THE ROLE OF MATERIALITY IN TANGIBLES FOR YOUNG CHILDREN'S DIGITAL ART DRAWINGS

A Thesis

by

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ABSTRACT

The purpose of this study is to explore the role of materiality in tangible interaction design for young children. We specifically target children aged 4 to 6 years old because of societal trend of early exposure to touch screen devices for children. This study compares three types of material (felt, wood, and plastic) for tangibles along with touch-based interaction and how the differences implicate child art creation on an iPad application. Through mixed-methods analysis of twenty-six participants' experiences, we use data sources of video recordings, drawings, and interview. The main findings looked at the relationship in hardness between digital and physical tools as well as the differences of interactions when using finger-based and stylus pens for physical drawing tools. The findings from this study may be applied to design tangible user interfaces for young children.

DEDICATION

This thesis is dedicated to my parents whose support and love cannot be measured.

ACKNOWLEDGEMENTS

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1. INTRODUCTION/MOTIVATION

Children have been exposed to touch devices such as tablets and smartphones at an earlier age and for longer periods of time. Additionally, young children are being specifically targeted as digital consumers. Children 5 years and younger are the top age category for applications on iTunes at 58% of the market for the year of 2011, which was a 23% increase from 2009 [31]. From 2011 to 2013, the percent of children 8 years and younger having access to a digital device at home increased from 52% to 75% [29]. Of those 2 to 8 year old children that have access to touchscreen devices at home, 36.4% own their own personal device [24]. Taking the market further, physicality has enhanced the digital experience for both education and play. Educational applications such as Tiggly and Fisher Price Stamp on, and toy products such as Apptivity and Skylander are examples of available products that add tangible objects to the digital realm (e.g. [1][2][12][17]).

Researchers furthermore have been conducting formal research in this area of physicality for purposes in education, socialization, visualization, performance, and play (e.g. [3][16][28][34][37][39]). Research in tangible interaction design for children has shown benefits such as enhancing children's strategizing, spatial exploration, communication, and collaboration [4]. While extensive research has looked at the general physicality of tangibles, it’s also important to note that tangibles offer a variety of physical properties (e.g. temperature, size, shape, texture, and weight) that convey information [20]. Making contact with tangibles offers instant tactile feedback and the type of feedback depends on the type of material. While the material of tangibles can have implications to interaction, a large area remains unexplored to inform the material design of tangibles used with digital devices.

This paper presents research on how the material of tangibles can influence a child's digital drawings. The rest of the paper discusses relevant background information, study design and methodology, followed by the findings from the user study with twenty-six children aged 4 to 6 years old.

2. RELEVANT BACKGROUND

2.1 Drawing

For this study on the materiality of tangibles, we used the domain of drawing, as it is one of the popular activities for children that help with creativity and motor skill development.

2.1.1 How Children Draw

Drawing is a complex skill that children learn during their development. It requires using a combination of motor, perceptual, and cognitive components. As children develop their motor skills, handling everyday objects can be a struggle. Objects are often held in various grasps and alternated between hands as well as orientation (e.g. [15] [22][23]). When learning to draw, the writing utensil is also held with various grasps in both orientations and hands [6]. How children use a writing tools as well as what type of tool they use is important since it can impact quality of drawing [38]. The drawing tool can influence the mark making gestures that children make such as basic marking styles of the horizontal-arc, push and pull, and continuous rotation [22]. Many components take into effect for the act of drawing during this developmental time of children.

2.1.2 Which to Draw on…Tablet or Paper?

Tablets act as a popular medium for drawing in addition to more traditional options such as pens, crayons, markers, and paint used with paper. There are both physical and digital advantages to drawing on tablets. Using a tablet limits the physical mess and requires minimal cleanup. Digital advantages to drawing on tablets offer options to undo errors, erase cleanly, and draw using a variety of digital drawing tools (i.e. crayons, markers, paint bucket). Additionally, an important difference between drawing on tablets and drawing on paper is that tablets offer the option to draw using finger-based interaction. Choosing to use a finger or writing utensil as a drawing tool for tablets may impact the quality of drawing. From a study conducted on children, drawing with the child's index finger on an iPad led to poorer drawing quality compared to drawing with a pen on paper [27]. While further studies on children drawing with stylus pens led to positive conclusions [10] such as increased engagement, persistence [7], and speed of replicating geometric shapes [21]. Possible benefits of drawing with stylus pens could be due to software assisting with fine-motor skills and general ease of use with drawing. Additional results from various studies have shown non-significant differences between drawing with stylus pens and pen with paper. In the same study by Martin, there were minimal differences in drawing geometric shapes by memory when using both drawing tools [21].

2.1.3 What Children Draw – Preschematic Stage

The age of the child would have an impact to the quality and type of drawing. Based on Victor Lowenfeld's 5 stages of drawing development, children 4 to 6 years old, our target age range, have left the scribbling stage and are now grouped into the preschematic stage [19]. During the first stage of development, children 2 to 4 years old use scribbles and geometric shapes (i.e. circles and squares) to represent the world that they see. The scribbling stage is mainly about exploring their motor skills. They then progress to the preschematic stage where they begin to draw objects and people to represent their ideas. While children will begin to show a greater interest in using colors at this age, the color selected tends to be highly individualized and tied to preference. There is a stronger relationship between the form and object rather than the color and object. Following the preschematic stage, children 7 to 9 years old will progress to the schematic stage where they possess greater awareness of space and more realistic use of color.

