Different interaction paradigms for different user groups: an evaluation regarding content selection

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ABSTRACT
In recent years there has been a boom of different natural interaction paradigms, such as touch, tangible or gesture-based interfaces, that make better use of human's innate skills rather than imposing new learning processes. However, no work has been reported that systematically evaluates how these interfaces influence users' performance with regard to their level of digital literacy or even age. Furthermore, it is also important to understand the interaction paradigms' impact when performing basic operations, such as data selection, insertion and manipulation, and which interface could be the most efficient for each task. This paper reports the first step of an exploratory evaluation about the relationship between different interaction paradigms and specific target-audiences: dealing with a selection task. We conducted an experiment with 60 subjects to evaluate how different interfaces may influence the performance of specific groups of users. Four input modalities are evaluated in a selection task and results for these different user groups are reported in terms of performance, efficacy (error rate) and user preference. For each group of users, we determined there was a statistically significant difference between the mean time taken to complete the task in each interface. Also, the one input modality every user was accustomed with (the computer mouse) was the one that showed the most discrepancy regarding performance between the groups. We believe that this study raises new issues for future research.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation (e.g., HCI)**]: User Interfaces – *evaluation/methodology, input devices and strategies (e.g., mouse, touchscreen).*

General Terms
Performance, Design, Human Factors.

Keywords
NUI, interaction paradigms, input modalities, mouse, touch, tangibles, gestures, selection task.

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1. INTRODUCTION
The recent advances made in human-computer interaction have allowed us to manipulate digital contents more intuitively, exploiting recognition-based technologies that interpret complex human behaviors, such as speech, eye gaze, body language or gestures. These interfaces are considered natural as they require low cognitive loads from the user and prioritize their innate skills [16].

State-of-the-art multimodal interfaces recognize up to two interaction modes within different fields of interest, whether through the combination of pen devices and speech [20, 26], speech and gestures [17, 14], or multi-touch and tangible interfaces [5, 21, 15]. As Oviatt and Cohen allude [18], multimodal interfaces tend to become more flexible as to how they apprehend the user's commands and what forms of input they permit according to the user's abilities and/or preferences, for instance: age, skill levels, cognitive styles, sensory and motor impairments, native language, or temporary illness. However, with the continuous addition of new input modalities in our daily lives there is no full conscious as to what paradigms can help or actually impair the user. That is to say, there is not much awareness of which interaction paradigms are the most adequate for different user profiles: children, people with different levels of digital literacy, elderly users, etc.

On the other hand, it is also important to understand which interface may be the most efficient regarding specific tasks performed by the user. In a virtual environment, the most basic tasks a user can perform are data selection, insertion and manipulation. It is important to understand if for different tasks there are different interfaces that can better assist the user. Nevertheless, to our knowledge there has not yet been a systematic study to understand this relation and throw some light as to which interfaces are considered best or worst for specific tasks.

In this context, this study is the first phase of a deeper research approach that aims to understand at which point the redundancy of commands, and constant addition of new input modalities, start to saturate and harm the user's performance. However, to reach this conclusion one must first grasp how the user relates to the different interfaces individually, and if the type of task and/or user profile influences this relation. In this paper, we intend to understand what is the most efficient interaction paradigm for specific target-audiences when performing one of the most basic tasks previously stated – selection. After presenting a brief outline of related work, we describe the methodology used for this study and discuss its results.

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2. RELATED WORK

We can consider as natural interaction all the input/output interfaces that incorporate gestures and body language, speech, objects' position and proximity, the whole spectrum of visual or auditory output, smell, tact and haptic perception [10]. In fact, either active and/or passive input modes [19] have been implemented in countless fields such as education, entertainment, advertising and others, not only as independent interfaces, but also as multimodal systems.

Multi-touch interfaces have shown great potential mainly due to their ease of use, efficiency and intuitive nature, as well as the possibility to augment productivity rates as far as information use [12]. This type of interface has been contemplated in studies regarding different contexts and age groups [3,27], but always as independent reports and not as a systematic approach combining multiple input modalities.

Likewise, tangible user interfaces encourage an interactive social experience, and provide the user with an opportunity to be able to think about virtual and abstract information in a direct and palpable manner, as well as receiving immediate feedback to the stimuli given through physical objects [11]. The use of this type of interface is greatly praised amongst children [22].

