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Drawing Across Media: A Cross-Sectional Experiment on Preschoolers' Drawings Produced Using Traditional Versus Electronic Mediums

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Abstract

Young children's growing access to touchscreen technology represents one of many contextual factors that may influence development. The focus of the current study was the impact of traditional versus electronic drawing materials on the quality of children's drawings during the preschool years. Young children (2–5 years, $N = 73$) and a comparison group of adults ($N = 24$) copied shapes using three mediums: marker on paper, stylus on touchscreen tablet, finger on touchscreen tablet. Drawings were later deemed codable or uncodable (e.g., scribbles), and codable drawings were then scored for subjective quality on a four-point scale. Girls and older children (vs. younger boys) produced more codable drawings; however, this gap closed when children drew with their finger on a tablet. Medium also affected the quality of adults' drawings, favoring marker on paper. Thus, drawing on a tablet helped younger children produce drawings but resulted in lower-quality drawings among adults. These findings underscore the importance of considering environmental constraints on drawing production. Moreover, since clinical assessments often include measures of drawing quality, and sometimes use tablet computers for drawing, these findings have practical implications for education and clinical practice.

Keywords

early childhood; drawing; media; touchscreens

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Many theories of human development emphasize the importance of contextual and transactional influences (e.g., Bronfenbrenner & Ceci, 1994; Sameroff, 2009). Consistent with these theories, the field of developmental science is increasingly acknowledging the complex and dynamic interplay between intrinsic and extrinsic factors that affect human learning and development. One contextual influence that has changed dramatically in the early 21st century is young children's access to and use of touchscreen devices. Based on nationally representative surveys of U.S. families with children under the age of 8 years, Rideout (2013; 2017) reported a dramatic increase over a six-year period in the percent of families who own a mobile device (e.g., smartphone, tablet computer) and young children who have used such a device. For instance, household tablet (e.g., iPad) ownership increased from 8% in 2011 to 78% in 2017, with 42% of young children owning their own tablet. These trends are not isolated to the United States, as increases in ownership of mobile devices have occurred across the globe (Poushter, Bishop, & Chwe, 2018). At present there have been few studies that examine this rapid technological transition on children's development, particularly as it relates to complex cognitive and motor activities. The overall goal of this study was to examine the impact of touchscreen devices on one important aspect of development: children's emerging drawing skills.

We focus on children's drawings because drawing is a complex skill, involves both motor and cognitive components, and develops throughout early childhood (see Braswell & Rosengren, 2008, for review). Drawing emerges early in life as children first create dots, lines, and scribbles around 18 months of age. Children then begin to draw simple shapes during the toddler and early preschool period. In later preschool and early childhood, children begin to combine shapes into more complex pictures (Cox, 1992; Goodnow, 1977; Kellogg, 1969; Willats, 1977).

We also focus on children's drawing skills because the proliferation of touch screen devices has changed the manner in which children are able to draw. In addition to using crayons, pencils, or markers on paper, many children now have the opportunity to draw using their finger or a stylus on an electronic screen. Parents have reported that their children often use digital programs or applications (i.e., apps) for drawing. For instance, in the U.S. Rideout (2013) has reported that 19% of children between 6 and 24 months of age, and more than 40% of children two years of age and older, use creativity apps (e.g., drawing, making music, creating videos) either sometimes or often. Similarly, tablet-owning parents in the U.K. reported that more than half of preschoolers (54% of 2-year-olds, 64% of 3-year-olds, and 63% of 4- to 5-year-olds) use a tablet for drawing and painting, and that apps for drawing were often among children's favorite apps (Marsh et al., 2015).

Changing the nature of the drawing implement changes the biomechanical and task constraints involved in drawing, which in turn may influence the final product being drawn in important ways (Braswell & Rosengren, 2008; Gerth, Klassert, Dolk, Fliesser, Fischer, Nottbusch, & Festman, 2016; Picard, Martin, & Tsao, 2014; Rosengren, Savelsbergh, & van der Kamp, 2003). For example, drawing with a finger on a touch screen involves different muscle groups and different frictional characteristics than drawing with a crayon or marker on paper. For young children, drawing with a finger may be motorically simpler than manipulating a drawing instrument that requires a certain level of finger strength and fine motor control (Braswell & Rosengren, 2008). Compared to using finger paints on paper, drawing with a finger on a tablet computer may enable children to engage in longer, more continuous marks on the surface (Price, Jewitt, & Crescenzi, 2015). Additionally, the increased tactile feedback of drawing with a finger (versus stylus or pen) on a touchscreen surface appears to help preschool-age children learn to write letters (Patchan & Puranik, 2016). However, at least for more experienced drawers who are used to drawing with an implement, drawing with a finger may be more fatiguing and thus result in less detailed drawings (Picard et al., 2014). Moreover, drawing with a finger (versus pen or marker) may make it more difficult to produce fine detail in a drawing, create sharp corners in the production of certain shapes, or use visual information to guide drawing.