2.2 Materiality in Tangible User Interface (TUI)

Our study examines art drawings created by custom-made stylus pens as a means to explore materiality of tangibles.

2.2.1 Materiality in Product Design

Material selection has had a history of importance for product design. Architects, industrial designers, product designers, engineers, and fashion designers have investigated materiality during the product design process (e.g. [5][8][9][13]). The material can affect the functionality, manufacturing, cost, quality, durability, product life, time to market, branding, etc. (e.g. [5][9][14][25]). Additionally, the material can affect the interaction and experience between the user and product. The material itself contains its own set of properties such as tactile, sight, and sound that informs users how to interact with the product (e.g. [5][35][36]). Designers use these sensory properties of material to elicit specific interactions and affective responses [36]. To create a cheerful affective response, a designer may choose materials that are warm, bright colored, smooth, and high gloss, while using materials that are mat gloss, one textured, and colorless would give a businesslike feel (e.g. [35][36]). The material selection for product design is an important component and may strongly influence the experience and interaction between user and product.

2.2.2 Material Design in Tangible User Interfaces

While material is important for product design, it also plays a dominant role in tangible user interfaces.

Further investigation in materiality of tangibles for children has been conducted. One such study looked at the associations made with varying hardness of tangibles. The results found that harder tangibles are associated with boring, sad, and old-fashioned emotions while softer tangibles associated with cute, speedy, and warm [18]. Although the tangibles were not used with any digital games, the purpose of the study was to inform TUI design for digital tabletop gaming. Another study looked at how the texture of tangibles can be used for TUI design. Based on past studies showing the potential of tangibles supporting children's reading development [32][33], this study specifically looked at how texture on tangible letters may help dyslexic children learn to read [11].

An empirical study conducted on 19 children looked at the connection between materiality and meaning through tangible stamp shaped objects composed of felt, wood, plastic, and silicone. The children had to pair a tangible object with a digital item from one of the four categories: animals, fruits, instruments, and clothing. The results from the study showed a strong connection between selections of digital category to material of tangible objects. The digital items contained a "material essence", causing greater association for one material over another [30].

While the material of tangibles can have implications for interaction design, a large area remains unexplored to inform the material design of tangibles used for drawing activities. In this study, we investigate the effects of materiality in the process of art creation on tablets, with a focus on:

a. stroke style
b. pairing of physical drawing tool with digital drawing tool and color
c. preference of material
d. the influence of material to final drawing creations
e. duration with digital tools and physical drawing tools

3. STUDY MATERIALS

To study the role of materiality in tangibles for children's art creation, we needed a system that would allow art creation on tablets by using tangible objects consisting of different materials.

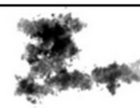
For this study, the tangibles took shape of three types of stylus pens: wood, felt, and plastic (Figure 1). The tips of all stylus pens were fashioned uniformly out of metal, copper tape, conductive rubber, and conductive fabric with the pen measuring approximately 6 by 0.5 inches. The material of the plastic and felt pens was left at its natural color of white while the wood pen was left with its natural color of hardwood. A strip of conductive thread or copper tape runs from the top of the object to the conductive rubber at the tip of the pen, allowing the pen to act as an extension of the user's fingertip on touchscreens.

Figure 1. Stylus pens (wood, plastic, felt)

Figure 2. *Hello Crayons* iPad Application

The iPad application, *Hello Crayons* (Figure 2) was selected for this study because it uses a simplistic user interface tailored towards young children and contains various drawing tools and colors that are critical elements to the study: five types of digital drawing tools and thirteen colors that use realistic texture [Table 1].

Table 1. Drawing tools and respective markings and colors

Drawing Tool	Markings	Colors
Crayon		Black, Gray, Red, Orange, Brown, Yellow, Peach, Light green, Green, Light blue, Blue, Purple
Sharpie		Black
Marker		Black, Gray, Brown, Light green, Green, Light blue, Blue, Purple, Orange, Maroon, Red, Yellow
Paint brush		Black, Gray, Brown, Light green, Green, Light blue, Blue, Purple, Orange, Maroon, Red, Yellow
Paint bucket		Black, Gray, Brown, Light green, Green, Light blue, Blue, Purple, Orange, Maroon, Red, Yellow

4. PARTICIPANTS AND STUDY PROCEDURE

Twenty-six children (14 boys and 12 girls), aged 4 to 6 years old participated in the (within-subjects design) experiment. Children were recruited through a university mailing list and volunteered by their parent. All participants had previous experience using touch screen devices while few had experience using tangible objects with touch screen devices.

Parents scheduled an hour time slot to bring their child to a designated room on university grounds. Upon entering the child friendly room (Figure 3), the researcher introduced herself to the parent and child while briefly explaining the study procedure. After introductions, the parent left the child and researcher to begin the study. While waiting outside, the parent filled out a questionnaire that inquired about the child’s interactions with touch screen devices and drawing activities.

Figure 3. Study room setup

The study began with icebreaker questions to build rapport between child participant and researcher. The study then proceeded with 4 stages (Figure 4): 1) an introduction session to *Hello Crayons* drawing application; 2) an exploration of textured stylus pens; 3) a minimum of 5 drawing sessions that consisted of using the finger, felt, wood, and plastic as drawing tool for the first four drawing sessions, followed by the fifth drawing session using any combination of drawing tools. In the first four sessions, the order of the tangible pens was counterbalanced with half of the participants beginning with the finger prior to the stylus pens and the other half engaging with the control after the stylus pens; 4) a rating and final expression stage.

