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To users, mobile touchscreen devices have appealing characteristics; among these characteristics is intuitiveness, which leads to mobile devices being used almost everywhere by almost everyone to accomplish almost anything. This statement, to some degree, holds for children too. Despite touchscreen devices' intuitiveness and popularity, we don't know much about how interacting with such devices affects children. Given that mobile touchscreen devices are both engaging and interactive, one can speculate that such an effect may potentially have some benefits. In this research we test whether touchscreen use over time can contribute to improving children's tactile skills or not. We also revisit "difficult gestures" to confirm children's ability to execute such gestures.

Investigating the Effect of Using Mobile Touchscreen Device on Children's Tactile Skills

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Rana Almurshed, Author

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Investigating the Effect of Using Mobile Touchscreen Device on Children's Tactile Skills

1. Introduction

The introduction and rapid adoption of mobile touch-enabled devices has made interacting with computation more accessible to children, both from an availability and usability perspective. Smart mobile devices (primarily smartphones and tablets) have been outselling personal computers since approximately 2011, and there were estimates, as of 2014, that more smart devices would be in use than traditional computers and laptops [33,68].

A report from Common Sense Media [70] showed that 72% of children aged 0 to 8 in the United States use or have used mobile devices such as smartphones or tablets, and that as many as 38% of children under the age of 2 use or have used such devices. This is not a trend restricted to the U.S. According to Ofcom [65], UK household ownership of tablets more than doubled between 2012 and 2014, (51% vs. 20%) and tablets are now in a majority of homes. Furthermore, a survey done by Formby [28] found that children under the age of five are being introduced to touchscreen devices at children's centers as well as day nurseries and preschools. Their numbers showed that most of such establishments allow children to access touch devices at least once a week. More specifically, around 30% allow children to use such devices daily.

According to the Michael Cohen Group [23], touch devices are appealing, charming and engaging for children, due to the accessibility, clarity and ease of use. Moreover, Cohen remarked that children interact with these devices "naturally." The direct interaction and tangible nature of touch interaction means that if a child is interested in a picture or an icon they can reach out and touch it. This can then set off appropriate interactions and feedback to the child. This feature makes touchscreens appealing to young children and encouraging them to spend more time using such devices [23,28].

In school settings Clarke and Svanaes [22] found that using touchscreens increased motivation to learn, engagement and collaboration. That might explain why iPads are finding their way to preschools and kindergarteners. For instance, EmBe Childcare Center in Sioux Falls, SD, are introducing iPads as a classroom weekly activity; teachers believe that using such devices contributes to child's "learning through play" [87]. At Laurene Edmondson Elementary, Loveland, CO, kindergarteners are using iPads to help them in their science projects; they take pictures, record videos and use Apps such as "Book Creator app" [34]. An additional unusual example is the Hempfield Area School District; they are using iPads at their kindergartner's gym classes, as they believe these devices help improve fine motor skills [84].

However, the effect of using computers or screen time more abstractly, especially on young children, is a hotly debated topic. On one side, there are researchers, developmental psychologists and educators who argue that too much screen time can be detrimental to a child's development (the skeptical party) [50]. Their advised approach is unfavorable to screens for children. The other side argue that touchscreens devices are tools and their effects depend on how we use such tools (the advocate party); their advice is supervised and guided use [4].

Supporting the first group (skeptical) is Harvard's Center on the Developing Child [88], they advocate that "Serve and Return" (i.e. the interaction with an adult) is the best way to encourage healthy brain development in young children. DeLoache et al. [25] supports the same conclusion – they found out that "face-to-face" communication with young children is most efficient for increasing vocabulary and improving language development. Furthermore, Robb et al. [71] discovered that watching a TV show teaching words did not enlarge a child's vocabulary. Not only language development can be affected, but also some aspect of cognition; Lillard et al., [50] assessed children's executive functions (i.e. their working memory, attention and inhibitory control) after exposing them to both an educational and a non-educational show. They also assessed children's executive functions in a control group of children who engaged in freeform drawing. Though the children who watched the educational program did better than the group who watched the non-educational program, neither group did as well as the children in the control group.

Nevertheless, much of this research dates back to studies of children passively watching television, i.e. not engaging all their perceptual, rather than interacting with software. In 2015, Moser et al. [59], looked at young children's ability to transfer learning from a physical demonstration then compare that to children's ability to transfer learning a touchscreen demonstration. Children ages ranged from two to three. They found that children perform better at mimicking a puzzle solution when the demonstration was with magnetic pieces, compared to when the demonstration was on a touchscreen. However, their finding didn't mean that the children couldn't solve the puzzle on a touchscreen but rather that the children did not reach the exact goal following a certain order of steps. Moser et al. noted that their findings could be a result of memory flexibility (or the lack thereof) plus the absence of "physical feedback" or cues, when compared to the physical puzzle. Furthermore, Moser et al. found that "gesture" learning from touchscreens appear to be advantageous over learning from TV, especially in young children. [59].

The move from passive reception to active interaction encourage the "advocate" party to speculate that interactivity, among other features, could help children develop skills, when used correctly and in moderation. Researchers found that, especially in young children, demonstration plus hands on activity facilitate transfer of learning better than demonstration alone [59]. Additionally, [59] remarked that children can learn by imitation and that social engagement (i.e. having an adult to interact with the child during their attempt to imitate) can help children in perfecting imitations of desired activities. In other words, social engagement can have a scaffolding effect on imitation. A touchscreen mobile device usually is not only a phone, it is also a game pad, a camera, a music player, a drawing pad and other applications [47]. Hence, giving that the child is not only passively watching, these devices can provide both features; interactivity and social engagement. In [72], Roseberry et al. have observed that young children (preschoolers) can learn new vocabulary when using touchscreen apps (video chat). In [10] they speculate that touchscreen could positively affect infants and toddlers fine motor skills. Moreover, in [46] the authors promote that a well-designed app with the presence of scaffolding could improve problem solving and increase vocabulary for two years old. In [42] children age four to six were able to solve Tower of Hanoi problem, after practicing with a touchscreen device. In Tower of Hanoi problem there are three bars and five disks stacked from largest to smallest on one of the rods. The goal is to move this stack of disks to another bar keeping the same order of disks. To accomplish this task the following rules must be applied : move one disk at a time, larger disks should always be below smaller ones and that disks should be placed on top of other disks or in an empty bar [30]. Huber concluded that for this problem, children were able to transfer learning from touchscreen as effectively as they did when using an actual 3D block model of the problem. Touchscreens are intuitive, which is very suitable to preschoolers[60]. In [86] they found that the learning of math concepts can be transferred from tablets. Chiong and Shuler [21] showed that three to seven years old children can benefit from using a tablet (with a special multimedia app) to increase and improve their vocabulary. Although there is interest in the possibility of using touchscreen to aid the development of fine motor skills, little work has addressed this issue for young children [60]. Nacher et al. [60] support the idea of the possibility of using mobile touchscreen devices to encourage motor, cognitive and social skill development in general.

Children as young as two are using these types of technologies [70] and this trend is only likely to increase not only because of their intuitive nature, but also due to diverse role in children lives (e.g. learning, self-regulation and distraction) [47,60]. Due to the lack of insight, parents are improvising their policies on touchscreens use by their children; some limit their use, and some find it difficult to do so [67]. As a result, parents wish to know whether the use of such devices by their children is affecting them in anyway or not? Is there a “right” way or a “wrong” way?

Since there are many factors governing such effects, longitudinal studies are needed [47]. Kucirkova and Zuckerman further recommend establishing clear and standard definitions of criteria that are measured or implemented in touchscreen research. For example, differentiating between child-adult interactivity and app interactivity. They also emphasize that touchscreen research should be distinguished from screen time research due to the different nature and context of touchscreen use. Additionally, Kucirkova and Zuckerman advocate for more diverse research methods to understand the issue and help extend theories explanations. Another issue is that children differ, therefore constraining them in age ranges could risk “exclusion” of other developing children. Hence, we want to look at the skill, not the age. Skills, even though they complete/compensate and aid each other, contribute differently. We need to look at skills individually to better understand how they contribute to a child’s development and what affects such skills [47].

In this research we investigate the effects of children’s use of mobile touchscreen devices on their fine motor skills development. We explore whether using a touchscreen device improves, hinders or fails to affect children’s fine motor and hand-eye-coordination skill development. Additionally, we explore whether training children to perform certain challenging gestures leads to improvements in children’s performance while interacting with touchscreen devices. More specifically, this research will answer the following research questions:

- RQ1: Within the context of touchscreen use, is skill acquisition bound by age or practice?
    a. Can a touchscreen gesture be mastered after multiple trials?
    b. How many trials are needed for a child to master a certain gesture?
    c. What challenging touch screen gestures can be performed after multiple trials?
    d. Does age determine what gestures a child can/cannot perform?

    H_0: Training has no effect on touchscreen skill acquisition.

- RQ2: How does children's interaction with touchscreen devices affect their fine motor skills?
    a. What skills were affected by touchscreen usage?
        i. Is there a causal effect of using touchscreen devices on children's grasping skills development?
        ii. Is there a causal effect of using touchscreen devices on children's visual motor skills development?

$H_{0.1}$: Using touchscreen devices has no causal effect regarding grasping skills development

$H_{0.2}$: Using touchscreen devices has no causal effect regarding visual motor skills development

The rest of this report is organized as follows: We start with detailed survey of the literature. In section 3, we walk through our study 1 methodology, results then discussion. Section 4 follows, explaining study 2 methodology, results and discussion. Finally, we conclude with section 5.

2. Mobile and Touchscreen Design Guidelines for Children: A Literature Review

Given that children as young as age two are using these types of technologies – and that this trend is only likely to increase – the challenge we as researchers and educators face is in identifying reasonable limits and applications to maximize the potential benefits and minimize potential harms, as well as improve the general usability for children. We therefore set out to survey the literature on design considerations for young children to identify best practices and guidelines based on both peer reviewed research as well as published reports of practitioner best practices. Our goals were to explore what researches have been done regarding children's use of touch technology, how to adapt such technology to children, and survey any other design recommendations.

We conducted our literature review by doing an initial search on research of touch devices and touch technologies, followed by an exploration of the available literature on children's use of touch and mobile technology. The third stage was to refine these findings through an exploration of related researchers and efforts.

Beginning with the initial search phase, we surveyed available touchscreen devices looking at their specification and the technology behind them. These are important constraints for understanding what children have to deal with. Additional aspects we looked at was offered interactions (i.e. gestures) in such devices, how to execute these gestures and what features, difficulties or limitations do such gestures introduce. Next, we looked to answer some general questions of interest: Are touchscreen devices designed to be usable by children? How best to consider children's psychological and physical limitations and needs, and any available research or findings regarding the matter. We also examined the research on how children adapt to such technologies. Information from the first phase allowed us to gain more insight of what work had been done. Next, we reviewed proposed design guidelines and documented issues and limitations regarding children and touchscreen devices.

We mainly used online databases and Google scholar for published peer-reviewed resources. We also conducted additional searches using general search engines such as Google to explore articles, which may be related to our research. Such papers, most of which were not peer reviewed, are referred to as "grey literature" [74]. Apart from not being peer reviewed, these publications often contain results of experiments done by private organizations, or practitioner reflections. These publications do provide interesting results and insights that are worth looking at, despite the fact that they often lack direct reports of experiments details. We focused only on English publications.

After that an analysis and synthesis of selected literature was conducted summarizing contributions and locating gaps that needed more attention.

2.1. Design and Interaction Space

The two main technologies currently popularly used in touchscreens are either capacitive or resistive screens. Capacitive touchscreens respond to the changing electrical characteristics of an object, such as a human finger, touching the screen surface [79]. This enables the screen to not just determine whether a finger or an inanimate object has touched the screen, but to track multiple touches at once as well. Resistive screens on the other hand, rely on pressure sensing from a stylus or a finger, as the pressure will connect two layers of the screen. The specific location allows an electric circuit to be formed, hence recording a touch action in that location [79].

In our review we were especially interested in capacitive touchscreens, as they are by far the most commonly used technology in smart phones and tablets.

2.1.1. Device Specifications

Here we provide a look at the dimensions and physical characteristics of popular smartphones and tablets for the year 2018. A smartphone screen can range from inches 5.5 inches (Google Pixel 3) to 6.4 inches (Samsung Galaxy Note9) and weighs from 0.32 pounds to 0.44 pounds [58]. A mobile tablet screen can range from 7.9 inches (Apple iPad Mini 4) to 10.5 inches (Apple iPad Pro 10.5) and weighs from 0.65 pounds to 1.03 pounds [24]. The market changes rapidly, and these figures will likely change by the time this research is published. However, it is included to provide some context for discussion about the implications for usability. As we see, devices do differ significantly on specifications such as size and weight.

2.1.2. Interaction Space

Touchscreens are often thought to be widely accessible, mainly because most gestures used are relatively simple and intuitive (i.e. they do not require an intermediate device to translate desired action, and they relate more naturally to actions in the real world). For example, if one were interested in an object in real life, one would reach out and touch it. On a touch device, most gestures are more direct translations of real-world actions.

The most common touchscreen gestures for mobile devices are carried out using one or two fingers. Tap, double tap, slide, flick, press & hold and drag & drop are gestures that are executed using one finger (see Figure1 (a)), while zoom (in/out through pinch gesture) and rotate are executed using two fingers (see Figure1 (b)). Tilt, on the other hand, is a gesture done with hand(s) rather than fingers (see Figure1 (c)), relying on the device's accelerometer rather than screen input. Since these gestures differ in description, one might speculate that they differ in execution complexity as well.

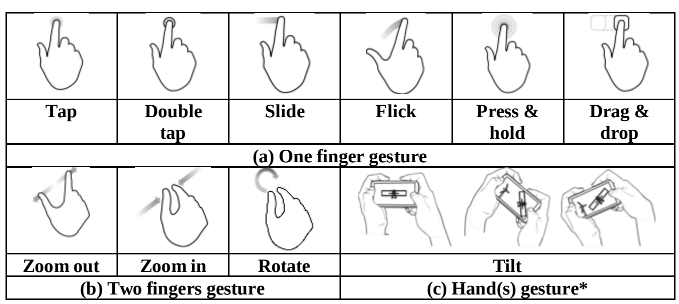


Figure 1: Common touchscreen gestures[15,52]

Unlike interactions with an intermediary device, like for instance a stylus or a mouse, recording input from human fingers can be tricky. As Holz and Baudisch [39] found, touchscreens are designed to read electric input from human fingers, which can affect the target selection precision. Because touchscreens acquire readings from the part of the finger touching the screen, rather than the tip of the finger itself, Holz and Baudisch found that people often misread where the point of contact is. This results in an "error offset" which in turn affects the precision of touch gestures such as tapping, drag and drop, swipe and double tap.

As for two fingers gestures, Hoggan et al. [37,38] investigated factors affecting the speed and accuracy of pinch and rotation gestures such as angle, direction, diameter/distance and position. For rotation gestures, Hoggan et al. discourage increasing rotation diameter/angle or choosing horizontal rotations. Moreover, they recommend counterclockwise rotations as these appear to be performed faster. To improve the speed of pinch gestures, they recommend choosing "contracting" (inward movement) pinches over "expanding" (outward movement) and encourage limiting pinch distance. An additional recommendation is to avoid placing pinch gestures along the screen edge, as this increases failure rates and decreases the speed of pinching.

2.2. Designing for Young Children

Children have often been looked upon as simply smaller adults. In some respects, and especially with older children, this is not always an incorrect approach. However, when dealing with younger children, it is virtually impossible to treat them in such a simplistic manner. Children, especially at an early age, change rapidly both physically and cognitively, and they develop at different speeds (i.e., not all children come to master the same skills at the same age [47]), making deriving a uniform set of design criteria difficult. Designers of apps and devices, as well as parents and educators looking to use mobile platforms, need more information to understand the relation between children and touchscreen devices, only then adults can exert the benefits of these devices for children and limit the adverse effect if any. Table 1 lists some of the child development concepts we will be mentioning in this section along with high level definition [9,16,31].

