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Evaluating the Accuracy of Pre-Kindergarten Children Multi-touch Interaction

Vicente Nacher, Javier Jaen

ISSI group, DSIC, Universitat Politècnica de Valencia, Spain.

vnacher@dsic.upv.es, fjaen@upv.es

Abstract. The direct manipulation interaction style of multi-touch technology makes it ideal for pre-kindergarten children. Recent studies have shown that these challenging users are able to perform a set of basic multi-touch gestures. However, little is known about the accuracy that they can achieve. This paper evaluates the performance of pre-kindergarten children when accuracy is required in the termination phase of these gestures and points out that a mechanism for dynamically adapting the accuracy level could help children in their motor skills development.

Keywords. Multi-touch interaction, gestures, usability evaluation, pre-kindergarten, accuracy

1 Introduction

Nowadays children between zero and eight years old are frequent users of digital media[3]. In fact, as touch allows a more intuitive and natural way of interaction [7], they are often exposed to multi-touch technology even before they learn higher oral communication skills.

This has been confirmed by recent works such as [6] which reveals that even children between the ages of two and four are able to perform a basic set of touch gestures and [9] which concludes that, overall, children aged 3 to 6 years are able to perform the tap, double tap, drag & drop and double drag & drop gestures. However, these works have also pointed out that very young children have precision problems in both the acquisition and termination phases of these interactions because of limitations in cognitive and motor skills.

Regarding this matter, there are no studies in the literature addressing the topic of accurate performance of multi-touch gestures by pre-kindergarten children. In this paper we explore whether children aged two to three years are able to perform a set of touch gestures when high levels of precision are required and evaluate whether factors such as age and gender have an impact on the performance of these interactions by pre-kindergarten users. This paper contributes to a growing body of literature in the area of children-computer interaction by providing findings from a controlled experiment with four touch gestures in which the termination phase must be performed with high-levels of precision. The findings will confirm that, at this early age-range, there are significant differences among subjects with respect to precision and, therefore,

designers of future touch based applications for these specific users should devise adaptive mechanisms to cope with different levels of accuracy that allow very young children to exercise and incrementally develop fine-grained touch interaction skills.

2 Related works

Several studies have analyzed the use of touch devices by pre-kindergarten children. The works of Abdul Aziz et al. [1, 2] evaluated the tap, drag, rotate, drag and drop, pinch, spread and flick gestures with children aged 2 to 4 years. Their results showed that 4 years old children were able to perform all gestures, the 3 years old ones only had some issues with the spread task and the youngest users (2 years old) were able to perform the tap and drag gestures properly but had some issues with the more complex ones.

On the other hand, the study of Nacher et al. [6] evaluated a basic set of multi-touch gestures with pre-kindergarten children (2 to 3 years old) and concluded that they are able to perform gestures such as tap, drag, scale (up & down) and one finger rotation. Moreover, the authors of this work point out that, when some proposed assisted strategies are used, pre-kindergarten children are able to perform more problematic gestures such as double tap and long press [5] with high success rates.

Vatavu et al [9] evaluated touch gestures (tap, double tap, drag & drop, multiple drag & drop) with children aged between 3 and 6 years on tablets and smartphones. Their results showed that although all children had high success rates, there was a significant performance increase with age in terms of success rate and time spent performing the gesture which is an expected behavior.

These works seem to conclude that pre-kindergarten children have the necessary skills to make use of multi-touch technology. However, they assume that children may not accurately perform the multi-touch gestures under consideration and always implement assistive techniques to deal with precision issues during the initiation and termination phases of each gesture. This results in interaction styles in which pre-kindergarteners do not have the control over the termination of the gestures despite some of them have the proper cognitive abilities to perform the gestures with higher levels of precision. As a result, existing applications designed under these assumptions do not benefit from the use of multi-touch technology to help children to develop their precision-related cognitive and motor skills. Hence, in this work we evaluate the drag, scale up, scale down and rotation gestures when accurate termination of the gestures is required. The goal is to gain additional knowledge about precision issues when pre-kindergarten users are considered in the design of future touch-based applications. The results of this work would allow the design of applications that provide assistive strategies to deal with precision issues in an adaptive way only for less skilled children and not in an exhaustive way for every child as current systems do.