Similarly, drawing with a stylus on a touchscreen also changes the motor constraints, as the frictional forces required to produce an image on a screen are considerably less than those required when drawing with a crayon or marker on paper. Reduced friction may make it both easier and harder for young children to control a stylus. Indeed, Gerth et al. (2016) found that when 5-year-olds completed a series of drawing tasks using a writing implement (pen or stylus), the lower friction of a tablet surface (versus paper) led to faster drawing velocity but decreased drawing quality. Gerth et al. also found mixed results when adults wrote and drew using a pen on paper versus a stylus on a tablet computer. Specifically, the quality of adults' products was lower for pen-and-paper than for stylus-and-tablet adults when they copied simple patterns (e.g., curved line, staircase), whereas pen-and-paper drawings were better than stylus-and-tablet drawings when adults copied a more complex design (wrote a phrase). Thus, the impact of digital drawing materials on the quality of drawings may vary by age and drawing experience. It remains unknown whether there would be substantial age-related differences within the preschool period as drawing begins to emerge.

Examining how the process of drawing across various media impacts the final drawing product is important as the product of children's drawing activity has long been used as part of assessments of general developmental level (e.g., the Denver Developmental Screening Test, Frankenburg & Dodds, 1967; McCarthy Scales of Children's Abilities, McCarthy, 1972), as well as more specific aspects of development. For example, children's drawings have been used to assess children's perceptual-motor development (e.g., the Bruininks-Oseretsky Test of Motor Proficiency, *2nd Ed.*; Bruininks & Bruininks, 2005), cognitive development (Case & Okamota, 1996; Piaget, 1976), emotional functioning (e.g., Kinetic family drawings, Burns & Kaufman, 1970, and intellectual functioning (e.g., Draw-a-person Test; Goodenough, 1926; Harris, 1963; Koppitz, 1968). Some scholars even argue that the quality of children's drawings represents stable, fixed traits. In a large study of mono- and dizygotic twins, Arden, Trzaskowski, Garfield, and Plomin, (2014) argued that genetic differences contribute to differences in the quality and level of detail of children's figure drawings. They found that drawings obtained at age 4 were significantly correlated with intelligence at age 4. Given this past research and use of drawings as a proxy for a wide range of abilities, it is important to examine more closely how changing technology influences the outcome of children's drawing behavior.

Overview of the current study

The purpose of this experiment was threefold: (1) to compare the quality of children's drawings when using traditional and electronic materials; (2) to examine how drawing using different mediums differs by age during early childhood; and (3) to identify potential correlates of children's drawing quality. Children (2–5 years) and a comparison group of young adults copied familiar and novel shapes using each of three mediums: a marker on paper, a stylus on a tablet computer, and their finger on a tablet computer. We also measured grip and pinch strength during the session. The session concluded with a free-draw activity in which participants were asked to select a surface and implement with which to draw. Parents of child participants completed a survey including information about their child's drawing experience at home and ratings of their child's fine and gross motor skill.

Of particular interest was the likelihood that children would produce a codable drawing (e.g., something resembling a closed shape) and, given that a codable drawing was produced, the subjective quality of that drawing. We predicted age-related increases in the production and quality of drawings (Cox, 1992; Gerth et al. 2016; Goodnow, 1977). Moreover, we predicted that children and adults would produce higher-quality drawings with a marker on paper than with a stylus on a tablet computer, as was found in previous research (Gerth et al., 2016). We further predicted that the effect of medium would be particularly evident for the novel shapes, which require more careful encoding (Braswell & Rosengren, 2008). An open research question was the impact of drawing with a finger on a tablet computer (versus stylus or marker), given that drawing with a finger may be motorically simpler for young children while also making it more difficult to create fine detail and use visual information to guide one's drawing (Braswell & Rosengren, 2008). Previous research has been mixed, in one case showing that young children are more likely to produce written letters following practice writing the letters on a tablet computer with their finger (versus stylus; Patchan & Puranik, 2016) and in another case finding lower-quality drawings when produced by a finger versus a pen (Picard et al., 2014).

Method

Participants

This study was approved by the Institutional Review Board for Education and Social/Behavioral Science at the University of Wisconsin-Madison (protocol number 2015–0564, "Children's Drawing Across Media"). Data were collected between July and November 2015. Children were recruited from preschools and a children's museum in a medium-sized, upper-Midwest city in the U.S. We also recruited a comparison group of adults, as in prior studies (e.g., Gerth et al., 2016). Adults were recruited through personal contacts and snowball sampling. Child participants provided oral assent. Parents and adult participants provided written informed consent.

A total of 82 children were recruited for this study. Nine children were dropped because they did not complete any of the drawing tasks ($n = 1$) or because they were age outliers (too young [$n = 2$] and too old [$n = 6$]). The final sample included 73 children between 2 and 5 years of age (range 2.08–5.70 years, mean = 3.75, $SD = 1.04$, 64% female). At the outset of this study, there was no published research to provide effect sizes for *a priori* power analysis. However, a power analysis assuming a medium effect (f = .25, with alpha = .025 for a two-tailed test and power = .80) for the main research question (i.e., overall main effect of drawing medium on children's average drawing score) yielded a target sample size of 15 or 33 children, assuming a correlation among repeated measures of .8 or .5, respectively. Our research team recruited a convenience sample of all families who consented to participate through the end of the year, which exceeded the sample size needed to detect a medium effect for the repeated measure.

