Examining the Link between Children's Cognitive Development and Touchscreen Interaction Patterns

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ABSTRACT

It is well established that children's touch and gesture interactions on touchscreen devices are different from those of adults, with much prior work showing that children's input is recognized more poorly than adults' input. In addition, researchers have shown that recognition of touchscreen input is poorest for young children and improves for older children when simply considering their age; however, individual differences in cognitive and motor development could also affect children's input. An understanding of how cognitive and motor skill influence touchscreen interactions, as opposed to only coarser measurements like age and grade level, could help in developing personalized and tailored touchscreen interfaces for each child. To investigate how cognitive and motor development may be related to children's touchscreen interactions, we conducted a study of 28 participants ages 4 to 7 that included validated assessments of the children's motor and cognitive skills as well as typical touchscreen target acquisition and gesture tasks. We correlated participants' touchscreen behaviors to their cognitive development level, including both fine motor skills and executive function. We compare our analysis of touchscreen interactions based on cognitive and motor development to prior work based on children's age. We show that all four factors (age, grade level, motor skill, and executive function) show similar correlations with target miss rates and gesture recognition rates. Thus, we conclude that age and grade level are sufficiently sensitive when considering children's touchscreen behaviors.

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CCS CONCEPTS

• Human Centered Computing~Human computer interaction (HCI)~Interaction devices~Touch screens

KEYWORDS

Touchscreen, gesture, child, cognitive, motor, NIH Toolbox®

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1 INTRODUCTION

Children are increasingly exposed to mobile touchscreen devices and are regularly using them in various contexts [11,18,19]. Previous studies have investigated how children interact with touchscreen devices to provide guidelines that inform the design of interfaces tailored towards specific age groups [2–4,23]. In particular, prior work has established that children differ from adults in the ways they touch targets and make gestures [23]. For example, children miss onscreen targets more often compared to adults [23]. Previous work has also examined the automatic recognition rates of children's touchscreen gestures, showing that these rates are lower than recognition rates for adults' gestures [23]. Understanding the link between cognitive and motor skill could help researchers understand children's interactions at an individualized level, allowing for more personalized interfaces.

The relationship between children's cognitive development and the way they interact with touchscreen devices has not been examined in the same systematic way as has been done with respect to age. There could be large variations in cognitive development within age groups, specifically motor skills and executive function [16]. Examining recognition rates based on age or grade level may be too coarse to fully explain the individual variations in how children interact with touchscreen devices.

Therefore, we designed a study with children ages 4 to 7, using a validated and certified suite of tests from the NIH Toolbox® [10,13] to measure children's cognitive development and motor skills. We also used touchscreen target and gesture tasks from prior work to examine whether these new cognitive measures are correlated to recognition rates.

In our studies, we show that each of age, grade level, motor skill, and executive function have significant, though moderate, negative correlations with the rate at which children miss targets. We also show that each of age, grade level, and motor skill have significant, though moderate, positive correlations with gesture recognition rate. We conclude that fine-grained measurements from cognitive and motor assessments are sufficiently approximated by measures like age and grade level for our tasks.

2 RELATED WORK

2.1 Motor and Cognitive Development

Children undergo a number of developmental changes as they grow up, and these changes affect their interactions with touchscreen devices. In this section, we specifically focus on the development of children ages 4 to 7. We chose this age range for our study because it allows us to examine children's abilities for their first few years before and after entering school, and because these are the ages in which the greatest changes occur as measured by the normed data from NIH Toolbox® [10,13].

2.1.1 Motor Development. Children's ability to smoothly use touchscreen devices depends on their motor skills, which in children are still developing. Prior work shows that children tend to be able to perform precise motor control actions like grasping an object around age 5 [8,16]. By ages 6 to 7, children become more aware of the position of their hands in space relative to their own body (i.e., proprioception [7]) and are able to engage in more fine grained interactions. Children are able to write with ease and precision by ages 8 to 10 [16]. Schneck and Henderson [17] showed that motor control can depend on the context of the task performed. For this reason, we use tasks like those in prior work on touchscreen interactions to allow for direct comparison.

2.1.2 Cognitive Development. In addition to motor skills, children are continually developing their cognitive skills, which relate to their ability to perform tasks like writing and problem solving [16]. When analyzing cognitive development, researchers often use Piaget's theory [15] to help categorize children based on their age. All of the children in our study fall into the second of Piaget's stages of development, the *preoperational* stage. Children in this stage, who range in age from 2 to 7 years old, begin to be able to use and manipulate symbols and to develop language skills, which will affect their interactions with touchscreen interfaces.