3 Experimental study

The overall goal of our experimental study is to identify whether pre-kindergarten children are able to get high success rates when performing gestures with high accuracy levels. More specifically, the research questions of the study are formulated as follows:

When high accuracy touch gestures are considered...

RQ1: ...is the degree of success independent of age group?

RQ2: ...is the degree of success independent of gender?

RQ3: ...is the completion time independent of age group?

RQ4: ...is the completion time independent of gender?

RQ5: ...is the average error independent of age group?

RQ6: ...is the average error independent of gender?

3.1 Participants

Forty children aged between 25 and 38 months took part in the experiment (Mean (M) = 31.60, Standard Deviation (SD) = 4.32). Children were balanced in gender and in age group, i.e., two age groups 24 to 30 months and 31 to 38 months, with 10 males and 10 females per group were configured. Participants from two Spanish nursery schools were involved in order to explore whether children could perform non static touch gestures, i.e. requiring the movement of contacts across the surface. Parental consent was obtained before carrying out the study.

3.2 Apparatus

The interaction framework for the experiment was implemented in Java using JMonkeyEngine SDK v.3.0beta. The devices used for the experiment were a Motorola MZ601 and a Samsung Galaxy Note 10.1 tablet with Android 3.2 both with capacitive multi-touch screens.

3.3 Tasks

Drag.

A static image of an animal appears in a random position on the screen and the same (reference) image appears in a white profile in another random position, always at a distance of 588 pixels so as to be able to compare execution times among the different subjects (**Fig. 1-a**). The random position of the reference image is subject to some geometric restrictions, to make sure that it is completely visible on the surface. Participants are requested to drag the target to the reference image with one finger. The task is successful when the target image reaches the location of the reference image with a precision of less than 15 pixels on both X and Y axis when the subject lifts his/her hand (like a drag and drop gesture).

Rotation.

A static image of an animal appears in the center of the screen in front of a blank profile of the same image in a different orientation. Rotation is always clockwise to a fixed position so as to be able to compare interaction execution times among subjects (see **Fig. 1-b**). Participants are requested to rotate the target image to the position of the reference image by dragging one finger around the center of the target image. Pressure can be applied on the target image itself or anywhere around it. The task is successful when the target image reaches the orientation of the reference image with a precision of less than 5 degrees when the subject lifts his/her hands.

Scale up.

A static image of an animal with a size of 5 centimeters appears in the center of the screen within a similar but 1.5 times larger reference shape (see **Fig. 1-c**). Participants are requested to scale up the target image to the size of the reference shape. This can be done by expanding the distance between two fingers of either one hand or two hands. The fingers do not have to be in contact with the reference image and the scaling factor applied is the incremental value returned by the JMonkeyEngine runtime for this gesture. If more than two contacts are made on the surface, JMonkeyEngine considers only the two most recent ones for communicating scaling events. The task is successful when the size difference between the manipulated and the reference images is less than 5% when the subject lifts his/her hands.