Table 1: Child development concepts and definitions

Concept	Definition
Motor skills	Refers to overall body movement
Fine motor skills	Refers to hand and fingers movement
Gross motor skills	Refers to trunk, legs and arms movement
Visual motor skills	Refers to the hand eye coordination
Cognition	Refers to set of processes that facilitate gaining and utilization of knowledge (i.e., thinking)
Executive functions	Refers to working memory, attention and inhibitory control

Physical. We know that children have smaller hands, weaker grip, and shorter fingers; we also know that these physical characteristics influence their fine motor skills. Children have smaller hands than adults; the hand of the average five-year-old boy is 32% narrower and 34% shorter than that of an average adult male. Their index fingers are 40% shorter, and 34% narrower than those of adults [64,66] (see Figure 2 and 3). This has some important design implications for user interface; bigger hand-held devices or more spaced out interfaces are likely to be harder for children to interact with, and special attention needs to be paid to the placement of UI elements in order to accommodate grasping and reach with shorter fingers and arms.

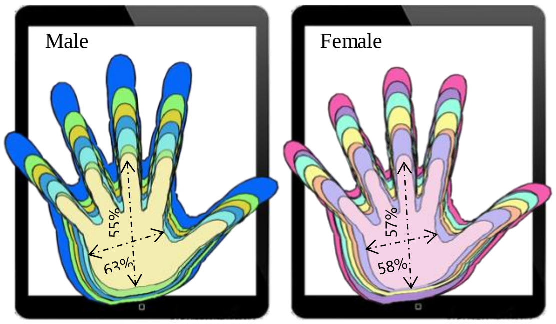


Figure 3: Average adult's hand size vs. a child's hand size at ages 2, 4, 6, 8, 10 and 12

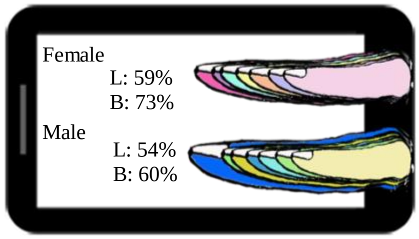


Figure 2: Average adult's index finger vs. a child's index finger at ages 3, 5, 7, 9, 11 and 12

Having such a rapidly developing body naturally extend to fine motor skills that are under constant development and readjustment. That, in light of touchscreen devices and app design, implies that establishing a set of can(s) and cannot(s) might be challenging, and generalizing such set might not be practical.

These physical characteristics influence their fine motor skills, including pointing precision. The shortage in fine motor skills raises some questions when evaluating children's use of touchscreen devices. For instance, some gestures including zooming and rotation could be difficult in general. Performing these gestures with shorter fingers could be even more difficult. Hence, how far can children drag, rotate or pinch objects on a screen.

Although some previous research found that children could use a mouse at as young as age three [49], other studies found that young children's acquisition speed, precision and control of the mouse was notably less than adults [40]. Factors such as age, motor development, cognitive development, visual motor coordination and previous experience are found to affect children performance when using a mouse [49]. Nevertheless, these studies also found that general mouse control improve as a child gets older [40,49].

Cognition. Children are not just developing physically; they lack many of the mental skills and abilities most adults have. They are relatively easily distracted and can get bored quickly. Their reading skills are limited, as is their iconic vocabulary and their experience with the real world. Non-physical skills and physical skills play a role in differences found between adults and children.

In regard to children's cognitive development, two influential theories are those of Piaget and Vygotsky. For Piaget, learning begins with the child, it is an inherited ability. Piaget explains that children start with a blank mind, then with experience they built schemas to deal with situation. These schemas themselves are affected by experience and are adjusted through assimilation or accommodation. Another characteristic of this cognitive development is that it goes through stages; stages are associated with age. Children go through these stages in order [56,73]. The idea of stages in Piaget cognitive development is parallel to the idea of having certain "milestones" in children development. In "Development Milestone" approach [90] children should be able to accomplish certain tasks by a certain age. That is the child age acts like an indicator for their ability to manage and complete a task. Hence, in light of "Development Milestone" approach, one might speculate that age will be a determinant of whether a child can successfully perform a gesture or not (i.e. there are age appropriate gestures). Therefore, certain gestures are to be introduced only at certain age due to the fact that a child won't be able to comprehend how to perform these gestures before that stage is reached.

Vygotsky, on the other hand, advocates for the idea that a child's learning is driven by their environment and social context and that development starts with words; language is the motivation of thought. Vygotsky introduces the

Zone of Proximal Development (ZPD), where the child can improve their skills with the presence of an adult's aid ("scaffolding"). In ZPD, a child cannot accomplish a task independently, yet with the guidance of an adult that child can [57,73]. Consequently, in light of Vygotsky theory of cognitive development, one might speculate that rather than age alone, it is the presence of scaffolding that determines whether a child can successfully learn to perform a gesture. This indicates that a child could do better with training, and when the child does better, their skills become better (mastery).

Whether it is "Development Milestone" approach (certain age can do certain things) or Vygotsky's approach (scaffolding presence boost development) or both (certain age can do certain things but with scaffolding they can overcome challenges to an extent) knowing that will enlighten our interpretation of the link between children and touchscreens if any.

Fine motor skills and school readiness. In a school setting, children rely on their motor skills to accomplish school tasks [9,11,44,51] Commonly, children spend from a third to two thirds of their time on activities that require their motor skills. [53]. Additionally, having advanced fine motor skills as a child impacts their academic achievement, specifically school readiness. It has been shown that children with better fine motor skills perform better in school. Research has shown a strong association between fine motor skills and school readiness; in [17] researchers found that preschoolers' fine motor skills predicts their math and reading achievement in first, third and fifth grade. Specifically, the copy design task is positively associated with writing and math [16,18,19,45]. These findings support the Theory of Embodied Cognition, which mainly emphasis that the body is part of the cognition process; cognition is not limited to the brain, physical body and limbs significantly affect cognition [9,81].

Furthermore, researchers have found that having "strong" fine motor skills and visual motor skills can have a compensating effect when children are faced with a challenging task [17]; that is, having strong skills aid their learning, especially in math and literacy [17,19]. One explanation is that children who have strong motor skills can navigate the school environment more confidently. Children with strong motor skills are likely to be less anxious and more willing to participate in socializing and to be accepted by their peers [16,45].

Another explanation for why fine motor skills are robustly related to school readiness stems from The Theory of Cognitive Load; which is built on the premise that cognition processing capacity is "finite". Hence, novel tasks consume most of the cognitive resources for the purpose of examining, learning and performing such tasks. Consequently, with strong fine motor skills, part of allocated cognitive resources is freed (i.e. atomicity happens; shift these tasks from prefrontal cortex to the subcortical motor areas), therefore, more cognitive capacity is located to solving other complex tasks [75].

2.3. Best Practices

2.3.1. Overview of Key Papers

Publications discussing designing guidelines for children's touch applications can be categorized based on their sources; peer-reviewed publications, and practitioner reports. Practitioner reports are often based on non-peer-reviewed studies, the results and specifics of which are not always shared with the research community. We borrow the term "gray literature" [74] to refer to such publications, in our case reports by the Sesame Workshop and the Michael Cohen group.

Our literature review identified five primary groups of authors; Lorna McKnight et al., Lisa Anthony et al., Quincy Brown et al., Nacher et al. and Abdul-Aziz et al. These groups were identified as key due to their multiple publications addressing children's usability of touchscreen devices. In addition, we identified six other peer- reviewed publications, and two publications from the non-peer-reviewed literature. Table 2 summarizes the peer-reviewed papers, with two or more publications covered in this section; what each paper investigated and who were the subjects of each study. We start the columns by listing the source author and their publication number. Then a description of the participants in those studies; number of children, their ages and number of adults that participated. Then we demonstrated with a check chart what gestures those papers looked at; there were gestures such as tap, double tap, slide, flick, long press, drag & drop, zooming and rotation. Some papers also investigated implementing drawing with and without a visible trace following finger movement on the screen. Last column presents another check chart illustrating what design issues have these publications visited. Some looked what terms used in apps instructions, others looked at icons and hotspots of other miscellaneous aspects of design.

Table 2: summary of covered peer-reviewed papers (sample and investigated features)

Source	**No.**	**Participants**			**Interactions Investigated**										**Design Issues Investigated**			
		No. of children	**children ages**	**No. of Adults**	**Tap**	**2x Tap**	**Slide**	**Flick**	**Long Press**	**Drag & drop**	**Zoom**	**Rotate**	**Draw** No Trace	**Draw** Trace	**Terms**	**Icons**	**Hotspots**	**Other**
McKnight & Cassidy	[a]	53	8-10	0														General Usability
McKnight & Fitton	[b]	13	7-10	0	✓	✓			✓	✓					✓			
Anthony et al.	[a]	25	10-17	16	✓									✓		✓	✓	
	[b]	16	7-16	14	✓			✓					✓	✓		✓	✓	
	[c]	44	6-17	30	✓								✓	✓		✓	✓	
Brown et al.	[a]	8	7-11	6	✓								✓			✓	✓	
	[b]	7	5-7	0	✓								✓	✓		✓	✓	
	[c]	44	6-17	30	✓								✓	✓		✓	✓	
Abdul Aziz et al.	[a]	33	2-12	0	✓		✓	✓		✓	✓	✓						
	[b]	37	2-4	0	✓		✓	✓		✓	✓	✓						
Nacher et al.	[a]	24	2-3	0	✓					✓	✓							Hinting gesture performance
	[b]	32	2-4	0		✓			✓									Improving performance
	[c]	32	2-3	0	✓	✓			✓	✓	✓	✓						

The studies we identified examined the usability concerns of children's use of touchscreen devices This included the study of touch gestures, the precision of finger movements, how much control children have over their actions, and whether children understand the relevant terminologies. In other words, as McKnight et al [54] put it "interaction design not interface design". We excluded publications that only focused on the learning/education use of touchscreen devices, as well as those that investigated available apps and what gestures they use. Moreover, covering other types of devices, such as multi-touch tabletops, tablet with only stylus as an input, PCs, video games or TVs is beyond the scope of this research.

We group the papers into four categories according to investigation approach: investigating acceptability and engagement, interaction intuitiveness, design restrictions or assessing proposed design recommendations.

Investigating acceptability and engagement: Early publications such as McKnight & Cassidy [54] as well as that of the Michael Cohen group [23] were interested in exploring how children receive touchscreen devices. In addition, they were concerned with general usability and exploration to identify potential issues.

Interaction intuitiveness: After touchscreen proved to be popular with children, researchers' attention shifted to evaluating how suitable available touch interactions were to children (i.e. intuitiveness and whether or not children were able to perform the actions successfully). Among publications that address this matter were Abdul-Aziz et. al [1,2], Baloian et al.[8], Nacher et al. [61–63] and Sesame Workshop [89].

Design restrictions: A second interesting aspect that multiple researchers looked at was how some design aspects may restrict usability for children. McKnight & Fitton [55] assessed how touch actions terminologies may present an obstacle to children. For example, when presenting a game instruction to touch a button or a target, using the term "select" proved to be confusion when compared to using the term "tap". On the other hand, Anthony et al. [5–7] and Brown et al. [12–14] were interested in how size or location of icons and hotspots affected the accuracy of a tapping action. Moreover, in the case of drawing or copying gestures, they investigated the effect of having a visual trace following a finger movement on the screen.

Assessing proposed design recommendations: Nacher et al. [62] suggested and assessed modifying the underlying implementations of touchscreen devices and interactions to accommodate a child's capabilities. For instance, they validated how increasing time intervals between double tap can improve children's performance when double tapping.

2.3.2. Design Recommendations

A number of recommendations were generated from studies mentioned in the previous section, and many of these are agreed upon across multiple publications. In this section we summarize the recommendations found in more than one source (i.e. the recommendations for which there is consensus) followed by recommendation found in a single resource (i.e. sparse support).

2.3.2.1. Broad Consensus Recommendations

Table 3 provides a summary of recommendations found in both peer and non-peer reviewed publications. We categorize these under either design or interaction recommendations. By design we refer to recommendations related to an applications' design. By interaction we mean findings related to touch gestures and how to adjust these for children.

Design. Most of Revell and Reardon [69], McKnight et al. [54,55] Anthony et al. [5–7] and Brown et al. [12–14] recommendations focused on different design aspects. In their publications they listed findings related to hotspots, icons and gestures terminology. For instance, they all agreed on not using ambiguous gesture terminology, and choosing gesture terms based on the context of both device and application, (e.g. substituting "Select" term with "Tap"). Another highly agreed upon design recommendation is decreasing system sensitivity to fit a child's precision level.

Interaction. Recommendations related to interactions are mainly based on studies of the intuitiveness of touch gestures. Across all studies that investigated the matter, tapping was found to be the most intuitive gesture while double tapping was the most difficult to perform for children. Additional notable interactions' aspect found in several papers (McKnight et al [54,55], Anthony et al. [5–7], Brown et al. [12–14], Nacher et al. [61–63], Sesame workshop [89] and Michael Cohen group [23]) is the effect of accidental touches on performance (i.e. sometimes a child unintentionally touches the screen either in the beginning of or while performing a gesture, causing the system to react incorrectly (not registering the gesture or doing another action)). For instance, if a child has one finger on the screen before initiating a touch gesture, this can be interpreted as a zooming action instead of dragging.

A final remark is that although publications by the Sesame workshop [89] and the Michael Cohen group [23] are non-peer reviewed, most of their findings and recommendation match the peer-reviewed ones. For example, we note that the Sesame Workshop paper agreed with other peer reviewed recommendation related to hotspots, icons, gesture intuitiveness level and how application's instructions should be presented in both audio and text format (see Table 3 for a summary of agreed upon guidelines).

Table 3: summary of agreed upon guidelines (by two or more publications)

	Element	Guidelines & notes	Ex. Sources
Design	Hotspots position	Away from edges	Revell and Reardon, Sesame Workshop
	Hotspot size	Enlarge	Revell and Reardon, Anthony/Brown et al., Sesame Workshop
	Icon size	Enlarge	Anthony/Brown et al., Sesame Workshop,
	Gesture Terminology	Avoid confusion	Revell and Reardon, McKnight et al., Anthony/Brown et al
	Instructions	Provide both Audio & text	Revell and Reardon, McKnight et al., Sesame Workshop
	System sensitivity	Adjust to child precision level	Revell and Reardon, McKnight et al., Anthony/Brown et al., Baloian et al., Nacher et al.
	Performance	It increases with age	Anthony/Brown et al., Abdul-Aziz et al., Nacher et al., Vatavu et al., Hourcade et al.
	Timing	Children take longer time	McKnight et al., Anthony/Brown et al., Nacher et al.
Interaction	Intuitive gestures	Tapping	Abdul-Aziz et al., Nacher et al., Vatavu et al., Sesame Workshop
	Least intuitive gestures	Pinch	Abdul-Aziz et al., Sesame Workshop
		Tilt/ Shake	Revell and Reardon, Sesame Workshop
		Double tap	McKnight et al., Abdul-Aziz et al, Baloian et al., Nacher et al., Vatavu et al., Sesame Workshop
	Scrolling	Vertical is discouraged	Revell and Reardon, Sesame Workshop
	Accidental touches	Consider	McKnight et. al., Anthony/Brown et al., Nacher et al., Vatavu et al., Sesame Workshop, Michael Cohen group
	Draw/copy	Provide visual trace path	Anthony/Brown et al., Sesame Workshop

2.3.2.2. Unique Findings or Recommendations

Beyond the recommendations supported by multiple authors and studies, papers also proposed some unique results. In this section we list each unique finding by Author(s).

