-air sensing mechanisms, through systems such as gaming consoles. Our surprising finding may also be related to the small number of participants used in Study 1. We acknowledge the limitations of the Big-Five personality test. It provides one aspect of a person's traits. Additional work is needed to identify how social acceptability tests can be linked to personality types.

Limitations

We acknowledge the limited methodological support for our central use of perceived 'mental comfort' as a predictor of social acceptance. However, as numerous previous study designers [13, 14, 15, 17, 18] and many of their participants have used a similar terminology, our choice was not a farfetched one. We also recognize that user acceptance and social acceptance are multifaceted concepts, by fare not limited to the perceived or expected levels of mental comfort [3, 13]. In our studies we focused on social settings and ignored important cultural factors, such as participants' cultural background. Our studies were conducted in Canada and Austria with persons living there. Little is known about how cultural aspects influences user perceptions about, and the social acceptance of novel interaction techniques [17]. Accordingly, and with all our participants living in a western culture, we are wary of generalizing our results to non-western users and cultures. We suspect that examining culture-dependent differences of technology adoption and social acceptance would be a challenging but very fruitful path for future work. Finally, we are also wary of assuming our results apply to other age groups. Most of our 60 participants were 25 to 35 years old (mean 27.8, s.d. 7.6).

CONCLUSION

In this paper, we have presented three studies that explored the acceptability of hand gesture input in 3D space around a smartphone. The studies were performed in various public locations. We surveyed users that performed such Around-Device gestures and people who passed by about their impressions. Most users and spectators answered they would use such interactions if available on their smartphone, but also indicated they would be concerned about others' reactions. Our results show that people are selective regarding in what public settings they would use gestures. Moreover, gesture properties, such as duration and distance from the device, have a great influence on how comfortable users feel when using Around-Device gestures in public. Acceptance and perceived mental comfort markedly sink if gestures are done further than 30cm away from the device or last longer than 6 seconds. Gesture size and region (e.g., on the side, above or below the device) also matter. According to our findings and study experiences, we presented recommendations for around-device input designers and suggestions about how to improve methods used in studies related to the social acceptance of novel interaction techniques.

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