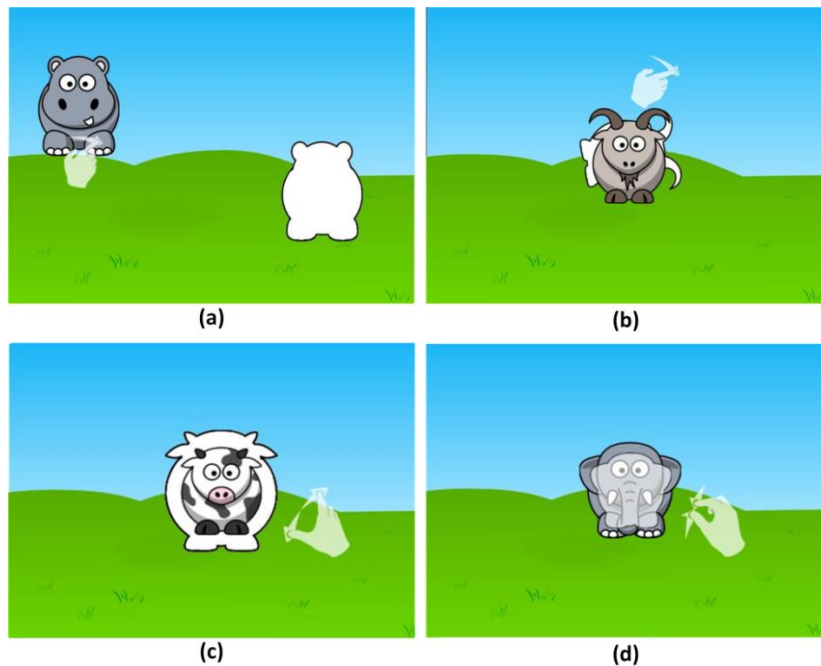


Fig. 1. Example tests: (a) drag (b) rotation (c) scale up (c) scale down

Scale down.

A static image of an animal with a size of 15 centimeters appears in the center of the screen superimposed on a similar reference shape half its size (see **Fig. 1-d**). Participants are requested to scale down the target image by making the target object shrink until it reaches the size of the reference image using two fingers of either one or two hands. The task is successful when the size difference between the manipulated and the reference images is less than 5% when the subject lifts his/her hands.

3.4 Procedure

For each task, the children participated in a 2-minute learning session with an instructor. Then, the experimental platform asked them to perform the task with no external adult intervention. They had to perform five repetitions of each gesture as described in the Tasks section. When the gesture was successfully completed, the platform gave a positive audiovisual feedback. If the instructor observed that the participant did not carry out the task in a given time, it was marked as unsuccessful and the child went on to the next one. For each interaction, the system recorded the start time (seconds needed to go into action after the test began), completion time (milliseconds until the gesture was completed), success (performed correctly or incorrectly), and the number of times that users lift their hands while performing the gesture. Additional notes were taken by an external observer for posterior analysis.

4 Results

4.1 Success

In order to aggregate the success variable over the five repetitions, the variable was expressed as a percentage according to the number of repetitions performed successfully (**Table 1**).

Task	Gender		Age Group		Overall
Drag	<i>F</i>	<i>M</i>	≤ 30	> 30	78.50
	82	75	73	84	
Scale up	<i>F</i>	<i>M</i>	≤ 30	> 30	42
	46	38	27	57	
Scale down	<i>F</i>	<i>M</i>	≤ 30	> 30	45.50
	48	43	27	64	
Rotation	<i>F</i>	<i>M</i>	≤ 30	> 30	60
	77	43	47	73	

Table 1. Success rate of each task by group.

The results of a two-way between-subjects ANOVA on the success revealed a significantly main effect of the *age group* factor in the scale up ($F(1,40) = 8.052$, $p = .007$), scale down ($F(1,40) = 10.913$, $p = .002$) and rotation ($F(1,40) = 5.930$, $p = .020$) tasks

but not in the drag task ($F(1,40) = .951$, $p = .336$). The statistical analysis of the *gender* factor only revealed a significant effect in the rotation task ($F(1,40) = 10.104$, $p = .003$).

4.2 Completion time

The average of each subject's successful tasks is used to obtain the completion time aggregated by users (see **Table 2**). The unsuccessful tests were not included in the completion time analysis.

Task	Gender		Age Group		Overall
Drag	<i>F</i>	<i>M</i>	≤ 30	> 30	13755.53
	13721.63	13793.40	16922.11	10588.94	
Scale up	<i>F</i>	<i>M</i>	≤ 30	> 30	9991.62
	9517.72	10402.34	8151.86	11586.09	
Scale down	<i>F</i>	<i>M</i>	≤ 30	> 30	9859.62
	10109.92	9591.46	7732.45	11361.15	
Rotation	<i>F</i>	<i>M</i>	≤ 30	> 30	16651.61
	16972.38	16239.20	17751.49	15681.13	

Table 2. Completion time in milliseconds of each task by group.

The conducted two-way between-subjects ANOVA on the completion time revealed significant main effects of the *age group* factor for the drag task ($F(1,36) = 7.844$, $p = .009$) where the older group performed significantly faster. No other effects were found significant for any gesture and factor.