Of the 48 families (66%) who completed the parent survey, the majority (n = 35, 73%) identified their child as white/Caucasian and non-Hispanic; other children were identified as Hispanic (n = 3, 6%), Asian/Pacific Islander (n = 5, 10%), black/African American (n = 1, 2%), or other/mixed race (n = 4, 8%). The mean years of education was 18.7 (SD = 2.8, range 13–25), which is roughly equivalent to a master's degree. Parents also responded to the MacArthur Scale of Subjective Social Status (Goodman et al., 2001), which asks respondents to place themselves along a social-status continuum. On one end are those people who have the least money, little or no education, and no job or a job that is not respected (1), and at the other end are those people who have the most money, highest level of education, and highly respected jobs (10). Parents' average social status on this measure was 7.14 (SD = 1.34, range = 4–10).

The adult comparison group was recruited during the same data collection period. This convenience sample consisted of 24 undergraduate students between 19–22 years of age (mean age 20.1 years, 79% female). The majority (91%) indicated their race as white/Caucasian and non-Hispanic; one adult indicated Asian/Pacific Islander, and another indicated both black/African American and white/Caucasian. Their average subjective social status was 7.0 (SD = 1.57, range = 4–10).

Design

This experiment was designed to examine drawing cross-sectionally throughout early childhood. Child age was treated as a continuous predictor. Descriptive statistics for adults are reported for comparison but not included in inferential tests of child age effects. Drawing medium was a repeated measure with three categories: marker-paper, stylus-tablet, finger-tablet (see Figure 1). Novelty was also a repeated measure: Participants were asked to copy four familiar shapes and two novel shapes (see Figure 1).

Stimuli and Apparatus

Drawing materials—Participants drew pictures using a marker on a piece of paper, a stylus on a tablet computer, and their finger on a tablet computer (see Figure 1). The paper was cut to match the dimensions of the screen on the tablet computer (21.34 cm x 13.72 cm). We created our own stylus from the shell of a marker using a small battery and conductive sponge; thus, the overall appearance, shape, and weight of the stylus was identical to that of the marker. The tablet was a Samsung Galaxy Tab 10.1, enclosed in a protective rubber case. Participants produced drawings using the Android application *Paint Joy Pro* (Doodle Joy Studio). The paint application was set up to produce black lines on a white background, and the thickness of the lines approximated the thickness of lines produced when using the marker on paper. All tablet drawings were recorded for subsequent coding using the screen-capture application *Recordable* (Uptodown). Paper drawings were scanned for subsequent coding.

Shape prototypes—Participants copied shapes that were printed on laminated cards that matched the dimensions of the paper and tablet screen (21.34 cm x 13.72 cm). The printed images were centered on the card and measured between 8.26 cm and 11.43 cm at their widest points (see Figure 1 for examples). There were six shapes in all, adapted from those used by Braswell and Rosengren (2002; 2005). The set included four familiar shapes that children had likely encountered outside of the study and may have had experience drawing (circle, square, triangle, cross). In addition, there were two novel shapes that were created by Braswell and Rosengren (2002) in order to eliminate the possibility of practice effects; these shapes were adapted from two familiar shapes (triangle, cross) so that they contained the same line number and orientation. The six shapes are depicted in Figure 1.

Grip and pinch—Grip and pinch strength were measured using a Preston Jamar hand dynamometer and pinch meter (Patterson Medical, Warrenville, IL). For grip strength, the smallest handle position was used for all participants. Pinch strength was measured using a lateral pinch grasp (i.e., key pinch with thumb on top). Additional details are provided in the procedure section.

Procedure

Participants were tested individually in a space that was reserved for research (e.g., empty room in preschool or museum). Upon request, parents were allowed to stay in the same room with their child but were asked to not interact with their child during the study. An experimenter sat across a table from the participant, and an assistant video-recorded the session. Then the participant completed a number of drawing and motor tasks, including block stacking, paper folding, and ball tossing. Of particular interest were the shape-copying task, grip and pinch strength assessments, and free draw during which participants chose their own medium.

Shape copying—Participants copied all six shapes using each of the three mediums (marker-paper, stylus-tablet, finger-tablet), resulting in a total of 18 drawings per participant. One of three orders (using a Latin square design) was assigned at random at the start of each session. Participants completed all drawings for one medium before doing the same task using another medium, following an identical procedure. Within each medium, the six shapes were presented in one of three orders (selected at random) that had the following constraints: The circle was always presented first, because it is a familiar shape to most children and is often the first shape that children produce reliably (Braswell & Rosengren, 2008). Participants then copied another familiar shape (square, triangle, or cross), followed by a novel shape (altered triangle, altered cross), and so on, alternating between familiar and novel shapes until all six shapes were copied.

