Touch or Touchless? Evaluating Usability of Interactive Displays for Persons with Autistic Spectrum Disorders

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ABSTRACT

Interactive public displays have been exploited and studied for engaging interaction in several previous studies. In this context, applications have been focused on supporting learning or entertainment activities, specifically designed for people with special needs. This includes, for example, those with Autism Spectrum Disorders (ASD). In this paper, we present a comparison study aimed at understanding the difference in terms of usability, effectiveness, and enjoyment perceived by users with ASD between two interaction modalities usually supported by interactive displays: touch-based and touchless gestural interaction. We present the outcomes of a within-subject setup involving 8 ASD users (age 18-25 y.o., IQ 40-60), based on the use of two similar user interfaces, differing only by the interaction modality. We show that touch interaction provides higher usability level and results in more effective actions, although touchless interaction is more effective in terms of enjoyment and engagement.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Usability testing**; **Interaction paradigms**; **Displays and imagers**; **Gestural input**; **Touch screens**.

KEYWORDS

touchless interfaces, mid-air gestures, touch, autism, usability evaluation, interactive displays

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1 INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurological developmental disorder that negatively affects the social and everyday living skills of individuals diagnosed with it. Studies have illustrated the potentials of computer-based learning interventions to teach social and daily living skills to children and adolescents diagnosed with ASD [3]. According to a recent review conducted by Khowaja et al. [29], most studies that investigate the effectiveness of computer-based interventions for individuals diagnosed with ASD use basic input modalities such as mouse, keyboard, and touch screen interfaces. However, the emergence of technologies such as virtual reality (VR) and augmented reality (AR) has increased the interest towards novel input modalities such as mid-air gestures and body movement [41], or eye-gaze input [15]. Several studies have illustrated the effectiveness of VR and AR interventions to teach social and everyday living skills to children diagnosed with autism [1]. Moreover, many studies investigated alternative input modalities such as gestures and body movements [18, 19]. However, how such novel input modalities differ from more traditional ones is still not clear, not only in the context of AR and VR, but also when interacting with other visualization means (e.g. traditional LCD displays).

Interaction of persons with special abilities with large displays is an interesting subject of study in human-computer interaction. For instance, many digital installations in museums (often empowered with interactivity) are based on such displays, and while usually intended for children, they are generally aimed at learning activity [7, 31]. In practice, ASD users may profit of novel interaction modalities in such contexts, since prior work proved how them positively impact in improving learning skills [6]. Similar considerations apply to the many interactive applications based on large displays, adopted in learning environments. Therefore, it is worth understanding which interaction modality is more useful in these contexts. Understanding the impact of specific interaction modalities on learning and enjoyment have been subject of study by prior work [38]. However, other factors are crucial too, e.g. user experience and usability.

In addition, there are two additional reasons that support the goal of understanding interaction of persons with special abilities with large displays: (i) different kinds of interaction may impose a different distance of users from displays; (ii) the specific abilities of special persons may modulate their peripersonal space. In particular, children with ASD are known to be reluctant to interact with others at close distance, and their peripersonal space is significantly enlarged as compared to children with typical development [10].

While touch-based interaction requires the display to be at arm's reach, thus intersecting the peripersonal space, touchless interaction can be established with a display that is outside such space. The role of peripersonal space in body-environment interaction in real, virtual, and augmented environments is an active topic of study in cognitive sciences [39].

Based on this reasoning, in this work we focus on two of the common input modalities used for supporting interactivity with large displays: touch-based input – i.e. the most traditional one –, and touchless mid-air gestural input. In particular, the main goal of this study is to understand which are the differences between these input modalities, from the particular point of view of ASD users.

To this end, we conducted a comparison study between two interfaces specifically designed in order to differ only by the input modality, but being equally designed in terms of content and appearance. In this study, we measured usability by means of standard questionnaires, and analyzed different metrics in order to understand the effectiveness of each input modality, as well as the level of enjoyment. Our results suggest that touch-based input allows for higher usability and more effective interaction, whereas touchless input makes interactions more enjoying.