4.3 Accuracy

In order to evaluate pre-kindergarten performance when accurate termination of the gestures is required, in this section the error values for each gesture by age group and gender are showed. For each task the error is calculated as the discrepancy between the reference and the manipulated elements. In the case of the drag gesture the error is measured as a distance in pixels between them, for the scale-up and down gestures the error is a percentage measuring the discrepancy of size and for the rotation gesture the error is measured in degrees as the difference between their rotation values.

On the one hand, the results show that both age groups have similar levels of accuracy when terminating the drag gesture, i.e., similar average error ($F(1,39) = .179$, $p = .675$) with $\text{avg_error}(\text{drag, young})=10.75\text{px}$ and $\text{avg_error}(\text{drag, old})=8.86\text{px}$.

On the other hand, the results show that in the scale (up & down) tasks the older group had almost a 50% greater precision than the younger one ($F(1,72) = 10.885$, $p = .002$) with $\text{avg_error}(\text{scales, young})=20.84\%$ and $\text{avg_error}(\text{scales, old})=10.74\%$. This is also the case for the rotation task in which older children have a 50% greater precision ($F(1,37) = 6.497$, $p = .016$) with $\text{avg_error}(\text{rot, young})=29.7^\circ$ and $\text{avg_error}(\text{rot, young})=12.06^\circ$. Finally, with respect to the gender factor no significant differences were found for any task.

5 Discussion and future work

There are several interesting conclusions that are obtained when considering multi-touch gestures with high-levels of termination precision. Firstly, the results reveal that age is the main factor affecting the degree of success variable (RQ1) for all tasks except for the drag gesture. In this specific gesture all children, no matter what age, achieve similar high success rates ranging from 73% to 84%. However, for more complex tasks such as rotations and two-finger scaling, the additional requirement of precise termination of the gesture has a high impact on less than 30 months children. Success rates decrease for this age group (27% -47%) and are significantly better for children aged 31 months and over (57% -73%). This result confirms that children start to develop their fine motor skills at this age [6] and, therefore, applications requiring higher levels of precision could be designed to stretch and challenge children in the second age group. This would be in concordance with the principles of differentiated instruction [8]. Secondly, it was also observed that girls are on average more successful than boys when precision is an issue (RQ2). These results are consistent with previous work which shows superior fine motor skills in girls [4]. However, our study only revealed significant differences for the rotation task. This is because the additional difficulty associated to the coordination of two finger contacts makes the scale-up/down tasks specially challenging for both boys and girls when precision is required (see **Table 1**).

In addition, if completion time is considered (RQ3 & RQ4), no significant differences were found in terms of age nor gender for all tasks except for the drag gesture. This means that relatively challenging actions in terms of cognitive and motor skills such as the scale-up/down and rotation gestures are performed by all children at similar speeds. It was observed that the additional precision requirement in these gestures forced all children, no matter their age or gender, to perform the final phase of the interaction (contact release phase) repeatedly until the final successful completion of the gesture was achieved. This was not the case for the drag gesture (see **Fig. 2**), specially perceived by older children (aged 31 months and over) as an easy to perform action they were able to complete with a lower number of attempts and, thus, resulting in significantly lower completion times.

Finally, when accuracy is considered (RQ5), the analysis of the average errors reveals that the most challenging gestures (scale up-down and rotation) are performed with significantly higher levels of accuracy (lower average error) by older children (see section 4.3). This observation brings up the matter of using assistive strategies to deal with precision issues in an adaptive way according to the actual motor skills of each child and not, as most existing touch-based applications for pre-kindergarten children currently implement, in a comprehensive way assuming all children have the same levels of accuracy.

The size of the objects involved in the experiments may have an impact on the effectiveness; hence, future research should be done to evaluate different sizes.

To sum up, the previous results point out that pre-kindergarten children (2 to 3 years old) are in the process of developing their motor skills and have different levels of accuracy. Particularly, older children are able to perform complex gestures with

significantly higher levels of accuracy and, therefore, future multi-touch application for this age range should consider assistive strategies that adapt their behavior to the actual levels of motor and cognitive development of each child. Not doing so, would prevent the more skilled children from exercising and further enhancing their precision related skills at an early phase of their development.



Fig. 2. Pre-kindergarten child performing the drag task.

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