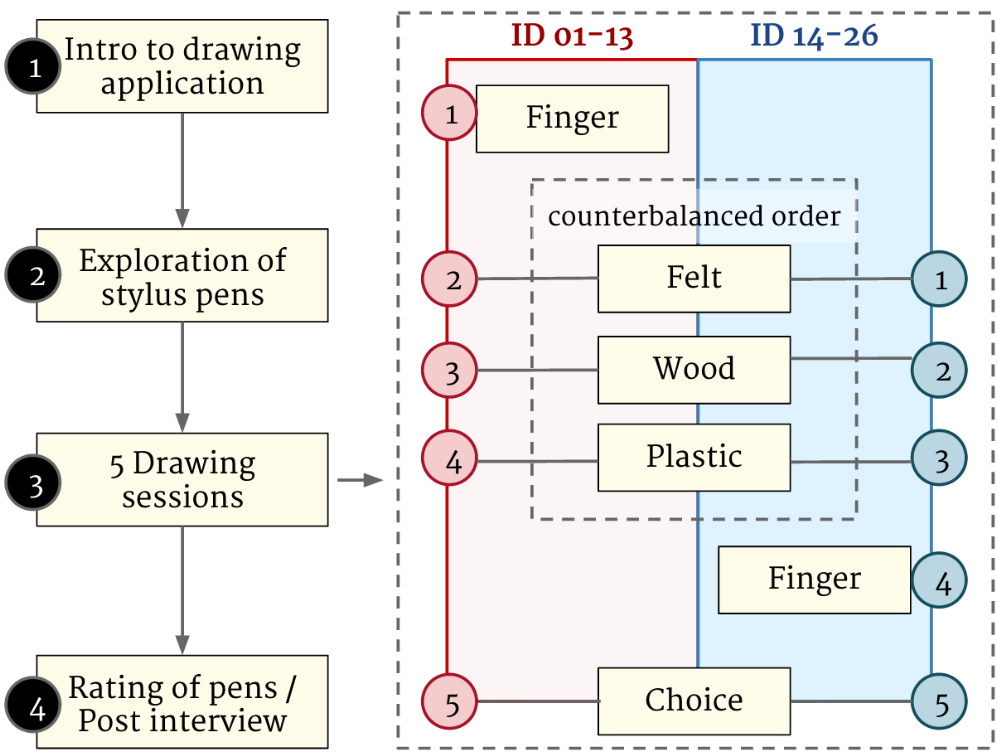


Figure 4. Study procedure

The physical drawing tools (pens and finger) served as the independent variables while the drawing tool selections (5 options), corresponding color (13 options), and art drawing creations acted as the dependent variables.

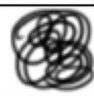
5. STUDY ANALYSIS AND FINDINGS

Mixed methods of quantitative and qualitative research data were used to analyze the collected data. All user study sessions were recorded with two video cameras to be later analyzed using video transcribing and encoding processes.

5.1 Stroke Style: Scumbling, Back and Forth, Outline, and Fill

Stroke style was broken down into four categories: scumbling, back and forth, outline, and fill. Categories were selected based upon references of an art drawing website [26], previous studies on children's stroke styles in drawing development [22], and overall observation of stroke styles used in current study. Table 2 shares further detail about the four types of stroke styles with its respected markings and applied drawing tools.

Table 2. Markings of stroke styles

Stroke Style	Markings	Description	Applied Drawing Tools
Scumbling		Circular motions	Crayon, Sharpie, Marker, Paint brush
Back and forth		Back and forth motions in similar direction	Crayon, Sharpie, Marker, Paint brush
Outline		Outline of object	Crayon, Sharpie, Marker, Paint brush
Fill		Enclosed section filled with one color	Paint bucket

Stroke styles were determined from analysis of final drawings and observations made during study. Multiple stroke styles could be used for the same drawing if for example a child used both fill and outline as shown in Figure 5. Stroke styles used for each session were classified and tallied by one researcher. From the results, a chi-square test of association yielded a weak relationship between overall stroke style to general physical drawing tool, $\chi^2(9, N = 195) = 6, p = .07$ (Figure 6). Upon further analysis of relationship between stroke style and drawing tool, a chi-square test of association yielded a strong relationship when grouping tangible pens together, $\chi^2(3, N = 96) = 52, p < .05$ (Figure 7). Although there was not a strong relationship when looking at pens individually, a stronger relationship was found when using two variables for the physical drawing tool: pens and finger-based.