The rest of the paper is organized as follows: section 2 provides an overview of the related work; section 3 describes the study design, including the descriptions of the two interfaces, as well as the study procedure; section 4 provides an overview of the results, which are discussed in section 5; section 6 concludes the paper, providing an outlook of the future work.

2 RELATED WORK

This work builds upon prior HCI work, within research areas such as touchless gestural interfaces, pervasive displays, and assistive technologies for ASD users. This section provides an overview of related works that guided our research.

2.1 Interaction with Pervasive Displays

Pervasive displays offer a plethora of possibilities in terms of supported interactions. Some displays offer implicit interaction, such as reacting to the user's natural behavior when they approach the display. This is the case of deployments where display is made more noticeable by showing silhouettes or avatars that mimic users' movements [27, 33, 40].

Apart from implicit interaction, many prior works investigated explicit interaction, allowing for modalities beyond keys and buttons, such as touch [37], touchless mid-air gestures [20], feet-based input [42], mobile devices [35], eye gaze [28], or multi-modal combinations of them [30]. Touch interfaces are currently the most used in common public displays, and they represented a significant improvement if compared to physical hardware (e.g. buttons and keys), since they expand the entropy of interaction possibilities [16]. However, a downside of touch interfaces is that they have to be physically reachable, whereas public displays are often mounted above user's height for visibility, or placed behind shop windows. Consequently, researchers have proposed alternative interfaces, often referred as touchless interfaces, where interaction can take place without physical contact between the user and any part of the interactive system [17]. While such class of interaction modalities includes also mobile-based and eye gaze-based interaction, here we focus on mid-air gestures.

The use of touchless gestural interfaces have been adopted in many contexts, both in research projects and in industrial applications. They have been used in order to interact with 3D virtual objects [4], access information provision systems [12, 40], create and support playful interactions [33], and many others. In the context of pervasive displays research, touchless gestural interfaces offer many advantages. For instance, they allow limiting vandalism by placing the display in unreachable places [40], keeping a high hygiene level of the screen surface [24], and removing constraints to the display size (as demonstrated by many applications involving media façades [14]).

Walter et al. analyzed prior work in order to categorize the possible user representation in touchless gestural applications, highlighting three possible options: hand-shaped cursors, avatars, and user's silhouette [44]. Recently, other works focused on the use of silhouettes or avatars [22, 33], since they proved to be very effective in solving some common issues of pervasive displays, namely display blindness (i.e. users do not look at the display because of their prejudice about the content [34]), interaction blindness (i.e. the inability of the users to recognize the interactive capabilities of a display [36]), and affordance blindness (i.e. the inability to understand the interaction modality of the display [13]). Gentile et al. showed also that the presence of an avatar makes two-handed interactions more "natural", reducing the cognitive workload while interacting with public displays [21].

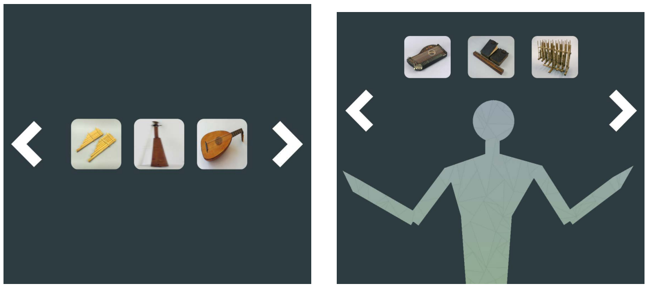
Given the large adoption of avatar- or silhouette-based interfaces for providing touchless gestural interactivity, and the advantages described above, in this work we based our design choices on this paradigm in order to develop our prototype.

2.2 ASD Users and Pervasive Displays

Prior work demonstrated how pervasive displays might be useful to support ASD users in many contexts. Matic et al. showed how such displays may encourage positive behavior [32]. Tentori et al. discussed the ability of displays to support learning activities, and proposed ways to increase behavior awareness, trigger social interactions, and promote teamwork [43].

Based on such findings, understanding the preferences between touch or touchless interaction modalities is thus crucial. Jakobsen et al. studied this difference in terms of effectiveness, showing that mid-air gestures are not as effective as touch-based input, since they are more error-prone and do not allow fine-grained selections (e.g. when targets are small) [26]. However, that study did not target the special abilities and preferences of ASD persons. Moreover, effectiveness is not the only metric of interest: enjoyment, engagement, ability to support learning or to facilitate attention are just a few of the many other factors that may have an impact on the choice between touch or touchless interfaces.