At the beginning of the shape-copying task, the experimenter presented a medium and said, "Now we're going to draw with this (referring to implement: marker, stylus, finger) using this (referring to surface: paper, tablet)." The experimenter demonstrated how to use the medium by drawing a wavy line. The experimenter then said, "Now can you draw like this for me?" The experimenter turned the materials to the participant and said, "Now it's your turn!" After the participant drew a single wavy line, the experimenter provided generic positive feedback (e.g., "Great!") and presented a clean drawing surface (a new sheet of paper or blank tablet screen).

Once the participant was familiarized with the medium, the experimenter presented the first shape prototype (circle) and said, "Now can you draw this for me?" The experimenter removed the drawing when the participant indicated that they were done (e.g., putting down the marker, responding in the affirmative when asked if they were done). If the participant did not immediately begin drawing, the experimenter provided another prompt. If the participant still did not draw, then the experimenter moved on to the next shape. The same procedure was followed for each of the six shapes using that medium. Then the experimenter followed the same procedure for the remaining two mediums.

Overall, children were asked to produce a grand total of 1,314 shape drawings (6 shapes * 3 mediums * 73 children). Sixteen percent of children declined to produce at least one of the 18 possible drawings; however, all children in the final sample produced at least one drawing using at least two of the three mediums. The final data set included 1,264 drawings (96% of all possible drawings). This did not differ by novelty (96% familiar, 96% novel) or by medium (97% marker, 96% stylus, 95% finger). For comparison, adults produced all 432 shape drawings (6 shapes * 3 mediums * 24 adults).

Grip and pinch strength—The experimenter first showed the participant how the dynamometer worked and demonstrated how to hold it (i.e., standing with the elbow against the body at a 90-degree angle). Then the experimenter handed the dynamometer to the participant while supporting its weight with their own hand. The researcher said, "Squeeze as hard as you can for three seconds when I say 'go…' Go! One… two… three!" Three measurements were attempted on each hand, alternating between left and right hands, for a total of six measurements. A similar procedure was followed for measuring pinch strength. Some children declined to complete one or more of the six measurements for grip or pinch strength; however, nearly all children had at least one measurement (99% grip, 97% pinch), and a majority of children had all six measurements (90% grip, 82% pinch). The maximum grip across all measurements (regardless of hand) were recorded and used in the analyses, as recommended by Roberts et al. (2011). For consistency, maximum pinch was similarly calculated across all measurements.

Free draw—At the end of the session, participants were given an opportunity to draw anything they wanted during a free-draw task. The purpose of this task was to determine the medium that each participant selected when given a choice. The experimenter placed a blank piece of paper and the tablet computer (with a blank drawing surface) side-by-side in front of the participant and asked, "Which one would you like to use?" If the participant chose to draw with a tablet, the experimenter then asked, "Would you like to use this (referring to the participant's finger) or this (referring to the stylus)?" If the participant chose to use paper the experimenter placed the marker on the table and removed the other drawing surface. The assistant recorded whether each participant selected the paper or tablet and whether the participant chose to draw with the implement or with their finger.

Survey

Parents of child participants were asked to complete a survey that included questions about demographics (as described earlier) and their child's experience with different drawing mediums at home. The parent survey also included the Ages and Stages Questionnaire, 3rd edition (ASQ-3) (Squires & Bricker, 2009) to assess children's achievement of developmental milestones. Sixty-six percent of parents returned the survey. Adult participants answered the same demographic and drawing experience questions about themselves.

Drawing experience—Respondents indicated the frequency of using each of several drawing mediums on a 4-point scale where 1 = never/almost never, 2 = occasionally (a few times per month), 3 = sometimes (a few times per week), and 4 = daily/almost daily. Mediums included markers on paper, crayons on paper, pens on paper, pencils on paper, finger on touchscreen device (e.g., iPad), stylus or similar tool on touchscreen device, chalk on pavement, and other. Nearly all parents (92%) reported that their child draws with markers on paper at least sometimes, compared to only 10% and 36% for stylus and finger drawing on a touchscreen device, respectively. The comparable frequencies for adult participants were 9% for marker-paper, 9% for stylus-tablet, and 43% for finger-tablet.

Parents (on behalf of their child) and adult participants also indicated enjoyment of drawing using traditional materials (e.g., crayons, markers, or pencils on paper) and electronic materials (e.g., stylus or finger on tablet computer) on a scale from 0 (not at all) to 10 (favorite activity). Finally, the survey respondents indicated how long a typical drawing session lasts before moving on to another activity when using traditional materials versus electronic materials. The latter question regarding the duration of drawing episodes was of particular interest because it was designed to capture not only the frequency of drawing but also the degree of engagement in drawing.

Developmental milestones—The ASQ-3 is a 30-item, parent-report assessment of the developmental progress of a young child across five domains: communication, fine motor, gross motor, problem solving, and personal-social. According to Squires and Bricker (2009), the ASQ-3 demonstrated strong test-retest reliability, strong inter-observer reliability, acceptable internal consistency among items, and high concurrent validity with other standardized tests. While the ASQ-3 is often used as a developmental screening tool, in the present study we used quantitative scores to examine differing levels of performance among a typically developing sample. Of particular interest in the current study were the fine- and gross-motor subscales. Parents completed the version of the scale that corresponded to their child's chronological age, responding to questions about their child's achievement of age-appropriate milestones (e.g., "Does your child walk well and seldom fall?") by indicating, "Yes," "Sometimes," or "Not Yet." Scores within each domain range from 0–60, with higher scores indicative of greater developmental achievement.