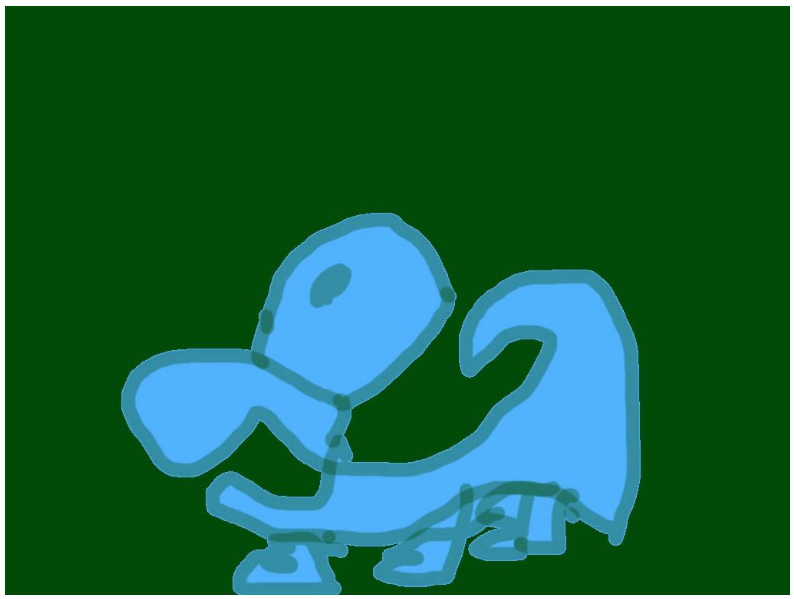


Figure 5. Child’s drawing showing stroke style of fill and outline applied

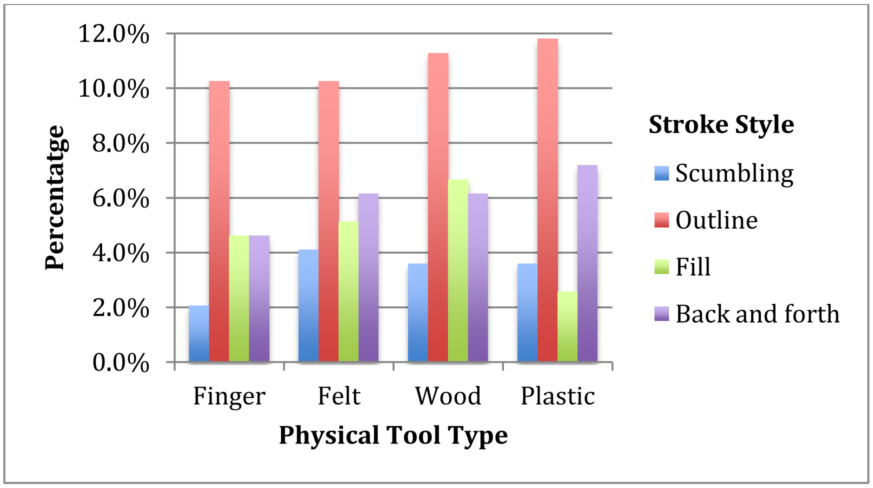


Figure 6. Graph of stroke style to physical drawing tool

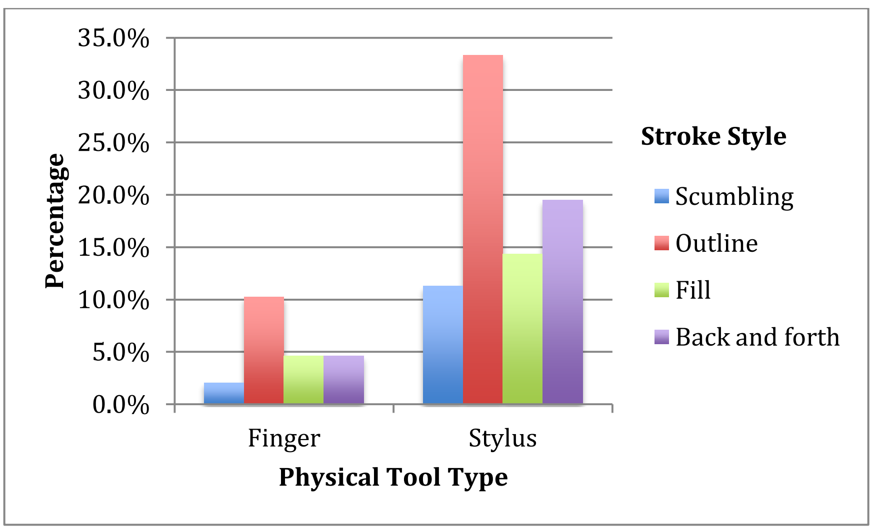


Figure 7. Graph of stroke style for finger and stylus

5.2 First Selection of Digital Tool

From the video data, initial digital tool and color selected at the start of each session was coded. The paint bucket tool had a higher selection count with the finger-based drawing tool in comparison to the stylus pens (Figure 8). No significant results found within materials of drawing tool, in addition to relationships with other digital drawing tools and color selection.

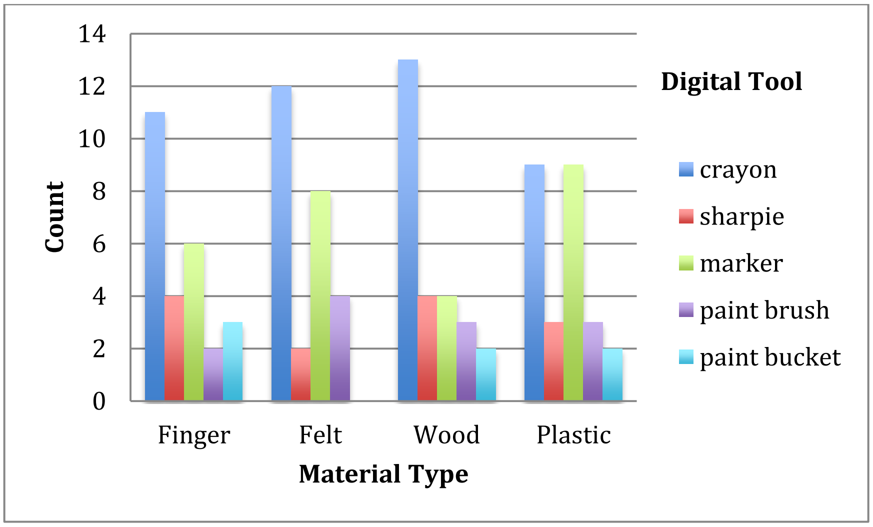


Figure 8. Graph of first selection tool

5.3 Stylus Pen Preference

The rating of physical drawing tool was recorded through use of a 5-variation likert scale represented through smiley faces. Children were asked to associate a face for each of the three stylus pens as well as rank their preference in order from 1 to 3.