- **Revell and Reardon** [69]**:** Their study was aimed at generating guidelines for migrating PC games to touchscreen devices. They suggested to substituting some "mouse" functions with touch actions (e.g. touch and drag instead of a "mouse over"). Moreover, Revell et al. advised simplicity in game designs due to screen limitation, as well as adding tutorials to aid children through the game.
- **McKnight and Cassidy** [54]**:** In their paper they observed general usability issues for children. They proposed two solutions to the "accidental touch" phenomena; the first was to increase the space between a device's edge and the screen's edge. The second was to present a visible notification for finger-screen contact.
- **McKnight and Fitton** [55]**:** This study's main goal was to assess whether or not children can understand touch gesture terminologies. Their findings suggest that using "tap" as an instruction for a single click resulted in increased number of successful gestures' executions. Similarly, when using "tap it twice" to refer to a double click, "press and drag" instruction to indicate a click and hold, as well as, "do a long click" instead of "click and hold" instructions.
- **Brown and Anthony** [12]**:** From this paper, two findings were reached; first, compared to adults, children are often less successful in touching targets. Moreover, children were found to draw using multiple lines, slower drawing pace with weaker pressure and the images they produce are to a larger scale.
- **Anthony et al.:** In [6] the authors noticed a phenomenon, which they later refer to as "holdover". Holdover happens if a participant retouches earlier target's position thinking that he/she missed it in a previous attempt. For holdover as well as accidental touches, Anthony et al suggested using time and position of touch action recorded to incorporate a better system response. They also noted that screen icons/ active objects size should fall between "0.25 inch and 0.5 inch".
- **Brown et al.:** In [14] they concluded that developing a gesture and touch recognition system that can adapt to user behavior might improve the recognition process across ages (i.e. developing a customized and trainable gesture auto recognition tool for children).
- **Geist** [29]**:** Observed 2 to 3 years old children. He noted that with tablets' natural interface, children are more capable navigating such devices. Moreover, he pointed out the "accidental touches" effect resulting from a child's hand/finger(s) resting on screen and that children do use their hands sometimes instead of just their fingers in dealing with a touchscreen. Lastly, he concluded that children's performance improved either after training sessions, observation of others or trial & error exploration.
- **Abdul-Aziz** [2]**:** Her main finding was that children age 2 face difficulties executing most actions. Moreover, she ranked gesture intuitiveness across ages (see Table 4 for an overview).

Table 4:Abdul-Aziz's rating of touchscreen gestures. Green (✓) smooth execution. Yellow (?) with difficulty. Red (x) failed to execute

Age	Tap	Slide	Flick	Pinch	Spread	Rotate	Drag
2	✓	✓	✓	?	✖	✖	✖
3-4	✓	✓	✓	?	?	?	?
5	✓	✓	✓	✓	✓	✓	?
6 +	✓	✓	✓	✓	✓	✓	✓

In a follow up two studies, one in UK and a replica in Malaysia, Abdul-Aziz et al. [1,3] focused on children aged 2 to 4 and what gestures they were able to perform. The results confirmed their pervious findings that children age 2 struggle with most gestures except for tap and slide. Moreover, they concluded that children 4 and above are more likely to master touch gestures. Researchers also take notice of gestures' nature, number and type of gestures to be used in relation to a task or a component, as well as components' number, design and placements within a screen.

- **Ibharim et al.** [43]**:** Surveyed and observed eight years old children in order to answer the following questions: Do children know what a touchscreen is? Do children succeed in performing touchscreen gestures? And how do children receive such devices. Specifically, what factors contribute in facilitating children's understanding and interaction with touchscreen devises? Based on their findings they categorized zooming out and rotation to be difficult gestures to be performed by 8 years old children. Further, they recommended using images, sounds and animation to communicate application instructions. They also noted that interface complex design could hinder children interaction with the device.
- **Baloian et al.** [8]**:** In their study, Baloian et al. explored not only how successful children are at executing a gesture, but also how much they like the gesture. The results showed that tracing ranked as a difficult gesture, while tilting and stretch & pinch were the easiest and most likable gestures to perform among children. It is worth remarking that tilting was considered the least intuitive in both the Sesame workshop paper as well as the Revell and Reardon paper.
- **Hamza** [85]**:** In her thesis Hamza assessed how four to five years old children perform point & touch, Drag & Drop, zoom in, zoom-out and rotate. Additionally, she identified some factors that can affect children's execution of these gestures; for example, she found that target size affect both rotation and drag & drop performance, object to target location distance affect point & touch, rotation is affected by orientation and degree. Her findings also confirmed that age is a critical factor that ought to be considered while designing for children and that performances improve generally with age. (rotation and zooming were difficult)
- **Nacher et al.** [63]**:** They were interested in ranking gesture intuitiveness for children aged two to three. An interesting finding was that zooming was among the most intuitive touch actions, which contradicts the findings of Abdul-Aziz [2]. Furthermore, double tap, press & hold and two-finger rotation ranked among the least intuitive touch screen actions. To solve double tap performance problems, they proposed an increment of the gesture's time interval. In [61] they found that increasing time between taps from 300 milliseconds to 1200 milliseconds proved to improved double tap performance among younger children. An additional suggestion was to introduce

a filter to discard unwanted initial gestures found to occur when children perform complex gestures such as press-and-hold (which they identified in [63] as a short drag), validated in [61]. Increased touch action performance can be achieved by providing extra hints on how to perform touch gestures [63]. They tested this recommendation in [62], using an "animated hand" to illustrate how to perform a gesture (adapting Hofmeester and Wolfe recommendation on providing hints to users how to perform gestures [36]). The introduction of an "animated hand" helped children understand how to perform touch gestures. However, in the case of gestures that did not require finger movement across the screen, the animated hand didn't make a difference in performance.

An additional interesting finding was that there was a difference in gestures performance if these gestures require spatial skills (which was scale up in their study); boys were found to perform such gestures better than girls.

- **Vatavu et al.** [78]**:** Assessed completion rate, time and accuracy for children aged three to six when performing tap, double tap, drag & drop of one and two targets simultaneously. Moreover, they correlate their findings with the motor skill development of the children. Their list of design recommendation not only addressed the importance of considering children motor skill level according to age but highlighted other aspect of child development such as children cognitive skills, egocentrism and imagination and how these aspects play a role in child interaction with the device/applications.
- **Hourcade et al.** [41]**:** Used YouTube as their data source; from where they collected videos featuring children, aged six months to 2.5 years, using tablets. They looked at how well a child can use a tablet, how a child uses a tablet (number of hands, number of fingers, gestures performed), how device as well as child are positioned, and what apps they used. They correlate these criteria with the child's age. Additionally, authors also kept track of children's emotions and whether or not there were other participants apart from the child in a video. Their findings support that children use and independence improve rapidly. In Figure 4, we summarized their finding by showing the percentage of video records found in each of their category. The first column represents a rank of how well the children were able to use tablet devices (from 1 to 5; 5 is very well) and the percentage of clips found in each rank. The second column shows the percentage of clips where children used single or both hands while playing with the tablet. The third column codes the percentage of clips were children used one finger, multiple finger or all five fingers at once. Fourth column summarizes the percentage of clips showing a certain gesture: tapping with one finger, hitting with the whole hand, swiping and dragging. Fifth and sixth columns display the percentage of clips were the tablets in use and the child using that devise were in certain positions. The "other ppl" column depicts the percentage of clips where there were adults helping the child using a tablet device. The last column, genre, illustrate the percentage of clips in each genre; G: games, E: educational, V: video, M: music, P: pictures and L: lifestyle.

Age	ability to use					hands		fingers			interaction				device pos				child pos			other ppl	genre					
	1	2	3	4	5	1	2	S	M	full	tap	hit	swip	drag	held	held for	flat	prop	stand	sit	lay		G	E	M	P	V	L
less than 12	32	58	9	2	0	33	67	9	75	77	14	67	12	2	14	28	39	19	13	62	26	46	14	16	40	0	19	5
12 to 17	0	42	40	19	0	56	44	72	30	10	70	12	58	16	19	14	49	14	31	62	8	33	42	16	9	5	26	0
18 to 23	0	20	39	35	6	63	37	67	27	10	67	14	39	27	25	10	41	25	31	69	0	33	27	45	8	6	18	0
24 to 29	2	5	32	41	20	71	29	76	22	7	80	10	29	34	44	10	44	24	12	76	11	46	44	36	10	2	14	0

Figure 4: summary of findings by percentage number of video records (the darker the shade the higher the percentage)

- **Hiniker et al.** [35]**:** Were interested in answering the question which App prompt forms are well received by children aged two to five. Four instruction prompt forms were examined: in-person modeling of an interaction, audio prompts, animated hand(s) demonstrations and visual prompts; where a target status changes to hint desired interaction. Results showed that for children under the age of three only in-person modeling was. Furthermore, visual prompts were the least communicative form regardless of children's age while audio prompts and animated hand(s) effectiveness increases with age.
- **Sesame workshop** [89]**:** They listed various guidelines from best design interactions, easy and difficult gestures to perform by children, screen element design, their placement on the screen, the choice of text display, layout, the use of visual as well as audio indications to guide children throughout the application, to the need to consider what they refer term "intentionality"; taking the child action's "possible intention" into consideration. In addition, the paper contains some "parent preference" tips and some special recommendations for book apps and e books (see Table 5 for examples).

Table 5: examples of Sesame workshop guidelines

Category	Example guidelines
Interactions	Use greetings and friendly characters Use of time-outs to propose suggestions and help messages
Gestures	Tapping is the easiest gesture/action Double tapping is a difficult action for children
Screen design	Enlarge hotspots Scrolling horizontally is easier than scrolling vertically
Intentionality	Use of confirming messages Be aware of possible unintended combinations of touch actions
Parent preference	Include tips for parents Add a voice recording feature

- **Michael Cohen group** [23]**:** Their findings confirmed children's eagerness and curiosity for exploring touch devices, due specifically to the immediate response to touch. The authors also noted that performance improve with practice (i.e. children tend to perform actions more accurately after playing with the device for a period of time). Finally, the authors pointed out that some app's designs introduced difficulties, for instance, having no feedback, too many distractions, or a complex interface.

Lastly, we emphasize that children are valuable designers as well as users. Druin [26] categorized children participation in design process based on the degree of their involvement into "user, tester, informant, and design partner". Users are the ones who try the final developed product and supply feedback, and design partners are commented participants in every part of the design. Children as young as four years old have participated as design partners [27], but a difference was noted between younger and older children's focusing ability, activeness, and other cognitive and social skills that are still in development, they had to adjust how they worked with younger children as design partners. In [32] Guha et al. remarked that involving children in design process not only benefit technology but also children themselves; among other advantages their involvement helped enhancing self-esteem, critical thinking and improving social skills

2.4. Open questions

We know that children have smaller hands, weaker grip, and shorter fingers; we also know that these physical characteristics influence their fine motor skills, including pointing precision. These features raise questions when evaluating children's use of touchscreen devices. We already mentioned how some gestures, including touch, pinch and rotation, could be difficult in general. Performing these gestures with shorter fingers could be even more difficult. For instance, how far can children drag, rotate or pinch objects on a screen.

There is an emerging appreciation for, and work towards understanding the special design and usability considerations needed to make children's interactions with touch screen devices effective and simple. However, there is still significant basic research left to be done; in mapping out device weight limits compared to children's physical strength and stamina or ergonomic considerations for device design and placement during use. Such ergonomic considerations could have a big impact on children whose bodies are still growing and changing rapidly.

Moreover, in relation to gesture interaction, the research literature contains no agreed upon experimental findings about the number and types of gestures children can reliably perform at varying ages. Figure 5 illustrates popular gestures and number of publications that investigated each gesture. The inner columns represent the researcher's conclusion on where a gesture lies on the easy-to-difficult spectrum. From Figure 5 we note that there are some gestures where the literature disagrees on whether a child of a certain age can perform them (e.g. drag & drop gesture). Another remark is some gestures got more researchers attention than others in investigating how easy that gesture was for children to execute (e.g. long press).

Age	Tap				Double Tap				Swipe				Rotate				Zoom In			
	Y	N	D	M	Y	N	D	M	Y	N	D	M	Y	N	D	M	Y	N	D	M
2	5	0	0	0	1	0	0	1	4	0	0	0	0	1	3	0	1	1	2	0
3	5	0	0	0	1	0	1	1	4	0	0	0	2	0	1	0	1	0	3	0
4	4	0	0	0	1	0	1	0	4	0	0	0	3	0	1	0	3	0	1	0
5	2	0	0	0	1	0	2	0	2	0	0	0	1	0	1	0	1	0	1	0

Age	Zoom Out				Drag & Drop				Flick				Tilting				Long Press			
	Y	N	D	M	Y	N	D	M	Y	N	D	M	Y	N	D	M	Y	N	D	M
2	1	0	3	0	1	1	2	0	3	0	1	0	1	0	0	0	0	0	0	1
3	3	0	1	0	3	0	2	0	4	0	0	0	1	0	0	0	0	0	0	1
4	3	0	1	0	3	0	2	0	4	0	0	0	1	0	0	0	0	0	0	0
5	1	0	1	0	2	0	2	0	2	0	0	0	2	0	0	0	0	0	0	0

Figure 5:Gestures and their reported difficulty based on the surveyed literature (Y: Can execute. N: Can't execute. D: execute with difficulty. M: can execute after adjusting the gesture specifications)

There is a similar lack of experimental data on the number of touch able icons a child can juggle or interact with within one display before they become overwhelmed. As a consequence, most applications aimed at children keep interactions and options extremely simple. While this may be an acceptable or even desired design choice, it does put severe constraints on the kinds of applications and interfaces that can be designed.

While we must acknowledge recommendations for limiting screen time for children given by many developmental psychologists and educators, we feel it is important to revisit some of the basis for these recommendations, often based on studies of children passively watching television. We are not sure if interactive experiences based on touch have the same negative effect on children as a passive television experience. Determining any potential benefits to the development of hand-eye coordination and fine motor skills would be important. As more and more children are using these devices, our goal should be to better understand the potential benefits and disadvantages of children using mobile devices for educational purposes.

3. Study 1: Practice Makes Perfect: Revisiting "Difficult" Touchscreen Gestures.

Two points stand out from our survey of the literature [refer to Section 2]: 1) there are easy gestures and difficult gesture. 2) there is conflict on classifying gestures as easy or difficult; e.g. Nacher et al. [63] concluded that zooming was the most intuitive, Abdulaziz [2], on the other hand, disagree. In Revelle [69] tilting was a tricky gesture, while Baloian et al. [8] grouped tilting with the easy gestures.

This disagreement found between researchers could be attributed to: 1) differences in when these studies were carried out (old paper vs. new paper). Gestures could have been seen as more difficult when touchscreens devices were new and novel. For instance, in Abdulaziz [2]**,** she mentioned that some of the children were never introduced to a touchscreen before her study. 2) From the same novelty point, most research findings were based on a one-time session, or with a short training session preceding the test session. Thus, concluding that a gesture is not intuitive based on such settings, one can foresee the conflict in gesture classifications. Moreover, in Section 2 we mentioned that Geist [29] pointed out that "children's performance was improving either after training sessions, observation of others or trial & error exploration". Touchscreen gestures are examples of a task that require motor and visual motor skills, perfecting such gestures need more trial and error [59]. Therefore, in this study we revisit the six gestures that were labeled "difficult" by the literature and test whether training helps children master these challenging gestures. Our purpose is to confirm if age is the determining factor (i.e., gestures mastery is controlled by age) or the skill (i.e., difficult gestures can be mastered by training), or both.

3.1. Methodology

Goal: the aim of this study was to explore popular gestures that were seen as difficult to perform by children; in particular double tap, drag & drop, long press, rotate, zoom in and zoom out. We wanted to verify that these gestures deserve the "difficult gesture" label that was attached to them by the literature [refer to Section 2]. That is, the child cannot succeed in these gestures due to the gestures' complex nature. The second thing we want to check is that if a child did indeed face difficulties with these gestures, does given that child a chance to try again allow them to overcome that challenge? In other words, can training or multiple attempts, as a child in real life would, allow the child to succeed in mastering the gesture?

Procedure:

Pre-experiment: At the beginning of the study we surveyed the parents for demographic information; asking about their child's age, how much time their child spent at the childcare facility, how much time their child spend using a touchscreen device, any extracurricular activities that relate to their fine motor skills as well as household socio-economic status. We also inquired about what apps their children use; to gather information about what gestures are being used in these apps.