2.2 Touchscreen Interactions

A growing body of work documents the many differences between children's and adults' touchscreen interactions in various contexts. Anthony et al. [3] offered several guidelines for developers working on touchscreen applications for children based on an analysis of the interactions of children ages 7 to 16. Woodward et al. [23] examined 5- to 10-year-olds' interactions in abstract and complex interfaces and found similar touch and gesture interaction patterns. The authors report that younger children had more trouble acquiring targets and that their gestures were recognized with lower accuracy than those of older children and adults. In another study, Woodward et al. [22] showed similar trends on smart phones, tablets, and tabletop computers and when using finger input and pen input. We replicate similar tasks as these prior studies but extend them to a younger age (4-year-olds) and add the cognitive and motor skills measurement tasks.

Little work has specifically examined the link between their cognitive and motor skills and their touchscreen interactions. Kim et al. [12] introduced KimCHI, a classification technique for sketch-based educational applications. The authors use a set of 15 features to classify a child's developmental level and gender based on their interactions. Other work has considered how designers can create appropriate experiences for children based on the child's age group. For example, Hiniker et al. [9] found that audio cues were more appropriate than video for 2-year-olds, but that video cues were more appropriate for 5-year-olds. Aziz et al. [1] examined the ability of 2- to 4-year-olds to perform common touchscreen gestures, and found that children in this age group had trouble with gestures such as drag and drop and pinch and spread. In contrast, Nacher et al. [14] found in their study that children ages 2 to 3 could perform touchscreen gestures like single finger rotate and two finger scale up/down. We build on this growing body of work by exploring the link between children's cognitive development and touchscreen interactions.

3 METHOD

A total of 28 participants took part in our study. There were 6 four-year-olds, 6 five-year-olds, 11 six-year-olds, and 5 seven-year-olds. 25 identified as right-handed, and 3 as left-handed. There were 11 females and 17 males. 6 participants identified as black or African American, 19 as white, 1 as American Indian or Alaskan Native, and 2 as another race. 2 of the black or African American participants and 8 of the white participants also identified as Hispanic or Latino. 26 of the participants identified as using touchscreen devices with moderate or high frequency.

Our study was composed of two phases. In the first phase, participants used an iPad to complete cognitive and motor assessments using the NIH Toolbox® application suite [10,13]. In the second phase, the participants completed touchscreen interaction tasks similar to prior work [3,22,23] to collect target and gesture data. The order of the tasks within each phase was counterbalanced, though the order of the phases was the same for each participant (NIH Toolbox® first; touchscreen tasks second).

Before each session, parental consent was collected in writing, along with a study survey required by the NIH Toolbox®. The demographic data is used by the NIH Toolbox® applications in computing the participant's *normalized* score, which gives a measure of how well the participant performed relative to the distribution of raw scores obtained by participants in large studies conducted by the NIH [10,13]. At the session start, a child assent

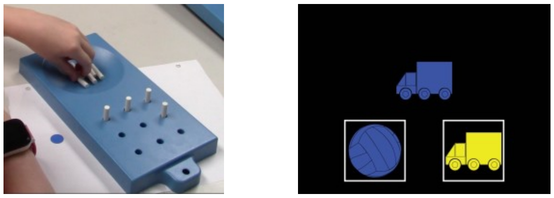


Figure 1. The 9-hole Pegboard Dexterity Test (left) and the Dimensional Change Card Sort Test (right) [14].

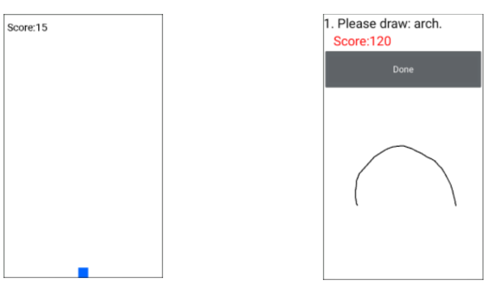
form was read to the participants to verify they wanted to participate. Participants earned small prizes such as erasers, stamps, and bouncy balls after each task to motivate them to complete the study [4]. Our study protocol was approved by our university's Institutional Review Board. We detail each phase.