Coding Shape Quality

We used a 5-point coding scheme adapted from Braswell, Rosengren, and Pierroutsakos (2007). Exemplars are presented in Figure 1. Each drawing was rated by two blind observers who did not know the study purpose, design, or conditions. Drawings that consisted primarily of scribbles or dots with no discernable shape were coded as a 0. All other drawings were given a subjective quality score ranging from 1 to 4. Drawings that were recognizable as a shape but not necessarily the prototype shape were coded as a 1. Drawings that were recognized as the prototype shape but varied greatly from the prototype shape in terms of orientation, angles, or proportions were scored as a 2. Drawings that varied from the prototype only marginally were scored as a 3. Drawings that were close copies of the prototype shape were coded as a 4. Mirror images or inverted images (i.e., rotated 180 degrees) that were otherwise high quality were given a score of 3. Cohen's Kappa was .85 (linear weighted for ordinal data), indicating substantial agreement between raters. Large discrepancies between raters were resolved by discussion and consensus; otherwise the more experienced rater's code was used.

Results

Descriptive Statistics and Drawing Outcome Measures

The current study was designed to test the quality of children's drawings using different mediums. Children copied both familiar and novel shapes using each of three mediums. The frequencies of quality scores for children and adults are shown in Figure 2. Given that the range of quality scores was narrow (0–4) and the scores were not normally distributed (see Figure 2), we created two dichotomous dependent variables reflecting whether each drawing was codable (i.e., score greater than zero) and whether each codable drawing was of high quality (defined in the following paragraphs).

Of the 1,264 shape drawings children produced, 62% were codable (i.e., quality score greater than 0). The majority (81%) of children produced at least one codable drawing. Overall, there were more codable drawings for familiar shapes (79%) than for novel ones (58%). The percent of drawings that were codable varied slightly for marker (61%), stylus (59%), and finger drawings (66%). For comparison, 100% of adults' drawings were codable.

The other dependent variable was the likelihood that a codable drawing was deemed to be of high quality. For children, high-quality drawings were defined as a quality score of 3 or greater on the 1–4 scale. Of the 784 codable shapes that children produced (i.e., score greater than 0), 28% (n = 218) were deemed to be of high quality (i.e., score of 3 or greater). About half (49%) of children produced at least one high-quality drawing. Across all children, the percent of high-quality drawings was 31% for marker, 27% for stylus, and 25% for finger drawings. Across medium, the rate of high-quality drawings was 39% for familiar shapes and 34% for novel ones.

For comparison, nearly all (98%) of adults' 432 drawings received a score of 3 or 4, with the remaining 2% of drawings earning a score of 2. Given the overall high quality of adults' drawings, a more stringent criterion was applied, with only those drawings receiving a perfect score of 4 being categorized as high quality. Using this more stringent criterion, 63% of adults' drawings were high-quality. All adults produced at least one high quality drawing. Overall, adults received a perfect score for 74% of marker drawings, 63% of stylus drawings, and 51% of finger drawings. With respect to shape novelty, the percent of high-quality drawings for adults was 74% for novel shapes and 57% for familiar ones.

Correlations Between Child Characteristics and Drawing Outcomes

A secondary goal of the current study was to identify potential correlates of children's drawing outcomes. Variables of interest included age and gender, grip and pinch strength (directly measured), motor achievement (parent report), and drawing experience with traditional and electronic materials (parent-reported frequency, enjoyment, and duration). To streamline analyses, drawing frequency scores were summed to create an aggregate score for drawing with traditional materials (using markers, crayons, pens, or pencils on paper) and for drawing with electronic materials (using a finger or stylus on a touchscreen device). Given the low frequency of codable drawings for the youngest children, correlations were calculated for children 3.0 years of age and older. Table 1 presents correlations with the two drawing outcomes: proportion of drawings that were codable and average score of codable drawings.

Age was positively correlated with all of the dependent variables. Hand strength (both grip and pinch) was positively correlated with most of the dependent variables; however, many of these correlations became non-significant after controlling for age. The only correlation for hand strength that remained significant after controlling for age was between pinch strength and average shape quality for marker-and-paper drawings, $r(74) = .32$, $p = .025$.

Parent-reported fine-motor achievement (but not gross-motor achievement) and duration of drawing episodes with traditional (but not electronic) materials were associated with most of the dependent variables. Moreover, parent-reported drawing frequency with traditional (but not electronic) materials was associated the proportion of codable shapes produced by children. Unlike pinch and grip strength, most of these correlations remained even after controlling for age.