Experiment: First we met with the children to assess their fine motor skills. This was an important part of our screening criteria; that our participants' fine motor skills fall in the range of a typically developed child. We gave each child a tablet in which we installed several games. These games were designed to cover six difficult gestures: double tap, drag & drop, long press, rotate, zoom in and zoom out. We choose these gestures based on our survey of the literature [see Section 2]; according to this survey, these gestures were labeled least intuitive by one or more author. We allow each child to play with these games; to try to accomplish the six “difficult” gestures. We planned the experiment so that on a particular day, each child could try up to three times to accomplish a certain gesture, over the span of three days. If the child masters a gesture before the three tries/days limit, we mark that the child mastered that gesture and their trials regarding that gesture ends. In our experiment we use a log to track our participants’ performance; A child can either fail to perform the gesture, perform the gesture but with difficulties (or without precision), or perform the gesture perfectly. If the child fails to perform the gesture, in this case we mark that task as (N). If the child succeeded in performing the gesture, but was not precise, we mark that task as (Y), as the child succeeded in performing the gesture but did not master it. Lastly, if the child masters the gesture, by making a successful attempt and having good control over the gesture, we mark the task as (M). For instance, if the child was able to accomplish zooming, and was very close to the targeted outline, we will mark it as (M). However, if the child was able to zoom (pinch/spread) but wasn’t able to match the target outline, we mark it as (Y) (see Appendix D). At the end of our study we compensated each child for their participation in the amount of $10.

Recruitment: we recruited from three childcare facilities in Corvallis, OR. We used flyers and emails to reach parents. To qualify for participation, the child had to have English as their first language (to facilitate communication), have no known fine motor skills issues, and be between three and five years old. We recruited 21 children. Before starting the study, we got verbal assent from the children and written consent from their parents. In the verbal assent, we explained to the children what the purpose of the study was and what activities we were going to engage them in (see appendix E). The study was monitored by the Institutional Review Board (IRB), at Oregon State University, through an expedited review[1].

Childcare centers: The study took place at 3 childcare facilities in Corvallis, OR, USA.

- Childcare center I: This childcare center provides full-day care from 7:30 am to 6:30 pm to children ages six weeks to five years. We recruited 14 children (ages from three to five) from two levels: the preschool level and the Pre-K level. There were two classes in each level. We carried out our study mostly in the “big room” which is a common area between classes. This area was open and relatively quiet most of the day. When the common area was in use (e.g. as an alternative playground during harsh weather), we carry out the study in the main office.
- Childcare center II: This childcare facility also provided full-day care service from 7:30 am to 6:30 pm to children ages six weeks to five years. Four participants volunteered (ages from Four to Five). All four participants were from one class. We carried out our study exclusively in the “big room” which is a common area between classes, that was open and relatively quiet most of the day.
- Childcare center III: This childcare/Head Start facility provides 3-hour care for the children enrolled. Children can be enrolled in the morning classes (either from 8:30 am to 11:30 am or 8:45 am to 11:45 am) or the afternoon classes (from 12:30 pm to 3:30 pm). There were three classes and nine children were recruited (ages from three to five). Children were from morning and afternoon classes. We carried out our

[1] https://research.oregonstate.edu/irb

study either in the “conference room” or the “children’s library”; both are common spaces which anyone can share. It is worth mentioning that since Childcare center III provides a half-day program, that implies that these children are exposed to less structured activities than other children in a full-day program.

More about the app: We identified six gestures that were marked difficult by the literature (see section 2) and limited game designers incorporate such gestures in their game plots. These six gestures are: double tap, drag & drop, long press, rotate, zoom in and zoom out tap, drag & drop, and touch & drag. We designed six games that capture these gestures, each game implemented one gesture only to help us verify if the child can do that specific gesture (see Table 6). In our implementation we followed design recommendations by previous researchers; we lean towards using real animal pictures instead of animated ones to increase the engagement of young children[48]. Moreover, Abdul Aziz et al. [1] remarked that, to young children unrealistic pictures can sometime appear scary. That unrealistic character’s design should be tested for acceptability, by young children, before including these characters in children’s apps. We made sure the narration was slow and calm with simple instruction and frequent pauses [35]. we accompanied the narration with animated hands to guide the children and illustrate how to execute a certain gesture [61]**.** As encouragement, following recommendations of Vatavu et al. [78], we added a congratulation message along with a clapping audio after the child successfully completed each game. Finally, we implemented our games using two game development tools: Stencyl [2]and Game Maker[3]. We deployed the games in to an Amazon Fire 7 tablet.

Table 6:Gestures used in each game in study 1

Gesture	Dancing Cow	Finger Family	Sheltering Lamb	Kittens on a Seesaw	Big Carrot	Small Carrot
Double Tap	✓	✗	✗	✗	✗	✗
Long Press	✗	✓	✗	✗	✗	✗
Drag & Drop	✗	✗	✓	✗	✗	✗
Rotate	✗	✗	✗	✓	✗	✗
Zoom Out	✗	✗	✗	✗	✓	✗
Zoom In	✗	✗	✗	✗	✗	✓

Following is our list of games along with their description, narration, the congratulation message and a screenshot of the game.

1. **Dancing Cow:** where the child is asked to double tap on a cow to get 10 milk bottles if the child succeeded the cow dances.

[2] http://www.stencyl.com
[3] https://www.yoyogames.com

	**<u>Narration:</u>** **When the game starts:** We need to get some milk bottles from our cow, Suzy. (short pause) We need 5 bottles. (short pause) To get a milk bottle you need to double tap on Suzy which means you need to tap on Suzy two times, (short pause) Like that. (short pause) Can you help? (short pause) Yes? (short pause) Then let's get 5 bottles. **When the child starts double tapping on the cow, counting bottles starts:** One! Two! Three! Four! Five! **When the task is accomplished, the cow dances and clapping plus one of these expressions is played:** Yay! /You did it! /Good Job!

2. **Finger Family:** where the child is presented with a hand with miniature figures representing dad, mom, brother, sister and baby finger, then the child is asked to touch and hold each figure (i.e. perform a long press). For example, the narrator will ask the child to touch and hold the baby finger on the screen. When the app detects a long press on the baby finger the baby finger song will start.

	**<u>Narration:</u>** **When the game starts:** The way to play this game is to tap and hold your tap for a while (short pause) like if you were doing a long press. (short pause) Let's play. **When the task is accomplished; the according song plays. After the song ends, one of these expressions is played:** Yay! /You did it! /Good Job!

3. **Sheltering lamb:** where the child will drag the sheep to their destination.

Narration:

When the game starts: It is going to rain soon. Can you help bobby the lamb, get to his barn? Just drag Bobby to his barn.

In case of collision, one of these expressions is played: Watch out! /We do not want to hit that! /Oops! /Be careful!

When the task is accomplished, clapping plus one of these expressions is played: Yay! /You did it! /Good Job!

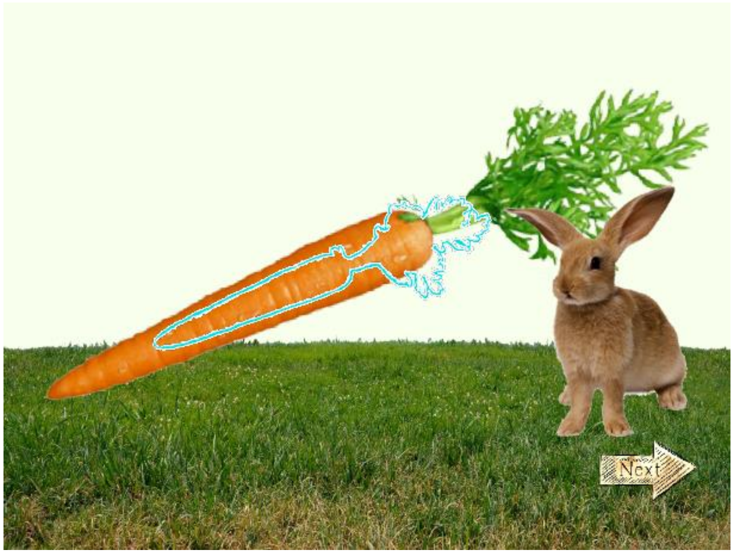
4. **Kittens on a seesaw:** in which the child is presented with kittens on a seesaw, which is angled, and is asked to balance them by rotating.

Narration:

When the game starts: Can you help our kittens balance? (short pause) you can do that by rotating these kittens (short pause) you can use two fingers to rotate. (short pause) touch the kittens with two fingers then turn both fingers around.

When the task is accomplished, clapping plus one of these expressions is played: Yay! /You did it! /Good Job!

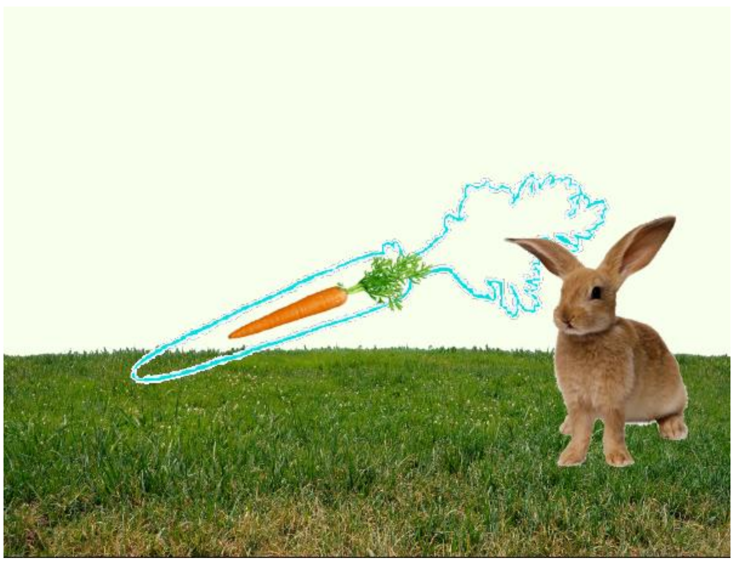
5. **Big carrot, Small carrot:** a child is presented with a huge carrot and asked to shrink it for bunny to eat by zooming out, after that the child is presented with a tiny carrot and asked to enlarge it for bunny to eat by zooming in



Narration:

When the game starts: Our bunny Brownie wants to eat this carrot, but it is too big (short pause), can you make it smaller? (short pause) You can do that by using two fingers to zoom out (short pause) touch the carrot with two fingers apart from each other, then pinch your fingers closer (short pause) Now let's help Brownie.

When the task is accomplished, clapping plus one of these expressions is played: Yay! /You did it! /Good Job!



Narration:

When the game starts: Now Brownie wants to eat this carrot, but it is too small (short pause), can you make it bigger? (short pause) You can do that by using two fingers to zoom in (short pause). touch the carrot with two fingers close to each other, then spread your fingers apart.

When the task is accomplished, clapping plus one of these expressions is played: Yay! /You did it! /Good Job!

3.2. Results

We recruited 21 children from three childcare centers. Eight were males and ages range from 38 months to 67 months (11 children were under five years). Figure 6 below shows distribution of the children according to their socio-economic background and touchscreen use (according to child guardian's report).

	Monthly House Income ($)								
Touchscreen Use (hours)	< 500	500 - 999	1,000 - 1,999	2,000 - 3,999	4,000 - 5,999	6,000 - 7,999	8,000 - 9,999	10,000 +	not reported
< 30 minutes	1						2	3	
1 to 2	1		2		1	1		2	
3 to 6			1	1			1		1
7 +	1	1			1			1	

number of participants: 1 – 3

Figure 6:distribution of participants (by socio-economic background and touch screen use)

We also surveyed the apps that our participants used along with other popular apps for young children (see appendix C). Majority of the games surveyed used either tap or drag & drop. Some used long press, tilt or swipe. Epic!, a reading app, was the only app in our survey that used zooming to enlarge pictures within books.

During our first meeting with the child, we asked the child to play six touchscreen games. Meanwhile we observed the child activities; recording their unsuccessful, successful or mastered trials. Figure 7 below shows the outcome, summarizing the number of unsuccessful/successful trials, in the first assessment of the first day.

Figure 7: number of successful (yellow triangle) and failed (red diamond) attempts on the first assessment.

After the first day, our experiment continues as follows: if the child mastered a gesture in a certain game, our testing of that particular gesture stopped, and we marked that gesture as being mastered for the rest of the trials. If the child gets a N (fail) or a Y (successful), then the child gets another try on the same day. Each child gets up to three tries on a certain day. Each child continued trying over 3 days, that is, each child was given nine chances to master a certain gesture. Figure 8 below summarizes the results over the study timeline.

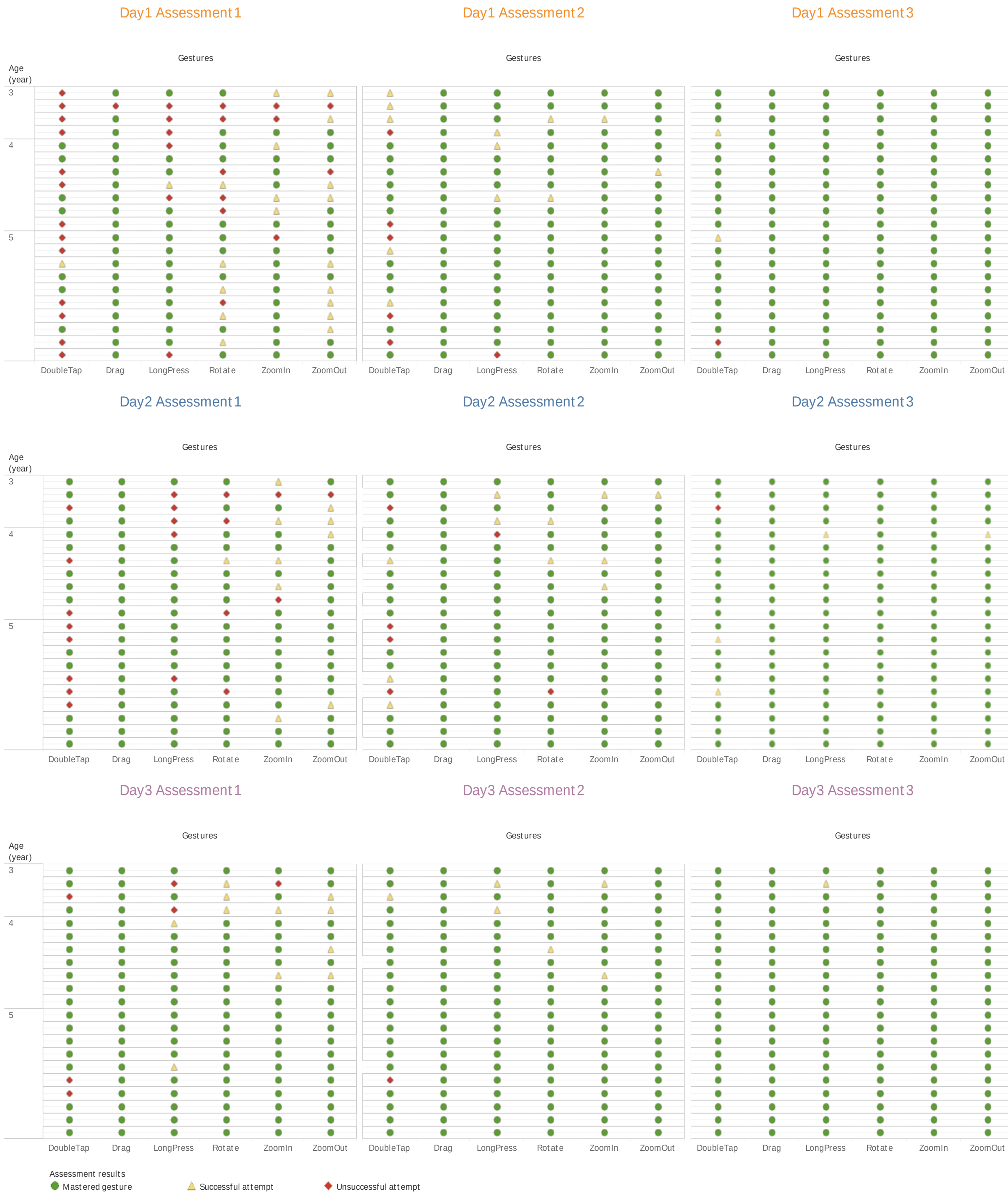


Figure 8: participants' attempts for three days; Mastered, successful and failed.