Based on the results from the smiley face rating, felt and plastic had the highest and equal amount of ‘big happy face’ (like it very much) and ‘small happy face’ (like it) sections. Although both had an equal amount of like selections, felt had a greater count of dislike selections (‘big sad face’ and ‘small sad face’). Wood was more on the neutral side with less strong preferences of likes and dislikes. See Figure 9 for results of smiley face rating.

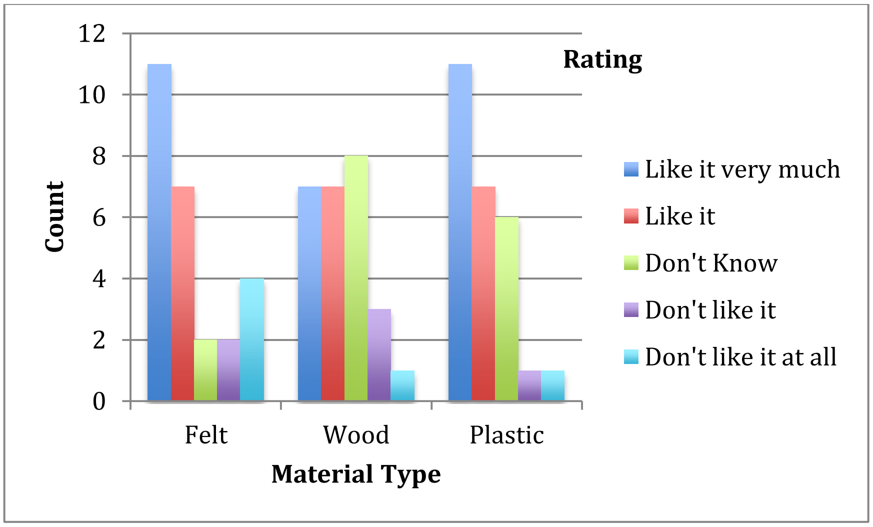


Figure 9. Smiley face rating results

Results from preference of order had similar results to smiley face ratings. The results found that the participants favored plastic with an average rating of 2.2; felt had an average of 2.1; and wood being the least favorite at 1.7 (Figure 10). Additionally, when broken down by gender, the results found that the strong dislike of wood came from boys (Figure 11). Females did not have as strong as a variation for preference compared to boys. When further analyzed by age, the strong dislike of wood specifically came from 6-year-old boys (Figure 12). For the final drawing session where the children choose to draw with a stylus pen first, 94% selected a material of preference that had the highest rating. Of the 94%, 56% of it was for plastic, 33% for felt, and the remaining 11% was wood.