On the other hand, three-dimensional gesture-based interfaces offer the user more freedom and the ability to manipulate virtual data taking advantage of depth in a well-defined spatial context [9]. As other interfaces previously stated, gestural interfaces have been implemented in a broad array of fields and contexts [23,25].

However, little is known about how the different interfaces affect one's performance in terms of age-related issues. Work has been developed in this area, but always independently as separate studies.

Other related experiments have been carried out concerning the user's response in performing a set of tasks with the computer mouse versus other interfaces, such as: multi-touch displays [2,7,8], tangible interfaces [1,28]; or even amongst each other [15,24]. Furthermore, some experiments reveal results where more than two of the above mentioned interfaces are compared simultaneously [4,6], but to our knowledge there has been little or no recent work done concerning a systematic evaluation of the above mentioned interfaces concerning different tasks and user profiles. Also worth mentioning is the fact that those assessments compare different interfaces but always amongst specific ages and not between age groups.

In this respect, published experiments have not yet provided an understanding of the nature or severity of the difficulties different user groups have when using distinct input devices. Also, there are no transversal comparisons of different age groups in one same study. This is, precisely, our point of action in this evaluation that falls within the scope of a broader systematic study we are conducting.

3. CASE STUDY

The aim of this work is to identify which input modality is the most efficient for different user groups in a selection task, regarding performance, efficacy (error rate) and user preference. To accomplish this, we explored the participants' dexterity in using different input modalities for a selection task: we compared the computer mouse, touch, tangible pieces and gestures.

3.1 Participants

In total, 60 unpaid volunteers who were naïve to the purpose of the experiment participated in the tests, and were divided into 3 groups, according to their age:

- *Children*: Consisted of 20 participants with ages varying from 9 to 12 years old. The children from this group attended the fifth and sixth year of primary school.
- *Adults*: Consisted of 20 participants with the age bracket of 20 to 30 years old and were graduate students from departments related to Computer Science.
- *Older-adults*: Consisted of 20 participants with the age bracket of 45 to 60 years old and were active workers of a secretariat department.

All of the participants were accustomed to working with computers on a daily basis and were all amongst the same level of digital literacy. We also ascertained how many had already experienced other means of interaction besides the computer mouse.
Table 1 shows their awareness in terms of the different input modalities used in the experiment.

Table 1: Percentage of participants that had already used the different interfaces

Interfaces	Children	Adults	Older-adults
Graphical	100%	100%	100%
Touch	95%	100%	65%
Tangible	15%	35%	15%
Gestural	40%	60%	15%

The interface with the lowest experience amongst all the participants was the tangible one. The graphical and touch interfaces were the most familiar, although 35% of the older-adults confirmed having never used a display with touch support. The gesture-based interface was familiar to most groups but mainly for the adults, due to their time spent playing console games with support to this modality. Also, we acknowledge that the percentage relating to tangibles regarding the adults was much higher than the other groups for this same reason.

3.2 Experimental Design

The experiment used a within-participant repeated-measures design. Each of the 60 subjects performed the different tasks 5 times each, which gives a total of 20 trials per participant, and a total of 1200 trials during the experiment. We set specific performance metrics related to a quantitative method of evaluation of the different input modalities: we considered the speed in successfully completing a task and the accuracy for the task completion (number of errors). Aside from this discrete data gathered throughout the tests, we also performed qualitative observational analysis of the subjects' behavior and applied at the end of each test a questionnaire with closed-end questions that relied on qualitative Likert Scales [13] and ranking lists to understand, for all the input modalities: the ease of use, ease of learning, fatigue effect, naturalism of interaction, level of user comfort / frustration, user's degree of presence and concentration, and also participants' preference.

3.3 Apparatus

Figure 1 shows the setup used for this study. The tests were performed in a closed room with artificial light and the system consisted on a 22'' touchscreen, a kinect sensor, a webcam, 8 tangible pieces, and a computer mouse. The kinect sensor was mounted on a tripod behind the screen and about 25 cm above it, facing towards the users in order to detect their hand position and movement. The tangible pieces were put right in front of the screen, always in the same order, and with the same space between them.

Figure 1: Setup used in the experiment

The software for the different tasks was developed in Python with the Kivy Framework. Also, we used the open source computer vision Framework reacTIVision to track the fiducials and TuioKinect to track the hand gestures.