3.3. Discussion

From Figure 8 above, the main observation is that children's performance of all the gestures improved. That is, practicing improved the children's interactions regarding the execution of touchscreen gestures. Our results agree with the finding of Geist [29], that children's performance improves with training. We found that in our sample, regardless of the age of the children, performance of the six "difficult" gestures improved. That answers our question in our hypothesis, which is: "within the context of touchscreen usage, is skill acquisition bound by age or practice?" More specifically, we found that after the third trial on the first day, 31 unsuccessful attempts were reduced to one unsuccessful attempt among our participants. We should note, however, that on the second day some of the children who mastered a gesture on the day before failed to execute it on their first attempt of the second day. These children adjusted their performance and were able to succeed, at least, in their last attempt. The same phenomena continued on the third day but was less evident (see Figure 9 below). Two factors can contribute to this observation. The first is age; younger children seemed to forget the training easier than older children, which could indicate that they need more practice than older children. The other factor could be that children simply need more time to practice. This is

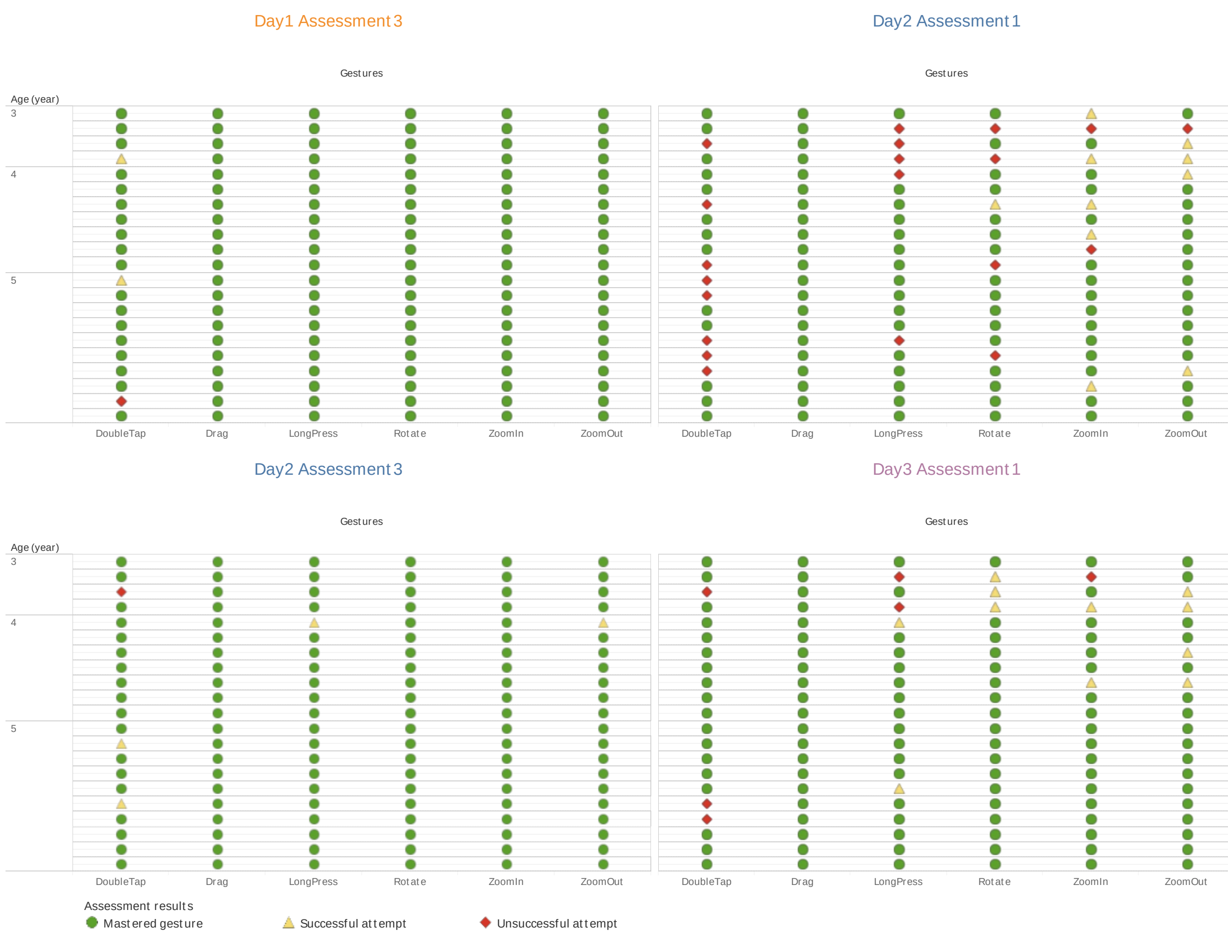


Figure 9: last assessment on a previous day compared to first assessment on the following day

supported by Moser’s note that for young children, tasks that require motor and visual motor skills (i.e., these touchscreen gestures) need more trial and error to perfect [57].

Our results also reveal that some gestures are more difficult to execute than others. After the third day, double tap and long press gestures continued to present some challenges to young children, especially for the younger participants. In our opinion, that doesn’t mean that those children couldn’t perform the gestures per se, but rather needed more trials to master such gestures.

Unlike previous research recommendations, our findings invite app designers to explore other gestures in their apps, along with an explicit training session for those complicated or new gestures. Adding a variety of gestures to the game plot enriches the child’s experience; by allowing different scenarios in the game plot to be implemented through using different gestures. Moreover, using “novel” gestures that children are not familiar with in their apps, keeps them engaged in the game by challenging them to mastering such gesture. Another benefit is that exposing children to these gestures will actually improve their skill in performing those touchscreen gestures.

4. Study 2: The Effect of Using Touchscreens on Children's Fine Motor Skills Development.

Study1 showed that children's performance of touchscreen gestures improves with training (see Section 3). That suggests that the underlying skills for executing a gesture improved with training. Moreover, Vatavu et. al [78] found that children who scored higher in fine motor skill assessment perform better when using their study app. That led us to our next question: if performance improves after practice, does that mean that performing touchscreen gestures can help improve the development of fine motor skills?

4.1. Methodology

Goal: The aim for our experiment was to explore the effect of using touchscreens, on children's fine motor skill development. More specifically, we wanted to see if using a touchscreen device could contribute to the improvement of finger movement control (i.e. grasping) and hand-eye coordination (i.e. visual motor skills).

To examine this issue, we followed a quasi-experimental setup. In quasi experiments, subjects' assignment to treatment is not random, the researcher picks and chooses which participant receive what treatment [77]. Quasi-experimental setups are used widely in fields where human behavior, development, interaction or health is of interest [77]. The reason we choose this design is that we considered "touchscreen experience" as a pre-determined condition, that is, it was our criteria for assigning participants to a "treatment". Further, we speculate that if the child has limited exposure to touchscreens, in this day and age, their guardian would like to preserve that condition. That speculation was based on the few of participants with limited touchscreen experience that volunteered for this study. Conclusively; our design was as follows, we place participants in one of two groups based on previous touchscreen exposure. In group 'A' were children who has limited exposure to touch screen devices (less than 30 minutes per week). In group 'B', children were experienced touchscreen users (more than 30 minutes of touchscreen use per week).

Recruitment: We recruited from three childcare facilities in Corvallis, OR. We used flyers and emails to reach parents. To qualify for participation, the child had to have English as their first language (to facilitate communication), have no known fine motor skills issues, and be between three and five years old. We recruited 30 children. Before starting the study, we got verbal assent from the children and written consent from their parents. In the verbal assent, we explained to the children what the purpose of the study was and what activities we were going to engage them in (see appendix E). The study was monitored by the Institutional Review Board (IRB), at Oregon State University, through an expedited review.

Childcare centers: The study took place at 3 childcare facilities in Corvallis, OR, USA.

- Childcare center I: This childcare center provides full-day care from 7:30 am to 6:30 pm to children ages six weeks to five years. We recruited 14 children (ages from three to five) from two levels: the preschool level and the Pre-K level. There were two classes in each level. We carried out our study mostly in the "big room" which is a common area between classes. This area was open and relatively quiet most of the day. When the common area was in use (e.g. as an alternative playground during harsh weather), we carry out the study in the main office.

- Childcare center II: This childcare facility also provided full-day care service from 7:30 am to 6:30 pm to children ages six weeks to five years. Four participants volunteered (ages from Four to Five). All four participants were from one class. We carried out our study exclusively in the "big room" which is a common area between classes, that was open and relatively quiet most of the day.
- Childcare center III: This childcare/Head Start facility provides 3-hour care for the children enrolled. Children can be enrolled in the morning classes (either from 8:30 am to 11:30 am or 8:45 am to 11:45 am) or the afternoon classes (from 12:30 pm to 3:30 pm). There were three classes and nine children were recruited (ages from three to five). Children were from morning and afternoon classes. We carried out our study either in the "conference room" or the "children's library"; both are common spaces which anyone can share. It is worth mentioning that since Childcare center III provides a half-day program, that implies that these children are exposed to less structured activities than other children in a full-day program.

Procedure:

Pre-experiment: At the beginning of the study we surveyed the parents for demographic information; asking about their child's age, how much time their child spend at the childcare facility, how much time their child spend using a touchscreen device, any extracurricular activities that relate to their fine motor skills as well as household socio-economic status.

Based on the survey results we split participants into experimental group 'A' and group 'B'. Children who had limited exposure to touch screen devices (less than 30 minutes per week) were in group 'A'. Children who were experienced touchscreen users, were placed in group 'B'.

Experiment: Group A was the "control group"; we didn't assign children in group A any tablets nor ask them to play with our app. Nevertheless, we assess their fine motor skills every month, as well as ask their parents to track any external tablet use. We gave each child in group 'B' (the experienced group) a tablet in which we installed several games. These games were designed around four tasks: Taping using one finger, tapping using different fingers, tracing, copying, and drawing. We modeled these tasks after tasks we found in assessment tests designed to evaluate fine motor skills development (e.g, PDMS-2[4] or NEPSY[5]). Our goal was to try to implement an app that would act as a training tool for these four skills. We asked each child in group 'B' to play with these games over the duration of the study. We requested that a child in group B plays with our games for at least five days a week (for a minimum of 10 minutes a day). Similar to what we did with group A, we assessed group B's fine motor skills every month, as well as ask their parents to track their external tablet use (see Figure 10).

Post experiment: When three months passed, we met with the children from both groups, for our final assessment. At the end of that assessment each child was compensated for their participation (an amount of $10, or equivalent, for each assessment)

[4] PDMS-2 tool: https://www.proedinc.com/Products/9280/pdms2-peabody-developmental-motor-scalessecond-edition-complete-kit.aspx
[5] NEPSY Tool: https://www.pearsonclinical.co.uk/Psychology/ChildCognitionNeuropsychologyandLanguage/ChildGeneralAbilities/NEPSY-SecondEdition(NEPSY-II)/NEPSY-SecondEdition(NEPSY-II).aspx

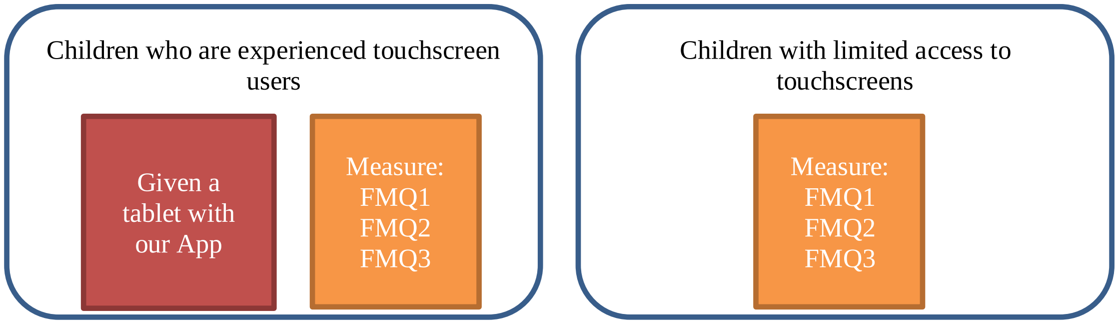


Figure 10: Study 2 design

More about the assessment and the assessment tool: The first thing we did is establish a baseline for the Children's fine motor skills. We met with each participant to assess their fine motor skills development using a paper-based assessment called Peabody Developmental Motor Scales (PDMS-2). PDMS-2 is a standardized tool developed by M. Rhonda Folio, Rebecca R. Fewel (2000). PDMS-2 is reported to have excellent reliability and validity scores [91], it has been also used to assess motor skills of children with special conditions such as children with Cerebral Palsy [80] and low birth weight preterm infants [76]. Studies also showed the robustness of PDMS-2 against gender and racial bias [91]. Moreover, in [20] the authors verify that PDMS-2 can be used to track changes in the fine motor skill development of children.

PDMS-2 was developed for screening motor skills development in children from birth to five years old. The assessment has six sections; namely: Reflexes, Stationary, Locomotion, Object Manipulation, Grasping, and Visual-Motor Integration. Grasping and Visual-Motor Integration are the tests related to assessing fine motor skills development. The other four tests are related to assessing gross motor development and focus on leg and arm movements. For the purpose of our study, we focused only on fine motor skills assessment. The assessment is designed as a series of predetermined standard tasks that the child is asked to complete. The person carrying out the assessment ranks the child's performance at each task with 0, 1 or 2.

Grasping assess children's control of their fingers. In that test we ask the child to complete a series of tasks that focuses on finger movement and grip. For example, holding a pen while writing or tapping the thumb with other fingers. Then, depending on how the child completes the task, that task will be ranked 0, 1 or 2. Visual-Motor Integration ranks children's hand-eye coordination. We ask the child to complete a series of tasks that allows us to measure how well a child can perceive and manipulate small objects. For example, we present a child with a square shape and ask them to copy it. If the child drew a perfect square, they will get a 2, otherwise, the score will be 1 or 0. Another example of a Visual-Motor Integration task is to ask the child to lace a string through three holes punched in a paper ribbon. Again, if the child completes the task, they receive a score of 2. At the end of each assessment, scores from both sections are totaled. Each assessment took an average of 30 minutes; however, some children's assessment took up to an hour due to their talkative nature.

We carried out fine motor skill assessments once every month during the period of the experiment to track the development of the children's fine motor skills.

More about the app: We focused our attention on capturing four tasks in our app: tapping using one finger, tapping using different fingers, tracing, and copying & drawing. We choose these tasks because when looking at fine motor skills, developmental assessment tools consider children's performance of these tasks (and/or variation of these tasks) as indicators to their fine motor skill development (assessment tool such a PDMS-2, NEPSY, … etc.). To model these four tasks, we used tap and drag & drop gestures (see table 7). From our survey of popular apps [see Section 3.2], we found out that large percentage of apps targeting children solely use tap and drag & drop. Therefore, children are more familiar executing these two gestures. Furthermore, these two gestures were the best fit for translating the tasks (tapping, tracing, and drawing) into the touchscreen environment. We designed eight games that capture these gestures; Dancing Cow, Dancing Chicken, Popping Bubbles, Finger Family, Piano, Feeding Dog, Sheltering Lamb and Teaching Kitty to Draw. In our implementation we followed design recommendations by previous researchers; we lean towards using real animal pictures instead of animated ones to increase the engagement of young children[48]. Moreover, Abdul Aziz et al. [1] remarked that, to young children unrealistic pictures can sometime appear scary. That unrealistic character's design should be tested for acceptability, by young children, before including these characters in children's apps. We made sure the narration was slow and calm with simple instruction and frequent pauses [35]. As encouragement, following recommendations of Vatavu et al.[78], we added a congratulation message along with a clapping audio as an encouragement after the child successfully completed each game. Finally, we implemented our games using two game development tools: Stencyl[2] and Game Maker[3]. We deployed the games in to Amazon Fire 7 tablets. We tested our app two times on two groups of children consisting of two children each (aged three and four years old). Our pilots resulted in modifications on the games regarding the gratifications at the end of each game. For example, although there was a clapping audio in the Teaching Kitty to Draw indicating that the child completed the drawing task, one child remarked that the Kitten didn't react after he taught her how to draw; "it is not happy" he remarked. Therefore, at the completion of the drawing task we added a smiling kitten. Additionally, at the pilot session we noticed that some of the parents were not familiar with the Amazon Fire tablet, therefore, we sent each child in group B with a simple manual that contained instructions on how to operate the tablet and the apps (see appendix F).