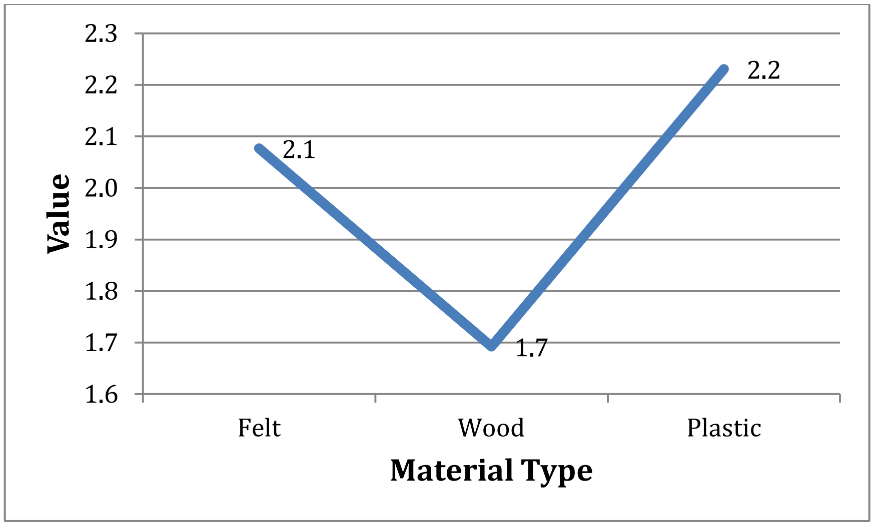


Figure 10. Preference of pens

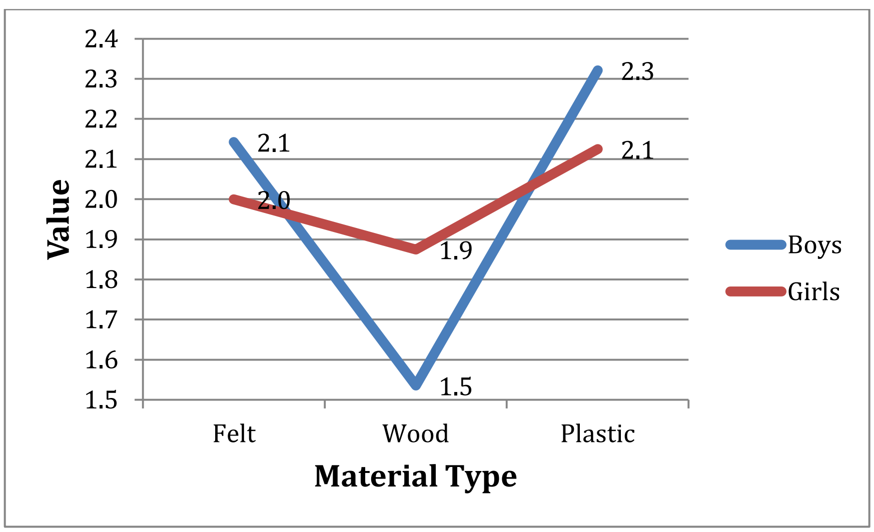


Figure 11. Preference of pens based by gender

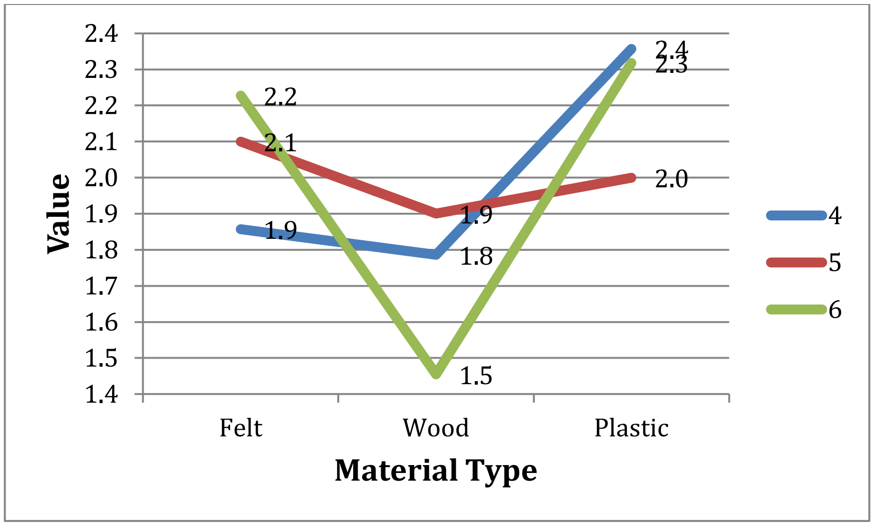


Figure 12. Preference of pens based by age

5.4 Final Drawing Categorization

Another area of focus for study analysis was the materiality in children's final drawings. A hypothesis for the study was that the material of physical tool would influence children's drawing creations. It was predicted that the objects that children drew would share similar material characteristics to that of the pens that children used for their drawing. The pens were categorized by hardness (soft and hard) and texture (fuzzy, smooth, rough). The felt pen fell under soft and fuzzy, plastic as hard and smooth, and wood as hard and rough for categorization. Using the participants' final response to what they drew, rather than the researcher's interpretation of drawing, all components within the drawings were grouped by the feel and texture. If a component did not fall into a category for hardness (soft or hard) and texture (fuzzy, smooth, or rough), it was labeled as neutral. Abstract concepts such as imaginary characters, the sky, and rainbows were labeled as neutral. For example, in one of the participant's drawing, a bunny would be labeled as fuzzy and soft, grass as soft and smooth, and neutral for heart and sun (Figure 13).

Figure 13. Participant's drawing containing soft, fuzzy, and smooth components

It was predicted that children would draw softer and fuzzier components using the felt pen while the wood and plastic would be paired with harder and rough/smooth components. The results showed otherwise.

A chi-square test of association yielded a strong relationship between hard and soft properties to general physical drawing tool, $\chi^2(6, N = 198) = 13.953$, $p < .05$ (Figure 14). The main relationship was between soft and neutral, $\chi^2(6, N = 198) = 14.913$, $p = .02$, over hard and neutral. A chi-square test of association yielded a weak relationship between fuzzy, smooth, and rough properties to general physical drawing tool, $\chi^2(9, N = 198) = 9.544$, $p = .39$ (Figure 15).