Several touch-based serious games for ASD-children have been reviewed by Zakari at al. [47], showing how this interaction modality may help children in expressing their feelings and improve the level of engagement with others. As for touchless gestural interfaces, Garzotto et al. discussed how this interaction modality can be useful for improving attention skills [19], as well as for facilitating



(a) (b)

Figure 1: Layouts of the (a) touch and (b) touchless UIs.

learning activities by exploiting imitative capacity due to the use of body movements [18].

All these findings suggest that both touch and touchless interfaces provide significant advantages for developing assistive technologies for ASD users. However, to the best of our knowledge, no prior work compared these modalities with the specific goal of understanding differences in terms of effectiveness, usability and enjoyment, especially considering ASD users' preferences. In this paper, we aim at filling this gap by reporting on a comparison study between touch and touchless interfaces.

3 STUDY DESIGN

As mentioned in the previous sections, the main goal of our study was to evaluate the usability and effectiveness of interactive displays for a specific class of users, i.e. young ASD adults. In particular, we were interested in understanding whether the use of mid-air gestures is more or less appropriate if compared with more traditional touch-based interfaces.

We conducted the tests in controlled conditions, during a time span of three days. All participants performed two interaction sessions, one per each interface (i.e. within-subject setup). The two interaction sessions were separated by a couple of days at least, in order to minimize any possible carry-on effect. Moreover, the order of the experiments was counterbalanced.

3.1 Design Choices

In order to evaluate the perceived usability and effectivenes of touch and touchless interaction modalities, we developed two similar interfaces (see Figure 1). Both the interfaces show three interactive tiles, each of which depicts a musical instrument. Two interactive arrows allow the user to navigate among the available instruments. When the user selects a tile, the corresponding instrument sound is automatically played.

In the touch-based interface, the user can select a musical instrument or an arrow just by tapping on them. This simple design is derived from the observation of traditional touch-based interfaces. Nowadays, many mobile-accessible websites and public display applications include sliders similar to the one shown in Figure 1a. Consequently, we built such interface with the aim of reproducing a traditional touch-enabled interface. Along with the affordance of a large display [13], this choice allowed us to consider this interface as a sufficiently generic and standard baseline against which we can test the second condition, i.e. the mid-air gestural interface.

The touchless interface exploits the presence of an interactive avatar that appears whenever a user approaches the display, and remains permanently present in the middle of the screen, continuously replaying user's movements. The user can select a musical instrument or an arrow by driving the avatar's hands on top of the available tiles, with no activation gestures. This is particularly useful for supporting immediate usability.

As already mentioned in section 2.1, the use of avatar-based interfaces has many advantages, including the ability of communicating the supported touchless gestural interactivity [33], and the reduction of the perceived cognitive workload, which should contribute to make the interactions more natural [21]. While adding the avatar to a gestural UI is crucial to make it reasonably effective, with touch-based interfaces the affordance of the display and the users' prior experiences can be considered sufficient to overcome these limitations [13].

3.2 Apparatus

Both the interfaces have been implemented using HTML5 and JavaScript, and run on a full-screen browser (Google Chrome), displayed on a 65-inches touchscreen[1] placed at eye-height. In order to support touchless interaction, gestural data have been gathered from nd May a Microsoft Kinect sensor placed below the screen, using a C#/.NET application for communicating with the JavaScript UI (similarly to architecture described in [23]).

The setup included also a camera, which was placed next to the Kinect during touchless interaction sessions, and behind the user during touch interaction sessions. The camera was used to record both video and audio. We also recorded screen captures during all the interaction sessions.

3.3 Participants

Our study involved a total of 8 participants (7 males, 1 female), aged between 18-25 y.o. (M = 19.73, SD = 2.37). All participants were students of STUEN Rødovre, a school for young adults diagnosed with mental disorders. All the students were diagnosed with autistic spectrum disorders, and the school informed us that participants' IQ ranged between 40 and 60[2].