3.1 Phase 1: NIH Toolbox

The two tasks on the iPad were (1) the 9-hole Pegboard Dexterity Test [13], and (2) the Dimensional Change Card Sort Test [10]. These two tasks offered by the NIH Toolbox® provide assessments of participants' fine motor skill level and executive function and attention level, respectively.

3.1.1 9-hole Pegboard Dexterity Test. The 9-hole Pegboard Dexterity Test is a test of a user's manual dexterity with their fingers [13]. In the test, participants are asked to place 9 pegs into a board of 9 holes (Figure 1), and then remove them as quickly as possible. Experimenters record the amount of time taken for the participant to complete the task. In our study, each participant completed the task twice with each hand, with the first attempt for each hand being a practice run.

3.1.2 Dimensional Change Card Sort Test. The Dimensional Change Card Sort Test provides a measure of a participant's executive function, which NIH defines as "the capacity to plan, organize, and monitor the execution of behaviors that are strategically directed in a goal-oriented manner" [10]. In the test, the participant is shown a series of two images and asked to select one that matches either a given color or a given shape (Figure 1). The application measures the amount of time the participant takes to respond and the number of correct responses.



(a) (b)

Figure 2. A screenshot of (a) the target application and (b) the gesture application we use in our study.

3.2 Phase 2: Target and Gesture Applications

The applications used in the second phase of our experiment were directly inspired by prior work [22,23]. The phase included two tasks: (1) a target touching task, and (2) a gesture drawing task.

3.2.1 Target Task. In the target touching task, participants were asked to touch a series of 104 different targets, which appeared as blue squares on the screen (Figure 2a). As in prior work, the size of the targets varied, including very small (0.125 in), small (0.25 in), medium (0.375 in), and large (0.5 in). Participants were instructed to attempt to touch the target as many times as necessary until they were successful, and they could not move on until they touched the target. Each touch event was logged with the location and time of the touch.

3.2.2 Gesture Drawing Task. The gesture drawing task consisted of a blank canvas on which participants were instructed to draw a series of gestures (Figure 2b). We used a gesture set from prior work consisting of 20 total gesture types: letters (A, E, K, Q, X), numbers (2, 4, 5, 7, 8), symbols (line, plus, arch, arrowhead, checkmark), and shapes (circle, rectangle, triangle, diamond, heart) [5]. The set was originally selected based on a survey of psychological and developmental literature as well as mobile applications for children [5]. Each participant produced two examples of each gesture type to keep the study brief while still obtaining enough gestures to run recognition experiments.

4 RESULTS

4.1 Target Task

For the target task, we focus on miss rate, which has been examined in prior work on children's touchscreen interactions [3,4,22,23]. We use per-user miss rate, which is the proportion of a user's misses over all targets, as in previous work [3,4,22,23]. We exclude holdovers, which are touches in the location of a target that has just disappeared because the user successfully touched it, but did not realize it. We examined the relationship between the dependent variable of *miss rate* and several independent variables related to the child's developmental progress: *age*, *grade level*, *motor skill* (as measured by the 9-hole Pegboard Dexterity Test), and *executive function* (as measured by the Dimensional Change Card Sort Test). Pearson correlation tests showed significant but moderate correlations between miss rate and all four independent variables:

- age and miss rate: $r(26) = -0.62$, $p < 0.05$
- grade level and miss rate: $r(26) = -0.47$, $p < 0.05$
- motor skill and miss rate: $r(26) = -0.41$, $p < 0.05$
- executive function and miss rate $r(26) = -0.56$, $p < 0.05$

The correlation coefficients are negative, indicating that miss rate decreases as motor skill increases. All correlations have a similar strength and would be considered moderate in the context of human-subjects research [6]. As an example, Figure 3 illustrates the correlation between miss rate and motor skill.

Age	Target Miss Rate (SD)	Dependent Recognition Accuracy (SD)
4	39.32% (9.04%)	32.68% (19.91%)
5	25.89% (5.65%)	59.10% (17.57%)
6	26.71% (7.23%)	67.32% (15.73%)
7	21.31% (1.47%)	75.52% (12.05%)

Table 1. Miss rate and dependent recognition accuracy by age.