Table 7: Gestures used in each game in study 2

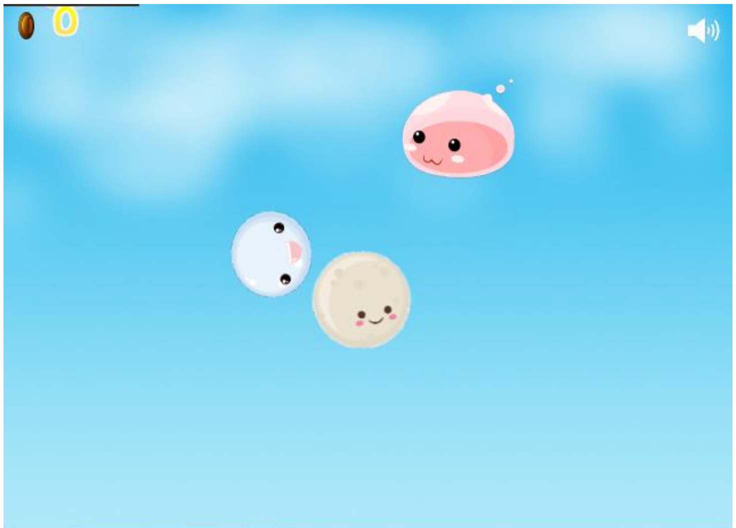
Gesture	Dancing Cow	Dancing Chicken	Popping Bubbles	Finger Family	Piano	Feeding Dog	Sheltering Lamb	Teaching Kitty to Draw
Tapping	✓	✓	✓	✓	✓	×	×	×
Drag & Drop	×	×	×	×	×	✓	✓	✓

Following is our list of games along with their description, narration, the congratulation message and a screenshot of the game.

1. **Dancing Cow/Chicken:** where the child is asked to tap on a cow/chicken to get 10 milk bottles if the child succeeded the cow/chicken dances.

	**Narration:** **When the game starts:** We are making breakfast, but first we need to get some milk bottles from our cow, Suzy. We need 10 bottles. To get a milk bottle you need to tap on Suzy. Can you help? Yes? Then let us go to Suzy! Tap on the cow picture. **When the child start tapping on the cow, counting bottles starts:** One! Two! Three! Four! Five! Six! Seven! Eight! Nine! Ten! **When the task is accomplished, the cow dances and clapping plus one of these expressions is played:** Yay! /You did it! /Good Job!
	**Narration:** **When the game starts:** We are making breakfast, but first we need to get some milk bottles from our cow, Suzy. We need 10 bottles. To get a milk bottle you need to tap on Suzy. Can you help? Yes? Then let us go to Suzy! Tap on the cow picture. **When the child start tapping on the cow, counting bottles starts:** One! Two! Three! Four! Five! Six! Seven! Eight! Nine! Ten! **When the task is accomplished, the cow dances and clapping plus one of these expressions is played:** Yay! /You did it! /Good Job!

2. **Popping bubbles:** where the child is asked to tap on bubbles passing by at different speeds.



<u>Narration:</u>

When the game starts: Do you like popping bubbles? Fast and slow bubbles? Yes ? then tap on this bubble picture to start popping bubbles.

When the task is accomplished: a 'popping' sound is played.

3. **Finger Family:** where the child is presented with a hand with miniature figures representing dad, mom, brother, sister and baby finger, then the child is asked to touch each figure with their matching finger. For example, the narrator will ask the child to touch the baby finger on the screen with their baby finger. When the app detects a touch on the baby finger the baby finger song will start.

<u>Narration:</u>

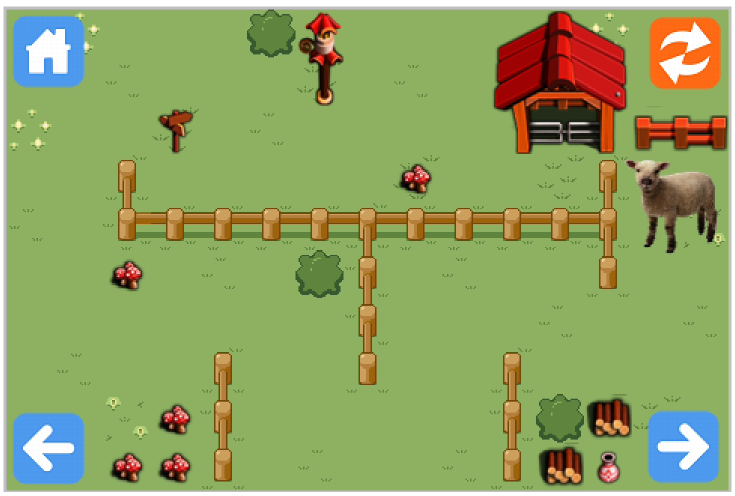
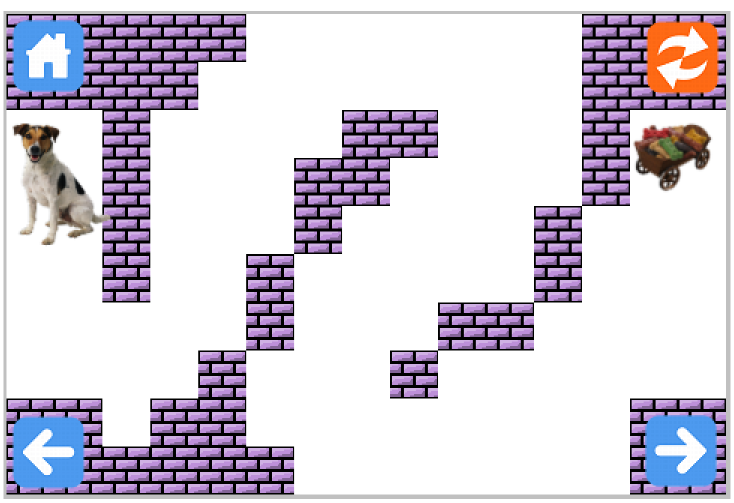
When the game starts: Do you know where is your daddy finger? Your mommy finger? Your brother finger? Your sister finger? your baby finger? Yes? Then would you like to play the finger family game? The way to play this game is to tap using your matching finger. If you are ready to play, then tap on the finger family picture below.

When the task is accomplished; the according song plays. After the song ends, one of these expressions is played: Yay! /You did it! /Good Job!

4. **Piano:** where the child is asked to touch the piano key when it lights up, if the child succeeded the piano key will play a note.

	**<u>Narration:</u>** **When the game starts:** How about we play a piano game? You can play by touching the piano key when it lights up. You have to touch the keys fast to get more points, you can use different fingers too. If you are ready to play, tap on our colorful piano. **When the task is accomplished:** a music note is played

5. **Feeding dog/ Sheltering lamb:** where the child will drag the dog/sheep to where their destination.

	**<u>Narration:</u>** **When the game starts:** It is going to rain soon. Can you help bobby the lamb, get to his barn? Just drag Bobby to his barn. **In case of collision, one of these expressions is played:** Watch out! /We do not want to hit that! /Oops! /Be careful! **When the task is accomplished, clapping plus one of these expressions is played:** Yay! /You did it! /Good Job!
	**<u>Narration:</u>** **When the game starts:** **In case of collision, one of these expressions is played:** Watch out! /We do not want to hit that! /Oops! /Be careful! **When the task is accomplished, clapping plus one of these expressions is played:** Yay! /You did it! /Good Job!

6. **Teaching kitty to draw**: in which the child is presented with several shapes and asked to copy them and shoe kitty how to draw them

Narration:

When the game starts Tami, our kitten wants to learn how to draw shapes. Can you help? Yes? Then tap on any of the shapes to show Tami how to draw them.

In case of collision, one of these expressions is played: Watch out! /We do not want to hit that! /Oops! /Be careful!

When the task is accomplished, clapping plus one of these expressions is played: Yay! /You did it! /Good Job!

4.2. Results

We recruited 30 children from three childcare centers; 17 males and 13 females. Ages ranged from 36 months to 67 months (16 children were four years old and ten children were three years old). The table below shows participant distribution by socio-economic background and touchscreen use (according to the child guardian's report) (see Figure 11).

	Family Income								
Touchscreen Weekly Use (hours)	< $500	$500-$999	$1,000-$1,999	$2,000-$3,999	$4,000-$5,999	$6,000-$7,999	$8,000-$9,999	$10,000 +	not reported
less than 30 minutes	1	1	1	2		1	1	4	
1 to 2			3	1	1				1
3 to 6				3		2	1	1	2
7 +								3	1

Distinct count of Id-1: 1 – 4

Figure 11:Participant's distribution (by socio-economic background and touchscreen use)

There were two groups; we assigned 11 children to group A (i.e. the none experienced touchscreen users) and 19 children were assigned to group B (i.e. the experienced touchscreen users). Most of our experienced users were reported, by their guardians, to use touchscreen devices from 3 to 6 hours a week (see Figure 12).

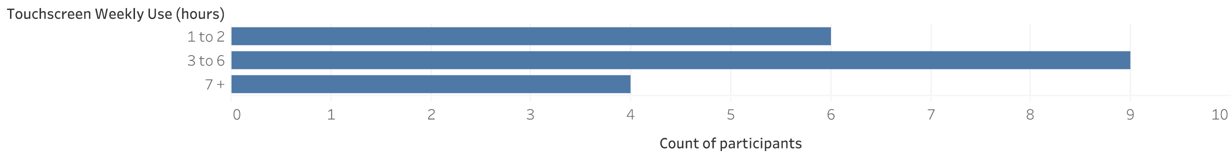


Figure 12: reported weekly touchscreen use

During our first meeting with the child, we assessed the child's fine motor skills using the PDMS-2 assessment tool; PDMS-2 reports, among other measures, grasping and visual motor skills scores. We used those two scores in our assessment, as these two measures are designed to assess fine motor skill development. Figure13 below shows the scores from the first assessment (Age vs. grasping score and age vs. visual motor score for each participant in group A (blue) and B (orange)).

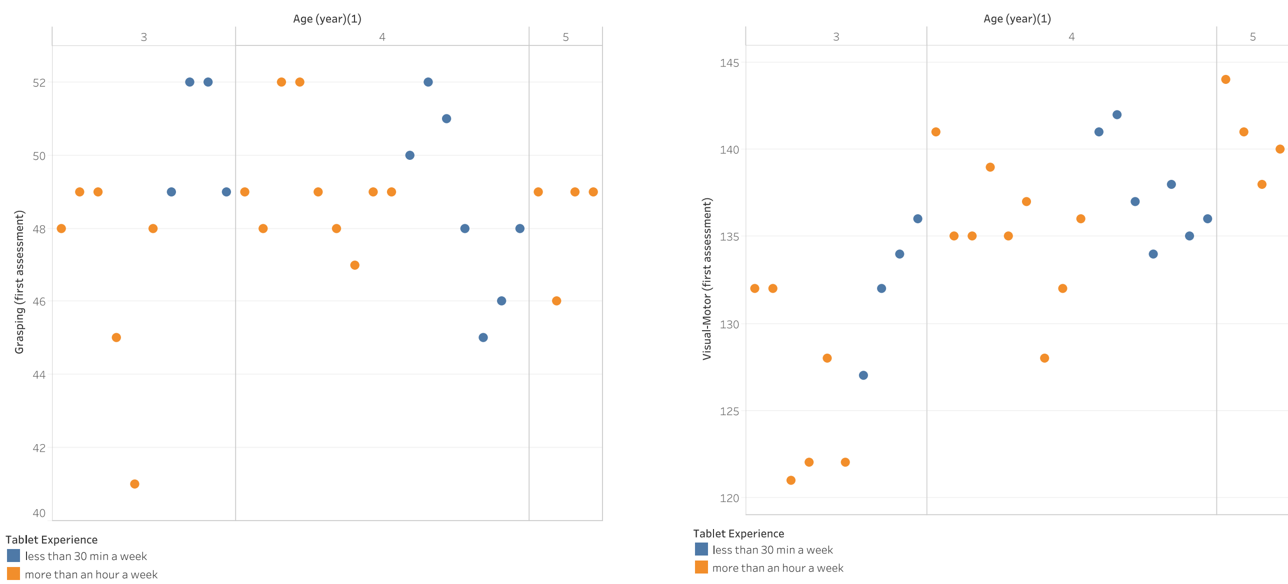


Figure 13: First assessment grasping scores (left) and visual motor scores (right) for each participant (by age and tablet experience).

We assess the children's fine motor skills development two more times (once each following month), for total of three times over three months. PDMS-2 reports: raw scores, standardized scores, percentiles and fine motor quotients. Raw scores are typically used in tracking progress. Standardized scores are normalized scores that can be helpful when comparing peer groups. Percentiles provide a meaningful number for educators and physicians to use when reporting their assessment to guardians. Fine motor quotient represents an assessment for overall fine motor skills, including grasping and visual motor skills. We used raw scores of grasping and visual motor assessments in our analysis because we were interested in month-to-month progress of our participants' fine motor skills development.

For our analysis we used the Linear Mixed Model (LMM). LMM is helpful for identifying explanatory/predictor variables that might contribute to a certain phenomenon [82,83]. The idea is to build several models, then compare them in order to find which model best fit the data. There are two ways to compare models, either using a top-down approach or a bottom-up approach. In the bottom-up approach, we build models starting from model0 which include the intercept only and start adding fixed or random effects to it. Fixed and random effect can be thought of as independent variables and confounding factors respectively. The goal is to determine if combining effects better explains the data. Thus, we chose LMM because it is most suitable when dealing with complex data with multiple factors that can affect the output [82,83]. Additionally, LMM uses all the data points for analysis [82,83], thus we do not lose power from blocking/nesting. LMM is also ideal when dealing repeated measures (i.e. dependent data) [82,83], which is the case in our study.

We used R (R Core Team, 2015) and nlme (Pinheiro J, Bates D, DebRoy S, Sarkar D and R Core Team (2016)) to perform a linear mixed effects analysis. We used a bottom-up approach to compare our models. We use anova() function in R to compare models based on a chi-square difference test to determine if the difference is significant.

When analyzing the grasping raw scores, our goal is to identify any predicting variables for our dependent variable (grasping score). We started with an empty model, then gradually added participant ID, age, gender, experience, income, and app time into our models (see Table 8)

Table 8: Description of each model.

Model	Description
Model 0	Only the intercept; this is an empty model
Model 1	Only the participant Id is added as a random effect
Models 2 to 6	Age, gender, experienced, income, and app time were added individually as fixed effect
Models 7 to 13	Models containing a combination of age, gender, experienced, income, and app time as fixed effect

4.2.1. *Grasping Score Analysis:*

After examining grasping raw scores and comparing the latest scores to the children's first score, children in both groups in all age groups (except for two participants) either improved or remain the same (see figure 14).