3.4 Procedure

In the beginning of the experiment, the participants were given a general guidance about the different tasks to perform as well as the range of available input modalities. We also collected data about their previous experience with the different interfaces through an individual questionnaire at the beginning of each test. The researcher was present at all times and when a new input modality was introduced, it was explained how it worked and how to use it.

We divided the experiment into four phases, each making use of a different input modality for the selection task:

- *Task 1 (Mouse)*: Make use of the computer mouse.
- *Task 2 (Touch)*: Make use of touch.
- *Task 3 (Tangibles)*: Make use of tangible objects.
- *Task 4 (Gestures)*: Make use of hand gestures.

The tasks relied on selecting the right button out of 8 displayed on the screen (**Figure 2**). These buttons were organized in two columns and were randomly positioned.

Figure 2: Layout of the buttons displayed on the screen

When the application started, a countdown appeared from number 3 to 1 and then the grid of buttons would be presented on the display. Only here the time would start to count. The users were given the name of the button to be selected moments before this grid appeared on the screen, forcing them to select the right button as fast as they could. When the task was successfully finished, that is, when the right button was selected, the screen would show messages of congratulations and "task completed". The user would then pass to the next trial. On the other hand, when the user selected the wrong button a message appeared on the screen letting him or her know about it and 5 seconds later the task would restart, giving the user a second opportunity to successfully complete it.

For the first task participants would use the computer mouse, and for the second one they would resort to the touch screen. On the other hand, task 3 consisted on a tangible interface, giving the users the chance to select the right button resorting to 8 physical pieces labeled with icons related to the button's name (**Figure 3**a). The users would be asked to pick up the piece and insert it in the webcam device prepared for this experiment (**Figure 3**b). Here, the system would recognize the fiducial engraved at the bottom of the pieces (**Figure 3**c).

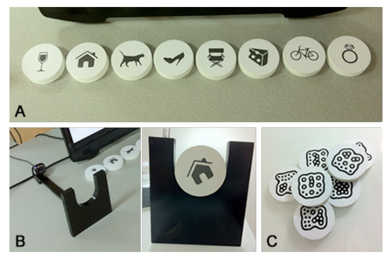

Figure 3: (a) Tangible pieces used in the experiment; (b) The webcam device used to recognize the fiducials; (c) Fiducials engraved at the back of the pieces

The fourth and final phase consisted in selecting the buttons resorting to 3D gestures. The user was asked to lift up his arm and hold it within a specific area between him and the screen. The camera would detect his hand and an image of a target would appear in the screen, indicating that the system was recognizing the point gesture. The goal was to select the button by moving the target with the hand movement to the front of the desired button and hold it so that a selection could be made. Here, the user had to point and wait for 0.8 seconds for the system to recognize the intended button. For evaluation purposes this time gap was removed from the total time variable. The target also provided a visual feedback for the user to be able to know that the selection was in progress. When the system detected that the hand was not moving, a green circle would grow inside the target, indicating the selection (**Figure 4**).

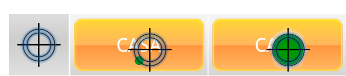

Figure 4: Selection process for the gestural interface

The participants were not given a specific time limit to complete the tasks, but they were told about the importance of performing the tasks as fast as they could and avoiding as many errors as possible. Given that it was a very stressful test for some audiences, mostly for children, the participants could choose to pause the test and rest at any given moment between the tasks. No training trials were performed, as it was one of our goals to be able to perceive how the participants who had never experienced the modality would react and the amount of time one needed to adapt to the new input modality. For purposes of understanding if the performance would improve with practice or not, for all the phases each task was repeated 5 times.

After the tests were concluded, the subjects completed a questionnaire in order to gather their opinion about the input modalities provided. Furthermore, we wanted to apprehend their own perspective about the efficiency and performance of those modalities.

4. RESULTS AND DISCUSSION

In this section, we present results of this pilot case study. We believe that we may help researchers begin to understand how different user groups, regarding age brackets, perceive different input modalities and which is the most effective in terms of basic selection tasks.