Fine-motor achievement was at least marginally correlated with the proportion of drawings that were codable [marker-paper: $r(29) = .53$, $p = .002$; stylus-tablet: $r(29) = .59$, $p < .001$; finger-tablet: $r(29) = .54$, $p = .002$] and the average quality of codable drawings [marker-paper: $r(29) = .36$, $p = .049$; stylus-tablet: $r(29) = .35$, $p = .054$; finger-tablet: $r(29) = .43$, $p = .015$].

As with fine-motor achievement, the duration of drawing episodes with traditional materials was at least marginally correlated with the proportion of drawings that were codable for all mediums [marker-paper: $r(26) = .35$, $p = .072$; stylus-tablet: $r(26) = .35$, $p = .065$; finger-tablet: $r(26) = .49$, $p = .009$] and the average quality of codable shapes for two mediums [marker-paper: $r(26) = .60$, $p = .001$; stylus-tablet: $r(26) = .35$, $p = .067$; finger-tablet: $r(26)$

= .31, p = .104]. Similarly, the frequency of drawing episodes with traditional materials was correlated with the proportion of drawings that were codable for two mediums [marker-paper: $r(26) = .43$, $p = .03$; finger-tablet: $r(26) = .41$, $p = .03$]. Put together, the correlational results indicate that both the frequency and duration of drawing episodes with traditional materials at home are correlated with the likelihood that children produce codable drawings in the lab, but only the duration of those naturalistic drawing episodes is correlated with the subjective quality of drawings that were produced in the lab.

Correlations between different mediums within each drawing measure (not shown in Table 1; e.g., quality of shapes produced using marker versus stylus versus finger) were positive and highly significant (all *r*s > .58, all *p*s < .001), reflecting at least some consistency within individuals when using different mediums.

Impact of Medium and Novelty on the Probability that Drawings Were Codable

We employed hierarchical linear modeling (HLM) to simultaneously consider variability in drawing quality within and between child participants. The first outcome variable was whether each shape was codable (i.e., score greater than 0). Because the outcome variable was dichotomous, we utilized Bernouli (binomial outcome) HLM. The within-subject (Level 1) predictors were medium (reference category: marker-paper; coded categories: stylus-tablet, finger-tablet) and shape novelty (reference category: familiar; coded category: novel). A subsequent model indicated that there were no significant interactions between the two tablet conditions and novelty (*p*s > .25), so these within-subject interaction effects were excluded from the final model. The between-subject (Level 2) predictors were age (years, mean-centered) and gender (reference category: male; coded category: female). Fixed effects are shown in Table 2. The predicted probability of a codable drawing as a function of age, gender, medium, and novelty is plotted in Figure 3.

Marker—The intercept for the model reflected the predicted value when all predictors were equal to zero: that is, boys (gender = 0) at the mean age of 3.75 years (mean-centered age = 0) drawing familiar shapes (novelty = 0) with a marker (stylus and finger = 0). All other effects in the model can be interpreted in comparison to this reference group of mean-aged boys drawing familiar shapes with a marker. There were main effects of age and gender such that older children and girls produced more codable drawings than did younger children and boys (at least when they copied familiar shapes with a marker), $ß_{01} = 2.31$, $t(70) = 10.70$, $p < .001$ and $ß_{02} = 0.85$, $t(70) = 2.16$, $p = .034$, respectively.

Stylus—The main effect of stylus tested whether the stylus condition differed from the reference (marker) condition when all other predictors equaled zero (i.e., mean-aged boys drawing familiar shapes). The main effect of stylus was not significant ($p > .25$), indicating that children in the reference group (mean-aged boys) were just as likely to produce a codable familiar shape when using a marker or a stylus. The interaction terms between stylus and child characteristics (age, gender) represent the extent to which the difference between the stylus and marker conditions varied by age and gender. These interactions were not significant (*p*s > .10), meaning that, as with marker drawings, stylus drawings were more likely to be codable when produced by older children and girls than younger children and boys, respectively.

Finger—Similarly, the main effect and interactions for the finger condition tested for differences between the rate of codable drawings for finger and marker conditions. There was a significant main effect such that the reference group (mean-aged males) produced more codable familiar shapes when drawing with their finger than with a marker, $ß_{10} = 0.63$, $t(1182) = 2.81$, $p = .005$. However, a significant finger-by-age interaction indicated that this condition effect decreased with age, $ß_{11} = −0.44$, $t(1182) = −2.30$, $p = .021$. Additionally, a significant finger-by-gender interaction indicated that this condition effect was not evident for girls, $ß_{12} = −0.86$, $t(1182) = −3.02$, $p = .003$. In other words, younger boys produced more codable drawings with their finger than with a marker, whereas older children and girls produced just as many codable drawings in these two conditions.

Novelty—The main effect of novelty represents the difference between familiar and novel shapes for the reference group (i.e., mean-aged boys drawing with a marker). This main effect was not significant ($p > .10$), but there was a significant novelty-by-age interaction, $ß_{31} = 0.64$, $t(1182) = 3.26$, $p = .001$. The novelty effect was such that younger (but not older) boys were less likely to produce codable copies of novel shapes than familiar ones. The novelty-by-gender interaction was not significant ($p > .25$), indicating that the size of the novelty effect was statistically similar for mean-aged boys and girls.