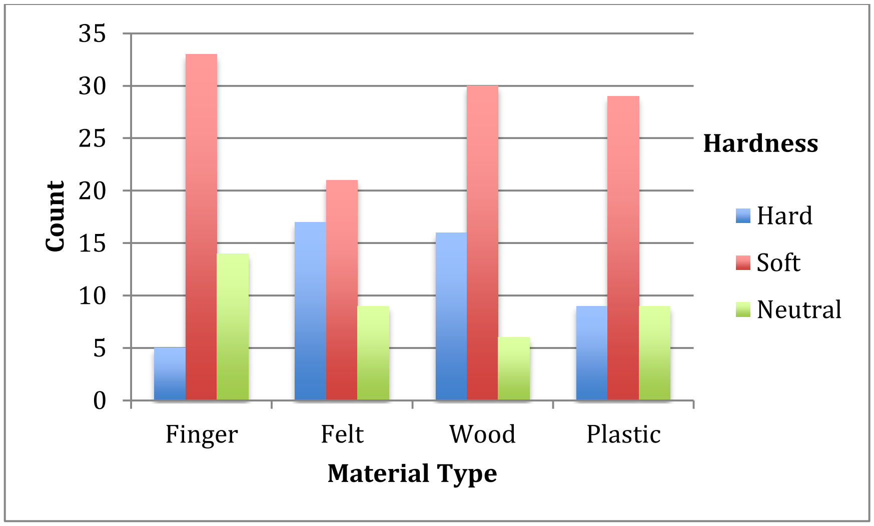


Figure 14. Graph of drawing components for hard and soft feel

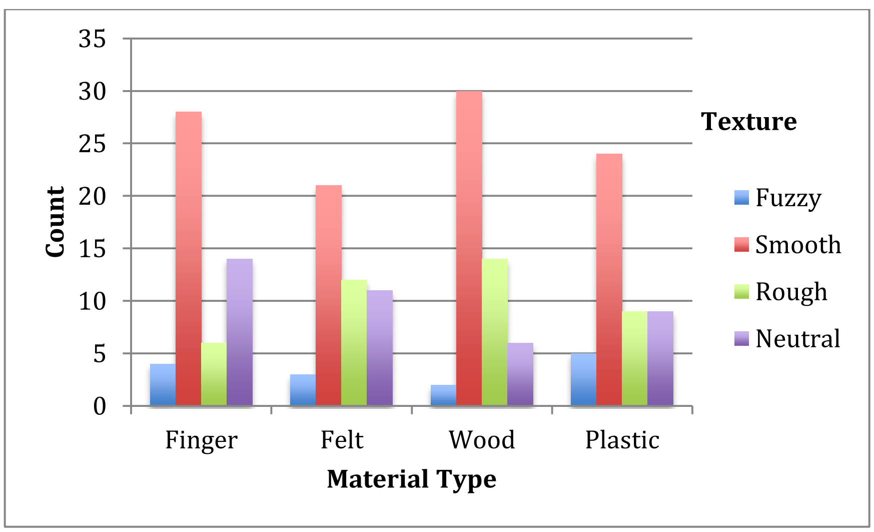


Figure 15. Graph of drawing components for fuzzy, smooth, and rough texture

For some participants that drew similar scenes for all sessions, the physical tool had no effect on the drawings whatsoever. For the 4-year-old participants, User ID10 drew only scenes from Pixar's movie, *Finding Nemo* (Figure 16), while ID11 drew only rainbows.

Figure 16. *Finding Nemo* drawings using finger, felt, wood, and plastic (starting from top left in counter clockwise order)

Similar results occurred for the older users with more advanced drawings such as 5-year-old user ID20 drawing all outdoor scenes that contained components of the sky, a horizon, and people (Figure 17).

Figure 17. *D*rawings of outdoor scenes using finger, felt, wood, and plastic (starting from top left in counter clockwise order)

On the other side however, there were instances where the material of the pen did have a direct impact to the participant's drawing creation. One such occurrence was for 6-year-old user ID05 when drawing with the felt pen. When asked to describe the feel of the felt pen, the child responded by saying, "this one feels like foam". Upon handed the felt pen, the child lifted the tool to eye level while giving it two squeezes with dominant hand. Proceeding with the session, when asked what he would draw, the child responded, "foam", and started to draw using the green paintbrush. Midway through the drawing, the researcher asked the participant "are you drawing green foam". In response to the question, the child replied, "there's no such thing as green foam". The participant then proceeded to do a new drawing and finished by drawing white foam on a black background. Verbal communication between participant and researcher helped to determine this specific relationship between drawing creation and material of drawing tool. Other direct textural and material feel similarities entailed drawing drums (ID25) with a wood pen, an eraser (ID03) and a dog (ID05) with felt pen, and a plastic alien balloon (ID05) with plastic pen.

5.5 Duration with Digital Tools

Time spent with all drawing tools (tangible and finger-based) were recorded. In sequential order, total time spent with finger-based was 56 minutes, felt was 65 minutes, wood was 66 minutes, and plastic at 72 minutes. To calculate total time, time started when child picked up drawing tool and stopped when child declared or confirmed finality of drawing. Time was further broken down by duration of individual digital drawing tool paired with physical drawing tool (Table 3). Time started when child selected a digital drawing tool and stopped when child selected a new digital drawing tool or completed drawing. Results from individualized physical and digital drawing tool can be seen in Figure 18.

Table 3. Duration of digital tools with physical tools

	Crayon	Sharpie	Marker	Paint Brush	Paint Bucket
Control	30:18	03:46	13:16	05:16	02:18
Felt	31:08	03:10	14:24	09:33	04:31
Wood	20:45	04:42	22:46	07:19	07:43
Plastic	25:27	08:47	24:13	07:53	04:12