4.1 Performance

4.1.1.1 Children's Performance

A repeated measures ANOVA with a Greenhouse-Geisser correction determined there was a significant difference between the mean time taken to complete the task in each interface (f (1.108, 21.044) = 19.904, p < .000). Post-hoc pairwise comparisons tests using the Bonferroni correction showed that, except for the mouse and touch inputs (p = .353), the mean times were statistically significantly different: mouse and tangibles (p = .001); mouse and gestures (p = .000); touch versus tangibles or gestures (p = .000); tangibles and gestures (p = .000). In terms of mean time, the input with the fastest results was touch (2,27 s), followed by the mouse (2.69 s), tangibles (4.16 s) and finally gestures (9.12 s).

4.1.1.2 Adults' Performance

As the Mauchly's sphericity was not assumed, like in the children's group, we applied the Greenhouse-Geisser adjustment to the repeated measures ANOVA (f (1.010, 19.190) = 12.520, p < .002). Regarding the mouse and touch input modalities this group also elicited a slight reduction in terms of mean time, which was not statistically significant as demonstrated by pairwise comparisons tests using the Bonferroni correction (p = 1.000). This difference registered as even lower than the previous group. Moreover, the difference between gestures and tangibles was also not statistically significant (p = .077), as opposed to the other combinations: mouse and gestures (p = .008); touch and gestures (p = .003); and tangibles versus mouse or touch (p = .000). Again, the touch input registered the lowest mean time (2.10 s), followed by the mouse (2.12 s), tangibles (3.61 s) and gestures (8.00 s). Indeed, this group registered such an insignificant difference between mouse and touch inputs (.02 s) that we can assume that for a selection task this group is indifferent regarding the input interface when it comes to mouse or touch.

4.1.1.3 Older-adults' Performance

The older-adults' performance also achieved a statistically significant difference between the mean times in each interface (f (1.137, 21.606) = 32.007, p < .000), as determined by a repeated measures ANOVA with the Greenhouse-Geisser correction. According to post-hoc pairwise comparisons tests using the Bonferroni correction, the mean times were statistically significantly different, except for the tangibles and mouse (p = .373): mouse and gestures (p = .000); touch versus tangibles or gestures (p = .000); tangibles and gestures (p = .001). Also, contrarily to the other groups, the difference between mouse and touch input was statically significant in the older-adults' group (p = .003). Indeed, this group registered a different pattern concerning performance when compared to the other two groups: mouse and tangibles did not register a statistically significant difference with .59 seconds apart from each other in terms of mean time; and, also very dissimilar to the other groups, mouse and touch registered a statistically significant difference with 1.17 seconds apart from each other in terms of mean time. These results led to a contrast between the groups concerning the different interfaces. The interface that scored the lowest mean time was touch (2.08 s), followed by the mouse (3.25 s), tangibles (3.84 s) and gestures (9.63 s).

4.1.1.4 Overall Performance

Additionally to comparing the performance inside each group regarding the different interfaces, we also analyzed the performance between each group. **Figure 5** shows the mean time taken to complete the tasks for all three groups in each interface. There were no outliers and the data was normally distributed for each group.

Indeed, there was no statistically significant difference between groups for each interface, except for the mouse input, that registered a significant difference between the groups of adults and older-adults (p = .002). Curiously, the one input device every participant uses on a daily basis – the computer mouse – had dissimilar results once compared between the groups. As this interface was the one that all participants had the most practice with, it seems that instead of increasing with experience it ends up suffering in terms of performance throughout the years.

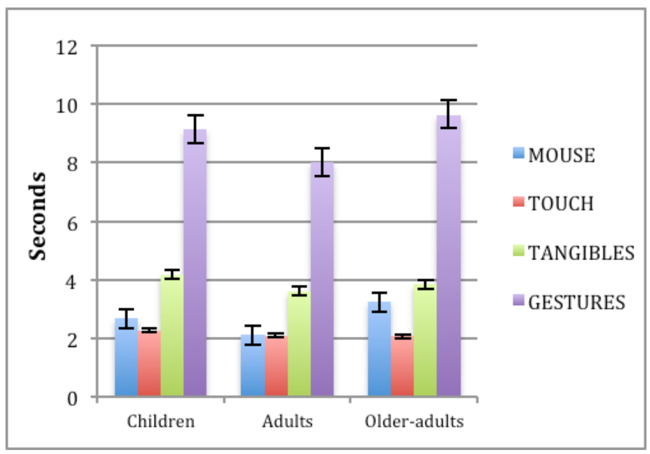

Figure 5: Mean time taken to complete the task (in seconds)

Overall, the adults' group presented the lowest mean time in most of the interfaces, comparing to the other groups. Also, the mean selection time for the several input modalities did follow a pattern throughout the three user groups: (1) the gesture-based interface was not nearly as efficient as the rest, showing much discrepancy when compared to the other interfaces in terms of mean time; and (2) touch was the fastest and proved to be more consistent throughout all the groups, with little variations in mean time. Also, for a simple selection task, touch appears to be more efficient amongst the three groups in terms of mean time, even considering that their awareness in terms of this input modality was distinctive (as concluded in the initial questionnaire).