Summary—To summarize, 62% of children's 1,264 drawings were codable (i.e., given a quality score greater than zero). By comparison, 100% of adults' drawings were codable. The rate of codable shapes for children did not differ significantly between the marker and stylus conditions. In both cases, the probability of a codable shape increased with age and was greater for girls than for boys. The only case in which boys produced as many codable shapes as girls was for young children while drawing with their finger. This advantage for finger drawings was not seen for older children or for girls, who were equally likely to produce a codable drawing with all mediums. Additionally, younger children were more likely to produce codable copies of familiar shapes than novel ones.

Impact of Medium and Novelty on the Probability that Drawings Were High-Quality

Children's drawings—An analogous binomial HLM model tested for effects of medium, novelty, age, and gender on the probability that children produced a high-quality drawing (i.e., score of 3 or greater). Fixed effects are shown in Table 2. The predicted probability of a high-quality drawing as a function of age, medium, and novelty is plotted in Figure 4. The probability of a high-quality score increased with age, $ß_{01} = 1.36$, $t(56) = 4.54$, $p < .001$. Additionally, there was a novelty-by-age interaction such that novelty had a negative effect for the youngest children and a positive effect for oldest children, $ß_{31} = −0.21$, $t(721) = 3.15$, $p = .002$. There were no main effects or interactions involving gender or medium (ps > .10).

Adults' drawings—For comparison, the observed proportion of adults' high-quality drawings is plotted in Figure 4 as a function of medium and novelty. Given the small size of the adult sample, we examined the overall proportion of drawings that were high quality (i.e., a perfect score of 4) for each medium and for familiar versus novel shapes, rather than fitting a hierarchical model to individual drawings. Adults produced more high-quality drawings with a marker or stylus than with their finger [marker-finger: $t(23) = 4.18$, $p < .001$; stylus-finger: $t(23) = 2.11$, $p = .046$], and the rate of high-quality drawings was marginally higher for marker drawings than stylus drawings [$t(23) = 2.00$, $p = .057$]. Moreover, as with older children, there were more high-quality copies of novel shapes than familiar ones [$t(23) = 2.89$, $p = .008$]. The condition-by-novelty interaction was not significant ($p > .250$).

Summary—Twenty-eight percent of children's codable drawings and 63% of adult's codable drawings received a high-quality score (3 or 4 for children, 4 for adults). The likelihood that children received a high score increased with age. Both older children and adults produced more high-quality copies of novel shapes than familiar ones. Additionally, there were significant effects of medium for adults only, with adults producing more high-quality drawings when using an implement than when using their finger.

Medium Selection

At the end of the session, participants were invited to draw anything they wanted using a medium of their choice. The experimenter recorded whether participants selected a paper or tablet as their drawing surface. If the tablet was chosen, the experimenter also noted whether participants chose to draw with the stylus or with their finger. See Figure 5 for observed frequencies for selecting each surface and implement for children and adults.

Three children chose not to complete the free draw task and therefore did not select a medium (one 2-year-old girl, two 3-year-old boys). Of the remaining children, the majority (79%) chose to draw with a tablet rather than paper. Of the children who chose to draw on the tablet computer, the majority (60%) chose to draw with the stylus rather than their finger. Whether children chose to draw on a tablet (versus paper) or to draw with their finger (versus stylus) was not correlated with the proportion of drawings that were codable or the subjective quality of codable drawings for any medium (all *r*s between −.20 and .20; all *p*s > .200). Moreover, medium selection was not predicted by child age (*p*s > .20).

By comparison, only 29% of adults chose to draw on the tablet computer rather than paper. Of the minority who chose to draw on the tablet, 100% drew with a stylus rather than their finger.

Discussion

The purpose of this study was to compare the quality of children's drawings using traditional and electronic materials, to examine how drawing using different mediums differs by age during early childhood, and to identify potential correlates of children's drawing quality. These research questions have practical significance given the rise in young children's use of digital media for creative endeavors, the broad range of skills for which drawing has been used as a proxy or indicator, and the increasing interest in using digital media in clinical assessment and intervention. We found that the quality of drawings produced by both children and adults depends in part on the medium used to produce those drawings, and that the quality of children's drawings is correlated with a range of personal characteristics including age, gender, and parent-reported fine motor skill and duration of drawing episodes at home.

Effect of Medium on Drawing Quality

Our primary research question dealt with the extent to which children's drawings differed when produced using traditional materials (marker on paper) versus electronic materials (stylus or finger on a touchscreen tablet computer). We found a different pattern of results for our two dependent variables: the likelihood that children produced a codable drawing and the subjective quality of codable drawings. Specifically, younger preschoolers (and particularly younger boys) were more likely to produce a codable drawing when using their finger on a tablet computer than when using either a marker or stylus. In most cases, girls (versus boys) produced more codable drawings, which is consistent with our finding that parents reported higher fine motor development for girls than for boys. However, the gender gap in producing codable drawings was reduced when younger boys were asked to draw shapes with their finger than with a marker or stylus. Thus, it seems that drawing with a finger requires less motor control than drawing with an implement (marker, stylus), enabling children in our sample with relatively low fine motor skill (younger children, boys) to produce more codable drawings (Braswell & Rosengren, 2008). This is consistent with previous research demonstrating that preschool-age children draw more continuous marks and show greater gains in letter writing when using their finger on a touchscreen than when using other mediums (Patchan & Puranik, 2016; Price et al., 2015).