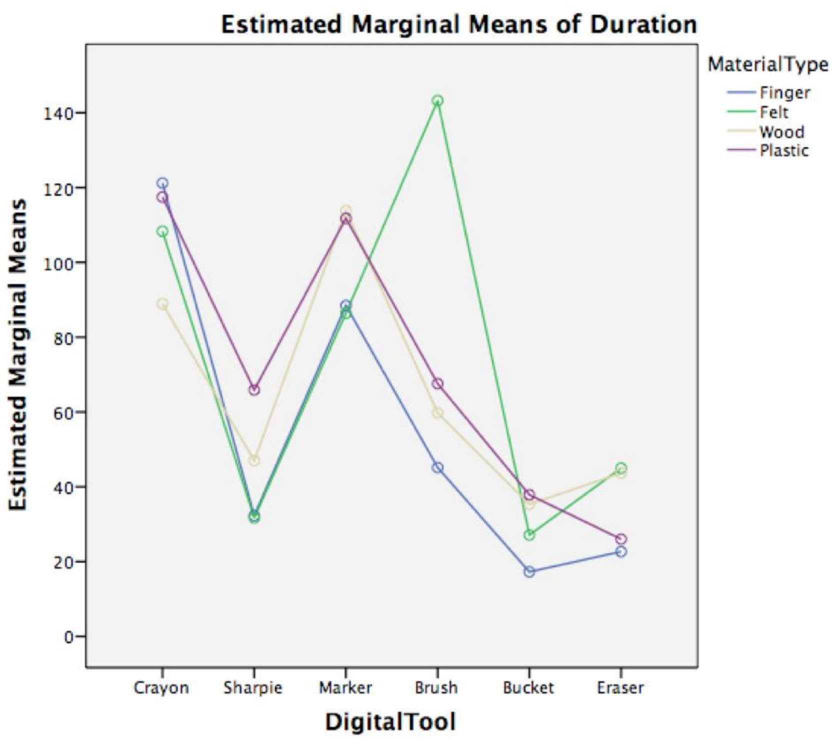


Figure 18. Graph showing duration of digital tools with physical drawing tools

6. DISCUSSIONS

We were interested in pursuing if the materiality in tangibles may have an impact on digital drawings, and whether this impact can help inform tangible interaction design for young children. Our findings showed two types of results:

1. a significant relationship in hardness between physical and digital drawing tools
2. a significant difference in finger-based and stylus pen interaction

The first group of results looked at the hardness of materiality for both physical and digital drawing tools. It was predicted that children would draw more soft components with the felt pen and more hard components with the plastic and wood. On the contrary, the hardness of the pen led to an opposite effect of drawing creation. Using a soft pen (i.e. Felt) led to greater instances of drawing harder components while using a hard pen (i.e. wood, plastic) led to an increase in softer components (Figure 11). An explanation could be that the harder pens allowed for more control to draw softer objects that may contain softer lines while the softer pens offered less control and therefore linked to drawing harder objects that may contain finer lines.

The digital tools used for drawing also contained properties of softness and hardness. The terms “soft” and “hard” refer to the edges and lines of the drawing. Crayons and paintbrush draw softer lines while sharpie, paint bucket, and markers draw finer and harder lines. From the results, the soft pen (i.e. Felt) was tied to the soft digital tools of paintbrush and crayons and the hard pens (i.e. wood, plastic) were tied to the sharpie, paint bucket, and markers (Table 4). More time was spent using the crayon and paintbrush tools with the felt pen. The hard pens likewise had more time spent with the harder digital tools. The plastic and wood pens were used longest with the marker, sharpie, and paintbrush digital tools. Additionally, the stroke style helps to support the connection of drawing hard objects with hard pens. Children tended to create more outlined drawings using the plastic and wood pen. Outlined style drawings would offer harder lines and tied to harder objects compared to using a drawing style of scumbling and back and forth.

Table 4. Duration of digital tools with physical tools showing hardness relationship

	Crayon (soft)	**Paint Brush (soft)**	**Marker (hard)**	**Sharpie (hard)**
Felt (soft)	31:08	09:33	14:24	03:10
Wood (hard)	20:45	07:19	22:46	04:42
Plastic (hard)	25:27	07:53	24:13	08:47

The second group of results looked at the differences between finger-based drawing and pen-based drawing. The key difference was the back and forth drawing stroke between the participants physical tool use of finger or stylus pen. The participants tended to create more back and forth drawings with the pens compared to the finger. The other drawing styles were not as significant. Children develop the back and forth stroke in their earlier years during their motor skill development. The participants' previous experience of drawing on paper using traditional tools (crayons, pencils, and markers) can tie to the translation of using more back and forth strokes with the stylus pens. The interactions of drawing with stylus pens on digital devices would have similar qualities as the physical interaction of holding a pen. Drawing on a tablet with your finger uses a different type of interactive drawing style.

Although all participants have had previous experience interacting with digital devices, not all have had drawing experiences on digital devices. Drawing with their finger may still have been a novelty to some of the participants allowing for the concept of drawing as a digital metaphor. The interactions with using their finger would have more digital drawing components. The only specific digital drawing components would be the options of fill through use of paint bucket and erase through use of eraser or undo button. On paper, children cannot erase the markings of crayons, sharpies, paintbrushes, and markers. They additionally cannot fill the entire space one color by tapping the paper. These two actions can only be done on a tablet. Although children tended to use the eraser evenly between all physical drawing tools, they did tend to use the paint bucket more with their finger on their first selection.

Surprisingly children spent more time and frequency using the paint bucket with the wood pen. It’s also important to note that the wood stylus pen was children’s least favorite selection so perhaps they wished to speed up their drawing by using the paint bucket when it was time to use the wood stylus.

7. CONCLUSION/FUTURE WORKS

This paper investigates the role of materiality in tangible interaction design for young children. In this study, children created digital drawings using their finger and various textured stylus pens. An association between the material feel of tangibles and digital interaction was found. Our findings looked at the relationship in hardness between digital and physical tools as well as the differences of interactions when using finger-based and stylus pens for physical drawing tools. The materiality of tangibles is considered as an important component when looking at the field of TUI for children and the results from this paper contributes to development of future tangible designs for young children.

Future development and research in materiality of tangibles can be expanded through other types of activities. One specific activity in mind is writing. As classroom settings add digital learning devices into their curriculum, it would be beneficial to investigate the implications of materiality when used for children's development of writing. Specific research in materiality of TUI with writing can look into learning the alphabets and numbers. Additional research in materiality can also expand to children with disabilities. A future goal would also be to open a fabrication method of creating material stylus. This would allow the community to explore their own research in the materiality of tangibles.

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