We might reach the conclusion that the type of group does not influence the performance but, instead, the type of interface that is used does. That is to say, according to the type of task, the usage of different interfaces may influence the users' performance and preference. Even when comparing the groups side by side, we may reach the conclusion that not all of the interfaces produced the same results.

4.2 Error rate

We considered an error when the button that was selected by the participant was not the correct one. The only input modality that registered faults during the task was the gesture-based one, with a total of 2 errors from the children's group, 8 errors from the adults' and 14 errors from the older-adults'. The group of the older-adults registered the higher error rate and also the higher mean time of all, which may imply that over the years their dexterity decreases. In this case, the older-adults would not have the motor reflexes to divert the hand from the current location before the animation of the target selection was completed. However, we will not further explore this assumption on the course of this paper.

4.3 Participants' Preferences

At the end of the experiment, when asked about the interface they liked the most regarding ease of use and intuitiveness, the majority chose touch. Even for those who had never used touch as the interaction mode, this was the most popular and every participant said it was easy to use and practical for an everyday use. As for comfort in interaction, all of the subjects designated the gestural interface as the least comfortable and more challenging of all. Also on this interface, the groups of adults and older-adults thought it was also more demanding in terms of concentration.

In terms of user preference, the children chose the touch modality and the tangibles as the top two favorites, and the groups of adults and older-adults chose the touch interface. This was registered during the final survey where the participants ought to pick their favorite type of interface and also their least preferred. Indeed, the majority of children chose touch as favorite, with 60% of the answers putting this modality in the first place, followed by the tangible interface (25%). At the bottom two places were the gestures and the mouse, with 40% and 30% respectively. Likewise, the majority of the adults' group elected touch as the favorite with 65% of the replies, and 60% of them pointed gestures as the least favorite. The older-adults chose touch as the favorite with 75% of the answers, leaving behind the other input modalities with just 10% for touch and the same for gestures, and 5% for the tangibles. This group also designated the gesture-based interface as the least popular with 60% of the answers, as did the adults.

4.3.1.1 Participants' Difficulties and Behavior

We observed different behaviors in the various groups concerning each modality. When using the computer mouse, all of the participants showed a regular approach of looking for the right button and clicking on it. However, we noticed that children and the older-adults first took their time searching for the cursor and only after finding its position they started searching for the right button. When resorting to touch and tangibles all groups demonstrated a similar behavior, and did not demonstrate an abnormal effort in completing the tasks.

The gesture-based interface was the one that proved to be more challenging, especially when selecting the buttons located at the top left and right corners. The most perceptible behavior of the participants in this situation was that they would push the arm foreword to try to select the button, and thus exiting the detection area, instead of lifting it upwards. This situation would lead the participant to a higher level of frustration and thus ending up affecting the rest of the task until successfully concluding it.

On a different matter, there was no apparent difference in behavior concerning users right or left-handed. They performed the task with equal comfort.

5. CONCLUDING REMARKS

This exploratory investigation was intended to understand which input modality was the most efficient for a specific target-audience in a selection task. Even though this study is completely exploratory and far from complete, according to the results presented it appears to be evidence that the creation of distinctive user profiles regarding interaction with different interfaces could be important. Furthermore, these indications have highlighted the need for further investigation to understand key issues related to input modalities and user preferences.

This is still a work in progress and more effort is being put in developing studies regarding other tasks, and compare each group's results between each other and each interface. Furthermore, we intend to follow other evaluation methods and test these same interfaces according to Fitts' and Steering Law for target acquisition and tracking performance evaluation for pointing devices. Therefore, we will be able to complement the usability test's results of this study with a more formal evaluation of the interfaces. Later on we will also apply these same evaluation methods to other tasks.

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