All the users had prior experience with technology. In particular, all of them had experiences with controller-based interaction in VR via head-mounted displays (HMDs), as well as with touch- and mouse/keyboard-based interaction with large displays, since the apparatus we used was already installed in their classroom. However, none of the participants declared to have prior experiences with mid-air gestural interaction. Since the application we tested was about musical instruments, we also collected information about prior experiences with them. Six users declared to have had prior experiences, but we did not notice any relation between such experience and the users' opinion on the whole application tested.

[1] Iiyama ProLite TH6564MIS-B2AG: http://tinyurl.com/perdis19 (last retrieved: May 2nd, 2019).

[2] The school was not allowed to provide us with IQ of each participants, but only a range within which each of the participants' IQ was included. IQ has been measured by expert psychologists, by means of standard tests [45].

It is worth mentioning that all the participants have been involved voluntarily, and all of them declared their intentions by signing an informed consent form before the beginning of each session. They were all adult, able to care of themselves and take the decisions such as to participate to this study.

3.4 Procedure

The test was conducted inside a classroom, using a wall-mounted display. During the test, only a user was invited to stay in that room, in the presence of two researchers and one teacher. At the beginning of the test, the user was welcomed and invited to fill out the aforementioned consent form. If required, a researcher and/or the teacher could help the user in understanding the content of the form, also replying to questions. The researcher and the teacher were instructed to not provide information about the interaction modalities, avoiding sentences that mention the use of body, hands, arms, gestures or touch.

The user was also informed about the need to record a video of the following interaction sessions. The interaction session consisted in two stages, namely training stage and main stage.

The training stage was inspired by the experimental design described in [38]. During this stage, the user was firstly asked to interact with the interface. In this case, she had to figure out how to properly interact by herself, with no instructions provided by the researchers. If the user was unable to understand how to interact with the display, a researcher was allowed to give her a suggestion every 30 seconds, from a list in increasing explicitness order (this situation is depicted in Figure 2).

The instructions list for the touch interface was:

- **Step forward** This suggestion was provided in case the user tried to interact from a distance with the touch interface;
- **Try to touch the screen** This suggestion was provided in case the user did not understand that she had to touch the screen;
- **Mimic** This suggestion consisted in the researcher showing how to interact properly.

The instructions list for the touchless interface was:

- **Step back** This suggestion was provided in case the user tried to interact by touch with the touchless interface, since being too close to the display did not allow the avatar to be visible;
- **Try to move your arms and hands** This suggestion was provided in case the user did not understand that she had to use her body, when interacting with the touchless interface;
- **Mimic** This suggestion consisted in the researcher showing how to interact properly.

In case none of the previous instructions allowed the user to understand how to interact, the researcher could have asked the teacher for some additional help in order to explain the user how to interact properly. Anyway, we never needed to use this extreme solution in our tests.

After the training stage was complete, the user was asked to perform the following tasks:

- **T1** Select the instrument in the middle
- **T2** Select the right arrow, twice
- **T3** Select the left arrow
- **T4** Select the left instrument
- **T5** Continue as long as you want
- **T6** Select your favourite instrument

After completing all the aforementioned tasks, the user was asked to fill in a final questionnaire, for usability assessment and to collect some demographic information.

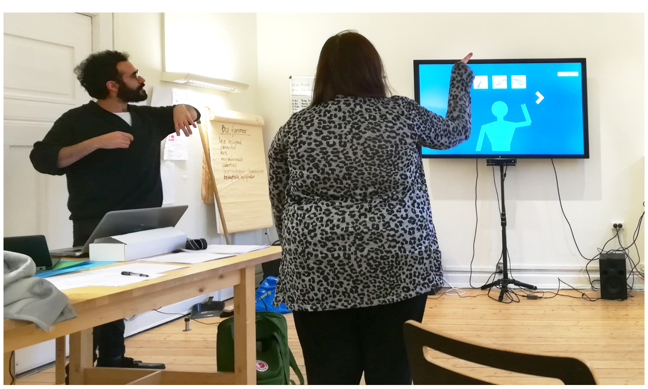


Figure 2: Study setup: a user interacts using mid-air gestures during the training stage, receiving instructions from an experimenter.