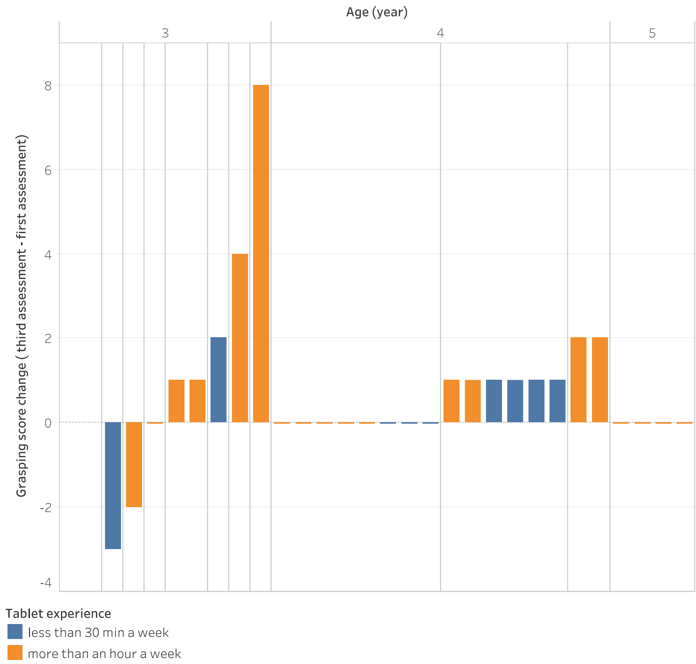


Figure 14: difference between grasping scores (last assessment- first assessment)

Analyzing grasping score against age, gender, experience, income, and app time, we found that after accounting for having different individuals (random effect), none of these variables alone had a significant effect on grasping scores. Interestingly, when combining Age and gender as affixed factors gender appear to be significant (see Figure 15 below)

```
> summary(model3G)
Linear mixed-effects model fit by maximum likelihood
 Data: Study2RawScoreGraspingLong
  AIC            BIC            logLik
  338.7616       348.6709       -165.3808

Random effects:
 Formula: ~1 | ID
           (Intercept)      Residual
StdDev:    1.621932         1.139586

Fixed effects: GraspScore ~ Gender
                  Value     Std.Error  DF  t-value    p-value
(Intercept)       49.57745  0.4923092  58  100.70388  0.0000
Gender(Male)     -1.08924   0.6538246  28  -1.66595   0.1069

Correlation:
               (Intr)
Gender(Male)   -0.753

Standardized Within-Group Residuals:
     Min        Q1          Med         Q3         Max
-5.0823114  -0.3085233  -0.0605351  0.3146314  1.9377793

Number of Observations: 88
Number of Groups: 30
```

```
> summary(model8G)
Linear mixed-effects model fit by maximum likelihood
 Data: Study2RawScoreGraspingLong
  AIC            BIC            logLik
  338.48         353.344        -163.24

Random effects:
 Formula: ~1 | ID
           (Intercept)      Residual
StdDev:    1.487927         1.140349

Fixed effects: GraspScore ~ Gender + Age
                  Value     Std.Error  DF  t-value    p-value
(Intercept)       49.40166  0.5947023  58  83.06958   0.0000
Gender(Male)     -1.66046   0.673702   26  -2.46468   0.0206
Age(Four )        1.11452   0.7148691  26  1.55905    0.1311
Age(Five)        -0.73655   0.9924597  26  -0.74214   0.4647

 Correlation:
               (Intr)     Gendr(Male)     Age(Four)
Gender(Male)   -0.451
Age(Four)      -0.513     -0.331
Age(Five)      -0.523     0.101           0.364

Standardized Within-Group Residuals:
     Min        Q1          Med         Q3         Max
-5.1174871  -0.3779917  0.0480832   0.2758428  1.8979107

Number of Observations: 88
```

Figure 15: detailed results of grasping score models. Left: Model3G (gender effect). Right: Model8G (gender and age effect)

However, when comparing the two models to model1 (random effect only model) the difference was not significant. In other words, none of the models were a better fit than Model 1. (see Figure 16 below)

> anova(model2G, model3G,model8G)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
Model1G	1	3	339.4790	346.9110	-166.7395			
model3G	2	4	338.7616	348.6709	-165.3808	1 vs 2	2.717470	0.0993
model8G	3	6	338.4800	353.3440	-163.2400	2 vs 3	4.281566	0.1176

Figure 16: Gesture scores models' comparison

4.2.2. Visual Motor Score Analysis:

After examining visual motor raw scores and comparing the latest scores to the children's first score, children in both groups in all age groups (except for three participants) either improved or remain the same (see figure 17).

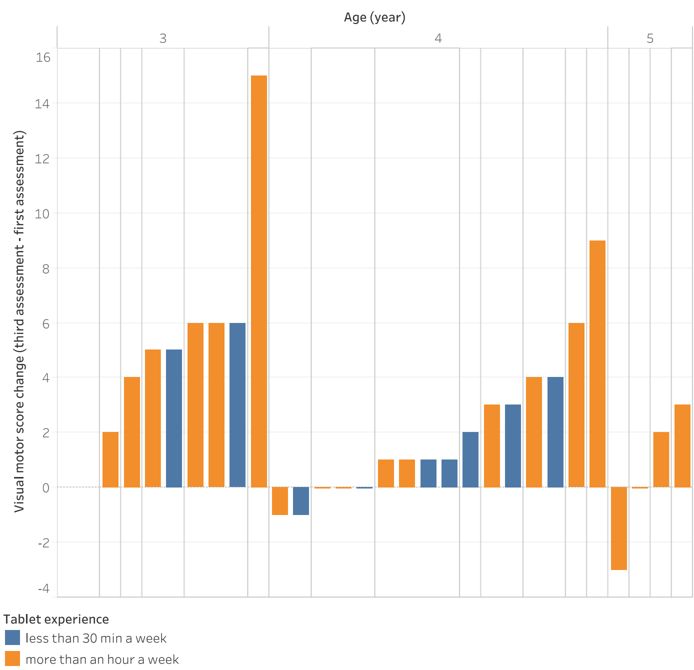


Figure 17: difference between visual motor scores (last assessment- first assessment)

We analyze visual motor scores, with the same goal in mind; to identify any predicting variables for our dependent variable (visual motor score). Similar to the analysis of grasping scores, we began with an empty model, then gradually added participant ID, age, gender, experience, income, and app time into our model (see Table 8)

Unlike in the case of grasping, age was a significant predictor for visual motor scores (see Figure 18). Furthermore, we found that age and experience (whether they are experienced users or not) were the best predictors for visual motor scores.

```
> summary(model4VM)
Linear mixed-effects model fit by maximum likelihood
 Data: Study2RawScoreVMLong
      AIC           BIC           logLik
 468.7499      481.1366      -229.3749

Random effects:
 Formula: ~1 | ID
             (Intercept)      Residual
StdDev:    2.553507         2.612565

Fixed effects: VMScore ~ Age
                     Value     Std.Error      DF      t-value       p-value
(Intercept)          131.57681 0.9653732      58      136.29631      0
Age(Four)            6.04819   1.2251816      27      4.93657        0
Age(Five)            9.33986   1.7912130      27      5.21427        0

Correlation:
                      (Intr)     Age(Four)
Age(Four)            -0.788
Age(Five)            -0.539     0.425

Standardized Within-Group Residuals:
      Min          Q1             Med            Q3            Max
-3.6010109    -0.3736221     0.1429514     0.5047809     2.1404726

Number of Observations: 88
Number of Groups: 30
```

Figure 18: Detailed results of visual motor score model; Model4VM (age effect).

More specifically, we entered experience (experienced users vs limited users) and age (without interaction term) into the model, as fixed effects. Additionally, as random effects, we entered participant ID. (See Figure 19 below)

```
> summary(model9VM)
Linear mixed-effects model fit by maximum likelihood
 Data: Study2RawScoreVMLong
      AIC           BIC           logLik
 463.6162      478.4802      -225.8081

Random effects:
 Formula: ~1 | ID
            (Intercept)       Residual
StdDev:   2.169633          2.607438

Fixed effects: VMScore ~ Age + Experienced
                     Value          Std.Error      DF      t-value       p-value
(Intercept)          133.40109      1.094566       58      121.87580     0.0000
Age(Four)            5.90494        1.100767       26      5.36439       0.0000
Age(Five)            10.50408       1.658209       26      6.33459       0.0000
Experience(Yes)      -2.98850       1.082546       26      -2.76062      0.0104

Correlation:
                     (Intr)     Age(Four) Age(Five)
Age(Four)             -0.657
Age(Five)            -0.262     0.398
Experience(Yes)      -0.610     0.054       -0.250

Standardized Within-Group Residuals:
      Min          Q1             Med            Q3            Max
-3.5030877    -0.2597313     0.1248326     0.5098379     2.2496865

Number of Observations: 88
```

Figure 19: detailed results of visual motor score model; Model9VM (gender and experience effect)

The coefficient “Experience (Yes)” is the slope for the categorical effect of experience. A coefficient of - 2.98850 means that the average visual motor score is lower in experienced participants than in limited experience participants. The p-value in this model indicates that the effect of experience is significant.

The coefficient “Age” is the slope for the effect of age. A coefficient of 5.90494 means that the average visual motor score is higher in four years old participants than in three years old participants. Similarly, a coefficient of 10.50408 means that the average visual motor score is higher in five years old participants than in three years old participants. The p-value in this model indicates that the effect of age is significant.

After comparing models, we found that adding experience and age as mixed effects provide a better fit of the data (see Figure 20 below).

> anova(model2VM, model4VM, model9VM)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
model2VM	1	3	488.8659	496.2979	-241.4330			
model4VM	2	5	468.7499	481.1366	-229.3749	1 vs 2	24.116014	<.0001
model9VM	3	6	463.6162	478.4802	-225.8081	2 vs 3	7.133706	0.0076

Figure 20: visual motor scores models' comparison

Lastly, visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity or normality (see Figures 21, 22 and 23). That is, our data does not appear to violate any of the LMM assumptions.

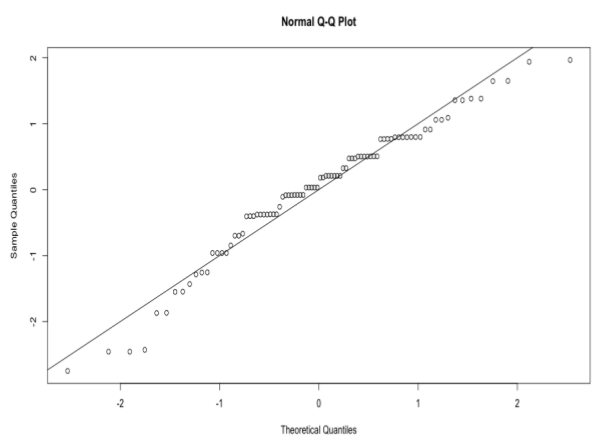


Figure 21: Q-Q plot for Model9VM standarized residuals

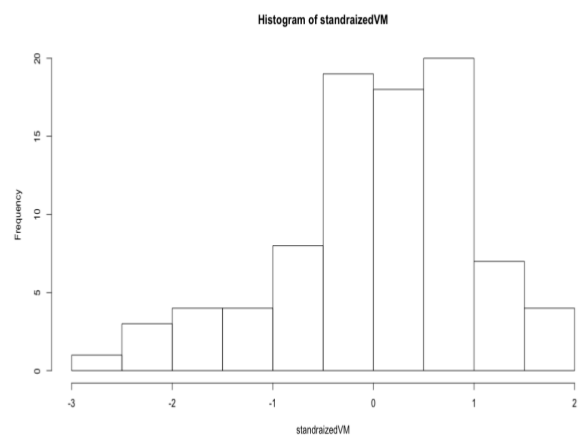


Figure 22: Histogram of Model9VM standardized residuals

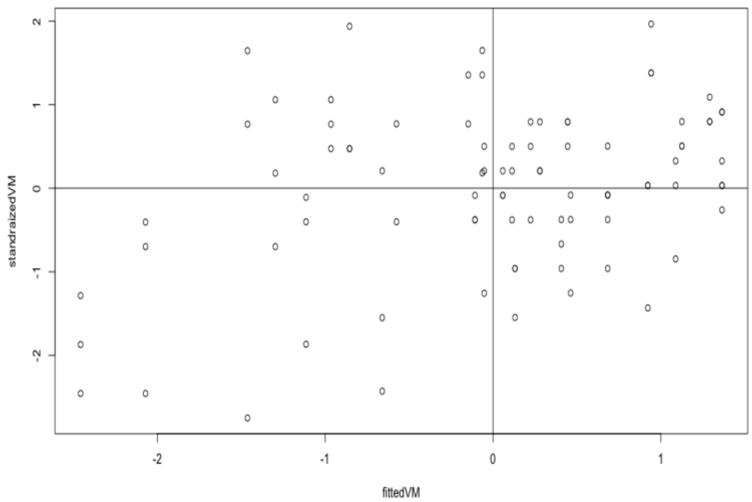


Figure 23: plot of Model9VM scaled residuals and fitted values

4.3. Discussion

Our results suggest that, during the study, our app did not affect children's fine motor skills development. Moreover, grasping scores were not predicted by any other factor. Thus, we cannot reject the first part of our null hypothesis, $H_{0.1}$, that using touchscreen devices has no effect on grasping skills development. However, regarding visual motor skills our finding suggests that, age and experience are predictors for visual motor scores. Therefore, it is really likely that part 2 of our null hypothesis, $H_{0.2}$, that using touchscreen devices has no effect on visual motor skills development is wrong.

Using our data, we investigated five variables to predict grasping and visual motor skills scores. We focused on these skills because we speculate that those are the motor skills used when interacting with touchscreen devices. The variables we used to explain variation in fine motor skills scores were: age, gender, family income, experience with touchscreen devices, and time spent on our app. Early analysis excluded time spent on our app as a predictor to grasping scores and visual motor scores. Overall, our analysis showed that grasping scores and visual motor scores improved for both groups. Figure 24 illustrate the improvement trend in raw scores (grasping and visual motor) for our participants.

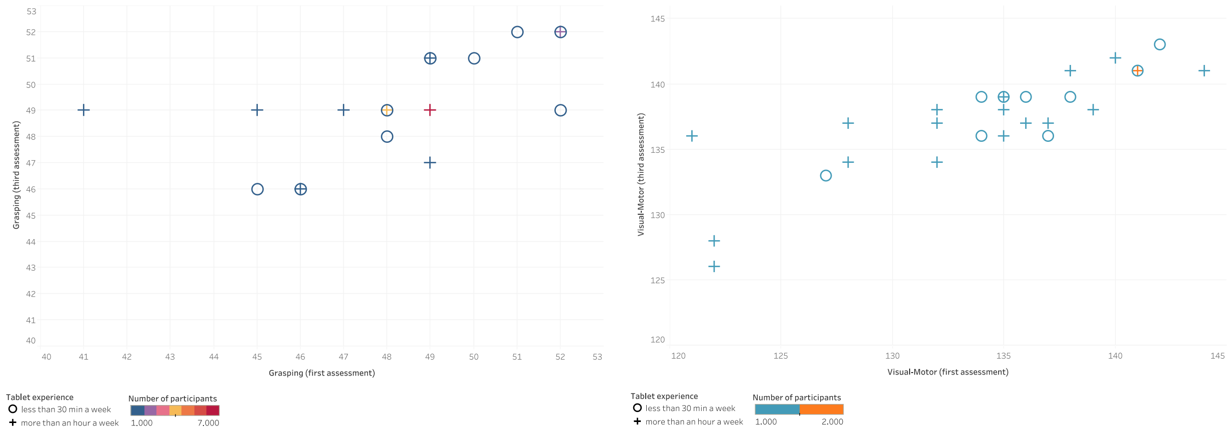


Figure 24: Grasping scores (first assessment vs last assessment (left). Visual motor scores (first assessment vs last assessment (right)

However, grasping and visual motor scores differ in how they respond to our candidate predictors. Grasping scores showed no significant predictors. That is, none of the factors explained the variability shown in our data better than variability caused by testing different individuals. Nevertheless, we noted that grasping scores have gender as a predictor, after adding both age and gender as fixed factors to the model. Although using gender and age as predictors didn't improve our model significantly, the results still indicate that gender and age can be of interest when considering grasping. The statement, "grasping improves with age", is a well-established fact. However, our is finding that gender is of interest too. More specifically, our data implies that female scores are higher than male scores. In our model, Model8G, although the difference between the genders was significant (p-value 0.02), the value of the difference is not considered significant (-1.7 points) when referring to grasping test scores (usually if the difference is higher/lower than two standard deviations, it is considered significant). That being said, more investigation should be done to assess the relationship between gender and grasping scores.

Visual motor scores respond to age being a predictor; older children scored higher points in visual motor skill assessment, as it is an established fact that skills generally improve with age. Interestingly, we noted that adding experience as an additional predictor better explains the variation of our data. Our findings suggest that after accounting for the variation relating to age, participants who are regular users appear to score less points in visual motor skill assessment than those participants with limited access to touchscreen devices. Looking closely at Model9VM, although the difference between the experienced group and the inexperienced group was significant (p-value 0.01), the value of the difference is not considered to be a significant difference (-3 points) when referring to grasping test scores (as it is within the two standard deviation interval). Nonetheless, since adding experience as a predictor is improving our model, we recommend further investigation into the relationship between experience and visual motor scores.