4.2 Gesture Task

To measure automatic recognition accuracy of the children's gestures in our study, we used the $P recognizer [20] to make our work comparable to prior work on children's gestures [22,23]. We used Wobbrock et al.'s procedure for systematic testing in a *user-dependent* scenario [21]. In the user-dependent scenario, the recognizer is trained on gestures from the same user as it is tested on. Because we only collected two training samples of each gesture per person, we train using only a single training example, as one must be kept for testing.

We analyzed the correlation between the dependent variable of *user-dependent recognition rate* and four of the same independent variables as above: *age, grade level*, *age*, and *executive function* using Pearson correlation tests. We found a significant moderate correlation between recognition rate and all independent variables:

- age and recognition rate: $r(26) = 0.66$, $p < 0.05$
- grade level and recognition rate: $r(26) = 0.57$, $p < 0.05$
- motor skill and recognition rate: $r(26) = 0.69$, $p < 0.05$
- executive function and recognition rate: $r(26) = 0.46$, $p < 0.05$

5 DISCUSSION

In the target task, we found moderate correlations between target miss rate and each of age, grade level, motor skill, and executive function. We also found moderate correlations between each of age, grade level, and motor skill for the gesture drawing task. The strength of the correlation with motor skill is slightly higher for gesture recognition rate ($r(26) = 0.69$, $p < 0.05$) than for target miss rate ($r(26) = -0.41$, $p < 0.05$), though both are in the moderate range. Thus, motor skill is slightly more predictive of gesture recognition rate for children than of target miss rate. We believe this is because of the direct mapping between the gesture drawing task and the writing skills children develop in school, compared to the target touching task. Children's performance on the target task is likely more related to the amount of experience they have using touchscreen devices rather than to schooling.

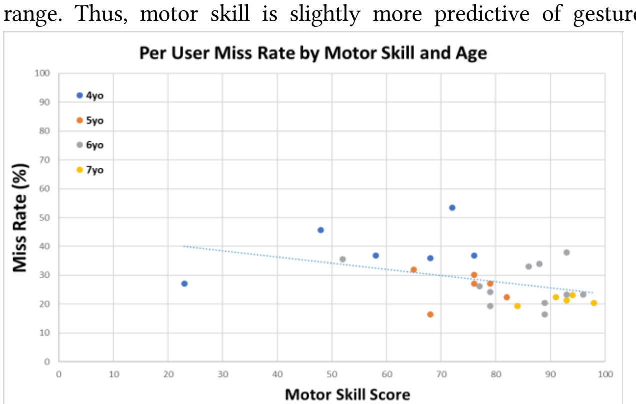


Figure 3. Correlation between motor skill and target miss rate. Circles are color-coded by participant age.

To compare our results to prior work, we also examined the effect of age on both target miss rate and gesture recognition rate. A one-way ANOVA on *target miss rate* with a between-subjects factor of *age* found a significant main effect of age ($F_{3,24} = 7.54$, $p < 0.05$). A one-way ANOVA on *gesture recognition rate* with a between-subjects factor of *age* found a significant main effect of age ($F_{3,24} = 7.63$, $p < 0.05$). Table 1 summarizes these results.

Our results show that using motor skill and executive function as a lens through which to examine touchscreen interactions does not provide much additional nuance beyond simply looking at age as prior work has done. Low motor skill will generally predict poor performance compared to high motor skill, but the same can be said for the relationship between age and performance and between grade level and performance. Thus, we conclude that it is reasonable for researchers to use age or grade level as a proxy for developmental level when studying children's touchscreen interactions, especially given the additional overhead incurred by measuring children's cognitive and motor skills.

6 LIMITATIONS AND CONCLUSION

There are several limitations to our work. We used two dimensions of cognitive development, based on the NIH Toolbox® 9-Hole Pegboard Dexterity Test and Dimensional Change Card Sort Test, but there are other measures that may further our understanding into children's touchscreen interactions. For example, a grip strength test may provide new insight into how children interact with stylus-based applications. However, we chose the factors that we felt were most likely to be strongly tied to the way children interact naturally with touchscreen devices, since they are similar to typical touchscreen tasks.

We presented a study of 28 children ages 4 to 7 years old spanning pre-school to first grade. We examined the children's cognitive development in terms of motor skill and executive function using two measures from the NIH Toolbox® assessment suite. We found target miss rate and gesture recognition rate were both moderately correlated to each of age, grade level, motor skill, and executive function. We conclude that age and grade level are sensitive enough to consider for researchers and designers studying children's touchscreen interactions.

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