3.5 Data Collection and Analysis Method

During the study, we collected data from different sources: demographic and usability from the questionnaire, notes and observations by the experimenters during the main stage of each interaction session, and timings coded looking at the videos (i.e. offline).

3.5.1 Questionnaire. The questionnaire was divided in four sections: the first three sections contained questions for the user, while the questions in the last section were intended for the teacher.

The first section was aimed at collecting demographic information such as age, gender, and possible previous experience with musical instruments.

The second section included two questions focused on users' preferences, asking how much they like music, and how much they enjoyed the application used during the interaction session. Answers to these questions were provided by means of 5-points Likert scales associated with emoticons, i.e. using the so-called *smile-o-meter* [25].

The third section represented a simplified version of the System Usability Scale (SUS) [9]. In particular, we selected 7 of the 10 questions, excluding questions number 2 ("I found the system unnecessarily complex"), 5 ("I found the various functions in this system were well integrated"), and 6 ("I thought there was too much inconsistency in this system"). The rationale behind this choice is that such questions appeared too convoluted for the specific class of users being tested. For this questionnaire section, the answers were provided using 5-points Likert scales associated with emoticon, i.e. again with the *smile-o-meter* approach.

The fourth and last section of the questionnaire was a full SUS, but without emoticons since this section was intended for the teacher, who was asked to answer by putting in user's shoes. This allowed us to collect a secondary usability score provided by an expert who can correctly understand the meaning of ASD users' reactions, signs, and behavior. This approach has been inspired by the procedure described in [11].

Results from the third and fourth sections were then used for computing two SUS scores. For the fourth section (i.e. standard SUS), we used the procedure described in [9], whereas the same procedure was slightly adapted for the third section, due to the lower number of questions. Both the SUS scores ranged from 0 (lowest usability) to 100 (highest usability).

3.5.2 Other data. Along with questionnaire data, we also collected the number of instructions provided during the training stage. Moreover, the analysis of videos allowed us to collect the following information:

- time required to complete the training stage of each interaction session;
- duration of each task during the main stage of each interaction session;
- any other relevant behavior not noted during the tests.

3.6 Limitations

We are aware of some limitation about our study. The low number of participants make significance of results difficult to assess. For this reason, we decided to use multiple metrics, triangulating them in order to enforce the results. We are also aware about the variegated nature of autistic spectrum disorders, and how this difference makes difficult to generalize any result to any other ASD user. However, we are convinced that our findings may be used along with prior and future work in order to draw design guidelines for interactive applications for ASD users.

4 RESULTS

All the users successfully accomplished the tasks they were assigned. In the following, we described the main results noted after analyzing the data, according the the methods described in section 3.5.

4.1 Usability Assessment

In order to evaluate usability, we analyzed the answers from the SUS questions included in the questionnaire. The average SUS score computed based on users' answers was 80.36 (SD = 12.81) for touch condition, which resulted higher than the touchless condition (M = 76.02, SD = 17.58). Looking at the answers provided by the teacher, results are in line with users' preferences. Indeed, the average SUS score for touch interaction is 91.25 (SD = 13.36), whereas it resulted 86.07 for the touchless condition (SD = 6.59). Despite the differences, it is worth noting that all the reported average SUS scores can be associated with an acceptable usability level according to [5].

An additional measurement that confirms the higher usability of the touch-based interface is the number of instructions provided by the experimenter in order to help the user in understanding how to properly interact. We computed an average number of instructions of 0.63 (SD = 0.74) for the touch condition, against 1.43 instructions required for the touchless interface (SD = 0.98).

It is worth noting that the difference in usability may be a direct consequence of the learning curve required from the touchless interface. This is not necessarily a problem, since users seemed to be able to deal with the initial learning stage, and often to autonomously overcome the initial difficulties. For instance, a user (ID: *ER*) decided to interact while thinking aloud, using sentences such as "*I can touch myself*", "*Do I have legs? No I don't*", or "*Let me try to press that*". Similar situations were observed with other users (IDs: *JO-R*, *MI*). This suggests the ability of identifying themselves in the avatar, as well as to control it. Moreover, the need to discover the interaction modality seemed to serve as a way to make the whole application more enjoyable. It is thus no surprise that touchless UI, although less usable, resulted in a higher level of enjoyment (as will be reported in section 4.3).