We gathered our data using a quasi-experiment design, further, our groups were unbalanced. That is, our sample was not randomly assigned to treatment, hence, we cannot generalize any of our finding about touchscreen use and fine motor development beyond our sample. However, we find interesting links between grasping skills and gender, as well as between visual motor skills and experience. We recommend investigating these links further.

In regard to the validity of our study, we assessed fine motor skills using an established tool. We tracked participants gender, age, income and touchscreen use to answer our research question. That is, our study did not violate construct validity. Our analysis looked at possible interesting factors and didn't claim any causal relationships, therefore, didn't impose any internal validity threat. Our methodology and result section detail the steps we followed to reach our results. Thus, there are no threats to the reliability of our study since this document allows the possibility for other researchers to repeat the study. Our study however poses a threat to external validity; since our study was designed as a quasi-experiment, our findings cannot be generalized beyond our sample.

5. Conclusion

Children are attracted to touchscreens and are using such devices as soon as they are able to touch and grip. Children and how they use mobile touchscreen devices were investigated through the literature to determine what technical specification fit the children's needs better. Among the results of previous research was the categorizing of touchscreen gestures into easy and difficult gestures. As a consequence, most young children's app designers limit themselves to mainly using two gestures (tap and drag & drop) in the games that they design. In this report we show that children, as young as three, can perform "difficult" gestures (e.g. rotate) after allowing them to try multiple times. That is, children can overcome the difficulty of a gesture by practicing. Our recommendation for app designers who are interested in incorporating new gestures to their games, is to add an explicit training session for that gesture. In order to allow the child to train multiple times on mastering that specific gesture before the actual game. Additionally, we investigate the effect of using touchscreen devices on fine motor skills development. Although we didn't find any evidence indicating causal effect, touchscreen use shows an interesting link to visual motor skills; therefore, we recommend further investigation into this issue.

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APPENDICES

Appendix A: Aggregated recommendations from surveyed literature (by age)

Guidelines	Age
• Increase the initial drag discarding filter's threshold to accurately capture press and hold interaction [Nacher et al.] • employ symbolic graphics in your design to guide a child's interaction [Vatavu et al.]	2
• Take cognitive development into consideration when assessing a gesture performance, for example, ability to count [Nacher et al.] • take motor development into consideration, for example, controlling the number of taps[Nacher et al.] • Adopt adaptive design of gestures according to child's age and skill level (motor and cognitive) [Nacher et al.] • Design filters to discarded initial dragging accompanying press and hold interaction [Nacher et al.] • Increase double tap "interval time" to 1200ms[Nacher et al.] • Utilize the use of animated hands to illustrate gestures, if needed, specifically those consisting of movements across the screen [Nacher et al.] • avoid designing more than one gesture to a task [Abd Aziz et al.] • Limit the number of touchable components available on one screen [Abdul Aziz et al.] • Unify the gesture set to be performed across the app, be consistent [Abdul Aziz et al.] • gesture and images should be chosen to be a close representation of real gestures ("for example using pinch to pick an item") [Abdul Aziz et al.]reduce the number of components in an interface [Abdul Aziz et al.] • remove any unrelated still component from the interface [Abdul Aziz et al.] • avoid unappealing/scary characters (test character design first) [Abdul Aziz et al.] • design a simple but consistent interface [Abdul Aziz et al.] • beware of conservation problems as conservation concept is not well developed [Vatavu et al.] • exploit centration; attracting child attention to the task by designing the target/task to "stand out" [Vatavu et al.] • account for greater tapping offsets and slower taps [Vatavu et al.] • limit distance of dragging [Vatavu et al.] • adaptive final target boundaries to deal with precision issues [Nacher et al.] • Adaptive gesture speed to match the child's speed [Nacher et al.] • be aware when using mathematical concepts, coordination and spatial problems; account for their cognitive development [Nacher et. al]	3
• Consider age related cognition and motor skills ("limited but developing") [Vatavu et al., Hamza] • Positive reinforcement [Vatavu et al.] • Use of age appropriate interactions [Vatavu et al.] • Account and deal with unintentional screen touches [Vatavu et al.] • Accidental touches can be avoided by blocking multiple touches [Baloian et al.] • Avoid frustration; accept different ways of executing a gesture, lower system sensitivity threshold [Vatavu et al.] • Utilize animism, artificialism, and magical thinking to communicate App instructions [Vatavu et al.] • Provide feedback indicating when fingers/hand touch the screen [Vatavu et al.] • Limit the use of multi-touch interactions as they tend to present a challenge and are more susceptible to screen occlusion and finger collisions [Vatavu et al.] • Adopt adaptive design according to child's age and skill level (motor and cognitive) [Vatavu et al.]	5
• Frequent use of audio prompt [Revelle & Reardon] • Employ text and audio instructions [McKnight & Fitton, Ibharim et al.] • Use wider scrolling area [Revelle& Reardon] • Avoid hotspots near screen edges [Revelle & Reardon] • When placing a target near the edge, either "align" it directly to the edge or widen hotspot to include the edge [Anthony et al.] • Add animation to help explain instructions [Revelle & Reardon, Ibharim et al.] • Utilities images use in instructions [Ibharim et al.] • Introduce several training sessions [Revelle & Reardon] • Beware when using touchscreen terms; avoid confusion [Revelle & Reardon] • Relax tilting sensitivity [Revelle & Reardon] • reduce system sensitivity and increase error tolerance [McKnight & Fitton, Anthony et al.] • visual feedback on any occurrence of a screen touch [Vatavu et. al, McKnight & Fitton, McKnight & Cassidy] • add an interaction timing for gestures like long press [McKnight & Fitton] • Use large buttons [McKnight & Cassidy] • Increase Space between edge and screen [McKnight & Cassidy] • Avoid edge-padded targets [Anthony et al.] • increase hotspots size [Revelle, Anthony et al.] • time and location can be used to discard holdover affect [Anthony et al.] • hand writing recognition should be specific to child age and adaptive to his development [Anthony et al., Brown et al.] • take conceptual sense into consideration when designing writing/drawing/copying tasks [Anthony et al.] • Support children collaboration [McKnight & Cassidy] • Consider platform recommendation for target size [Anthony et al.] • Provide visual feedback, as visible trace, with writing/drawing/copying apps [Anthony et al.]	7+

Appendix B: Family Questionnaire (used in study 1 and study 2)

FAMILY QUESTIONNAIRE

Thank you for volunteering to participate in our study. Kindly, complete the following questions.

1. Your email: ____________________________
2. Your child's name: ____________________________
3. Your child's birth date: ____________________________
4. Is your child a: ❑ Girl ❑ Boy

5. What is your total MONTHLY income (before taxes)? Please check the category that is closest to your family's total MONTHLY income: (for classification purposes)

❑ Less than $500/month	❑ $4,000-$5,999/month
❑ $500-$999/month	❑ $6,000-$7,999/month
❑ $1,000-$1,999/month	❑ $8,000-$9,999/month
❑ $2,000-$3,999/month	❑ More than $10,000/month

6. How many hours WEEKLY does your child attend childcare?

❑ Less than 11 hours/week	❑ From 28 to 36 hours/week
❑ From 11 to 18 hours/week	❑ From 37 to 45 hours/week
❑ From 19 to 27 hours/week	❑ More than 45 hours/week

7. Do you have an Internet connection at home? ❑ Yes ❑ No

8. During a typical week, how often does your child use touch screen devices (smartphones, tablets…etc)?

❑ Doesn't use any touchscreen device	❑ Between 3 hours to 6 hours /week
❑ Less than 30 minutes/week	❑ 7 hours or more /week
❑ Between an hour to two hours / week	

9. Please list the names of the apps your child uses (if applicable).

____
____
____
____
____

10. In the last three months, has your child participate in extracurricular activities involving fine motor skill development outside their class curriculum?
(check all that apply)

❑ None	❑ Playing a music instrument (Please specify: ______________________)
❑ Cooking	❑ Ball based games (Please specify: ______________________)
❑ Painting	❑ Other: ____________________________
❑ Sewing	

Appendix C: List of Apps Surveyed

Doc McStuffins	BlastMonkey	Shopkins app
Talking tom apps collection	Skyview	Amazon video, Netflix
youTube Kids	Bubble witch	Endless apps collection
PBSKids apps collection	Angry Birds apps collection	Coloring book
NickJR apps collection	Disney Jr apps collection	Epic!
Lego apps collection	Lightning McQueen races	Pango Play
Storybots	Toca Boca apps collection	Toca Builders
Toddler fish	SmashHit	SushiMonster
DinoPuzzle	abcmouse.com	SubwaySurf
EduKidsRoom	Imagine learning	Feed the Animals
Pettson's Inventions	Discovery Kids Dinosaur Puzzles and Play	Speakaboo's
Kids Doodle	ABC apps	TeachMe Kindergarten
Makeover Apps	Abby Basic Skills Preschool	Sesame Street Love2learn Elmo
Dragon Rise of Berk	Fisher Price Puppy play	Minecraft

Gestures used in these apps were: drag and drop, tap, press and hold, tilt, swipe (epic! was the only one with zooming gestures)

Appendix D: Study1 Log

We used the below log to observe children activities in study1. Gesture column list all the gestures in our experiment games; each game implement one gesture. ID and Gender column refer to each participant's ID and gender respectively. In Try columns we track the child execution of a gesture; whether they were successful or not. In the Control columns we track the child precision while executing a gesture; whether they were precise or not. We use Try and control columns to mark a child performance as fail (N), successful (Y) or mastered (M). if the child try was not successful, we mark the child's performance as (N). If the child try was successful then we look at the control column; if the control column marked a precise execution then we mark the child's performance as (M), otherwise we mark it as (Y). Lastly the Comments column was for additional observational logs (e.g. the child status: sad distracted, shy...etc.

DAY1

Gestures	ID	Gender	Try1	Control1	Try2	Control2	Try3	Control3	Comments
Double Tap Long Press Rotate Zoom Out Zoom In Drag & Drop									

DAY2

Gestures	ID	Gender	Try1	Control1	Try2	Control2	Try3	Control3	Comments
Double Tap Long Press Rotate Zoom Out Zoom In Drag & Drop									

DAY3

Gestures	ID	Gender	Try1	Control1	Try2	Control2	Try3	Control3	Comments
Double Tap Long Press Rotate Zoom Out Zoom In Drag & Drop									

Appendix E: Assent Guides

- *Study1 Assent Guide*

Hello,

We are researchers from Oregon State University; we are trying to learn how kids, like you, learn how to use their fingers. Also, we want to know how kids control where their fingers move. So, we are going to do a study and we would like you to help us in our study. In our study we are going play some fun games to see how you trace, draw and touch things with your fingers and we will play a game on a tablet. Would you like to help? If you have any questions you can ask anytime you want.

- *Study2 Assent Guide*

Hello,

We are researchers from Oregon State University; we are trying to learn how kids, like you, learn how to use their fingers. Also, we want to know how kids control where their fingers move. So, we are going to do a study and we would like you to help us in our study. In our study we are going play some fun games to see how you trace, draw and touch things with your fingers and we might play a game on a tablet. Would you like to help? If you have any questions you can ask anytime you want.

Appendix F: Study 2 games manual

Dear Parent,

Thank you for allowing your child to participate in this study. As a participant, your child received an Amazon fire tablet that contains six games called: Dancing Cow, Dancing Chicken, Popping Bubbles, Finger Family, Piano, Feeding Dog, Sheltering Lamb and Teaching Kitty to Draw. We would highly appreciate your cooperation on the following:

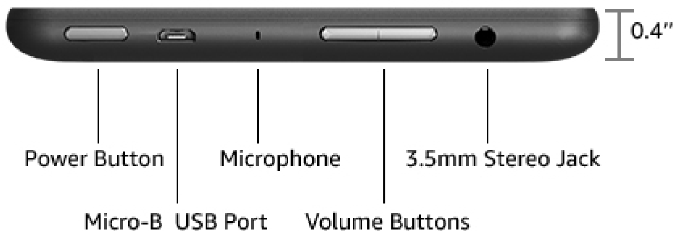
- Please make sure to connect the tablet to your Internet before your child plays with the app.
- Please allow your child to play these games frequently (at least, 5 days a week for a minimum period of 10 minutes a day).
- Please make sure that only your child, who is a participant in this study, has access to the tablet.
- You are encouraged to offer verbal guidance to your child to help them operate each game, for example, you can help them navigate out of a certain game by saying: "you can touch the blue house icon". Since our apps are tracking your child's finger taps, please refine from actually demonstrating how to play a game yourself.

Following in this document you will find an illustration on how to operate the tablet as well as how the six games work.

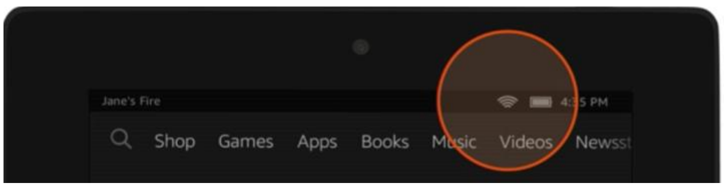
Kindly, feel free to contact us with any questions at: irb.7375@gmail.com
With our most appreciation, thank you!
The study team

<u>*Operating the Fire Tablet:</u>

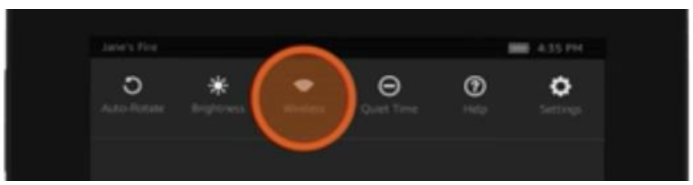
You can find all buttons and plug ports at the top edge of the device as shown in the picture below



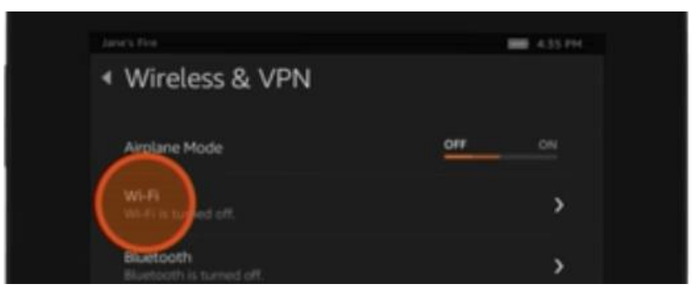
<u>*Connecting the Fire tablet to your Internet:</u>



1. Swipe down from the top of the screen to show Quick Settings, and then tap Wireless .



2. Verify that Airplane Mode is Off.
3. Next to Wi-Fi, tap On.



4. Tap a network to connect to it. If you see a lock icon, a network password is required. Enter the Wi-Fi network password, and then tap Connect.

<u>*Operating the Study game:</u>

You can find our study games towards the end of the home page. After tapping on a game, the main menu of that game will load with instructions on how to play. Your child can proceed to play by tapping on the game's icon

	In the finger family game, your child is supposed to use different fingers to tap on the matching fingers on the screen. For example, tap on the daddy finger using your daddy finger .
	In the cow/chicken, game your child is supposed to tap on the cow to get 10 milk bottles/ eggs.
	In the Bubble game, your child is suppose to pop as many bubbles as possible.
	In the piano game, your child is suppose to tap on the piano keys when they light. We encourage that your child use multiple fingers to do so. That is tap with the finger closest to the target key.
	In the lamb/dog game, your child is supposed to drag the lamb/dog to its barn. While dragging your child should avoid hitting finces and other obejcts. Additionally, this game has 4 common navigation buttons: next  (to navigate to next game), back  (to navigate to previous game), home  (to navigate to main menu) and refresh  (to reload the second game).
	In the cat game, your child is supposed to try to draw the shapes shown at the corner of the white board. When your child is happy with her drawing she can tap on the check button. If she wants to erase her drawing she can tap on the cancel button . Additionally, this game has 4 common navigation buttons: next, back, home and refresh.