4.2 Timings and Effectiveness

We were also interested in understanding the capabilities of these interfaces to communicate the type of supported interactivity (touch vs. touchless). The average number of instructions already mentioned in the previous section indicates that the touch interface is more able to communicate the interactivity. To better support this observation, we also analyzed the average time required for the training stage, and compared the two conditions. On average, the touch interface required a training stage of about 65.71 seconds (SD = 30.64), whereas this average duration increases for the touchless conditions (M = 73.43, SD = 15.52). This is in line with the number of given instructions we recorded, suggesting that the touch-based interface is more able to communicate the interactivity if compared with the touchless one.

We also wanted to understand which of the two interfaces can be considered most effective in assisting users for selecting tiles and accessing information. To this end, we analyzed the timings collected during the main stage of each interaction session. In particular, we considered the time required for performing tasks T1-T4 (so excluding those where users were allowed to interact *ad libitum*, as long as they wanted). We measured an average time of 33.86 seconds (SD = 19.20) for the touch condition, and a higher average time for the touchless UI (M = 40.86, SD = 11.45). This result is in line with the previous observations about effectiveness, suggesting that better performances in terms of interactions can be achieved by adopting touch-based solutions.

4.3 Enjoyment and Engagement

In order to evaluate the differences between the two interfaces in terms of their capabilities of fostering enjoyment, we analyzed the answers to the question "*How much did you enjoy the application?*". Moreover, we looked at the average duration of task T5, since this appeared a decent estimation of how engaging was the tested interaction modality (the more the user interacted, the more the interface appeared interesting, or engaging, or enjoying).

Our analysis showed that the perceived level of enjoyment (based on the questionnaire answers) was 4.38/5 on average for touch-based interface (SD = 0.74), whereas for the touchless gestural it was higher (M = 4.86/5, SD = 0.38). This is confirmed by the duration of task T5, which was higher in the touchless condition

(M = 95.00, SD = 53.54) than in the touch-based UI (M = 84.14, SD = 68.15).

5 DISCUSSION

Results showed a preference towards touch input in terms of effectiveness. This is in line with prior work by Jakobsen et al., where touch input has been proved to allow for fine grained interactions, while mid-air gestures are more error prone [26]. However, there could be other reasons for this higher effectiveness. Indeed, all the users had prior experiences with touch interfaces (e.g. smartphones or tablets screens), so it is likely that users have much higher familiarity with touch input, especially if compared to touchless interaction. This might also affect the ease of accomplishing assigned tasks, in turn reducing the task duration. This means that the effectiveness of touchless interaction might be improved by practising with touchless gestural interfaces.

On the other hand, enjoyment is another crucial factor when designing for ASD users, especially considering that most applications are meant for learning activities. Indeed, enjoyment has been proved to foster higher engagement [46], and consequently improve learning capabilities [2]. Prior studies showed that using body movements for interacting may increase enjoyment [8], and this may explain why the touchless interface has been found to elicit higher levels of enjoyment. This would mean that supporting touchless mid-air gestures is more appropriate when learning and engagement have a higher priority, as compared to effectiveness and fine-grained selections. However, it is fair noticing that the ability of touchless interaction to foster higher enjoyment levels may be due to a novelty effect, simply because participants were less familiar with this kind of interaction.

6 CONCLUSION AND FUTURE WORK

We presented the results of a comparison study aimed at understanding the differences between touch and touchless interaction with an interactive display from an ASD user's point of view, in terms of usability, effectiveness and enjoyment. Our analysis suggests that touch-based input allows for more effective and usable interactions. However, using mid-air gestures seems to increase the level of enjoyment due to the higher engagement of this type of interaction.

All in all, we are convinced that touchless gestural interfaces are more suitable for all those contexts where enjoyment (and thus engagement) are crucial, e.g. scenarios where learning is the main actual goal.

Future work may consider longitudinal studies in order to account for possible novelty effects. Moreover, we are planning to extend our study with a higher number of participants, in order to improve the significance of our results.

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