While drawing with their finger did seem to increase the younger children's ability to produce drawings, this advantage did not translate into producing higher-quality images. On the contrary, the likelihood that children would produce a high- (versus low-) quality drawing did not differ as a function of drawing medium. This finding differs from Gerth et al. (2016), perhaps because the youngest age included in their study was the oldest age in our sample (5 years). It seems that among novice drawers (i.e., younger preschool-age children), medium is more likely to affect whether a representational drawing is produced at all rather than the quality of the produced drawings, at least when children copy simple shapes.

Conversely, medium did affect the quality of drawings produced by more experienced drawers. In the current study, there were significant medium effects on the subjective quality of adults' drawings, favoring more traditional materials (marker-paper) over digital ones (especially finger on tablet). Gerth et al. (2016) reported the same effect for children copying simple shapes and adults copying a written phrase, with higher accuracy for pen-and-paper drawings than for stylus-and-tablet drawings. This may be due to our participants' varying experience using each medium to write and draw: it is likely that adults in particular have more experience drawing on paper (versus a tablet computer) and with an implement (versus their finger). Additionally, it may be that the touchscreen surface itself produces lower-quality drawings. For instance, the touchscreen surface may not lend itself to drawing sharp corners on squares, and the reduced friction of a glass surface may alter the drawing process (Gerth et al., 2016). It is important to note that we observed effect of medium on simple shape copies. Other differences may emerge for more complex drawing tasks, such as drawing a house from memory (Picard et al., 2014).

Effect of Shape Novelty on Drawing Quality

Notably, the impact of shape novelty differed for younger versus older drawers. Younger children produced more codable drawings when copying familiar shapes such as circles and squares than when drawing novel shapes, regardless of medium. On the other hand, older children and adults (who reliably reproduced both novel and familiar shapes) were more likely to produce high-quality copies of novel shapes than familiar ones, regardless of medium.

It is likely that differences between familiar and novel shapes are due to the extent to which participants had an existing motor plan for creating each shape. This task would have been particularly challenging for the youngest children in the sample with relatively little drawing experience. For these children, having an established motor plan for producing common shapes likely helped them to produce shapes rather than simple scribbles or dots. For older children and adults, perhaps well-rehearsed motor plans (e.g., for drawing a circle) resulted in more carelessness when producing shapes. In other words, older children and adults may have relied more heavily on their own schema for a prototypical shape than on the prototype that was actually shown when drawing the familiar shapes. On the other hand, copying a novel shape requires participants to carefully encode and reproduce the shape in front of them, rather than relying on existing motor plans. Thus, in producing the novel shapes, older children and adults may have devoted greater attention to examining the shape and to the motor actions required to produce the novel shape. In this way, the drawing context influenced the importance of different cognitive and motor components (Braswell & Rosengren, 2008). Gerth et al. (2016) had a similar interpretation of their finding that adults produced higher-quality copies of their simplest patterns (e.g., wavy line) when using a stylus than when using a pen, while they found the reverse when adults copied the most complex pattern (a written phrase).

We predicted that the impact of medium would be greater for novel shapes than familiar ones, given that drawers would lack a motor schema for reproducing novel shapes and would therefore have to invest greater mental effort. However, unlike Gerth et al. (2016), we did not find that the impact of medium varied by drawing activity. This is likely because the novel shapes used in this study were adapted from the familiar shapes (e.g., same line number and orientation), and thus required a similar degree of motor control. Conversely, the drawing activities in Gerth et al. likely required very different processes (e.g., copying a wavy line, a circle, and a written phrase). Thus, it would seem that in the current study the impact of medium is likely due to a main effect of the medium on the physical constraints on drawing (e.g., reduced friction; Gerth et al., 2016) rather than acting on the cognitive component of motor planning.

Drawing Correlates and Medium Selection

The drawing outcomes that we measured in the current study were correlated with parents' reports of their child's fine motor milestone achievement and their child's duration of drawing episodes (with traditional materials) at home. Thus, it seems that the shape-copying task used in the current study is capturing meaningful variability in children's experiences and skills. However, it is important to note that less than two-thirds of parents returned the survey, so these correlational findings are based on a relatively small sample of children.

We also observed age differences in the mediums that children and adults selected for the free-draw task. Specifically, children were more likely to select a tablet than a piece of paper, which contradicts parents' reports that their children are less engaged and have less enjoyment when drawing with digital materials than when drawing with traditional materials. Adults, on the other hand, rarely chose to draw on a tablet computer (versus paper), and when they did, they always chose to draw with a stylus rather than their finger. The medium that children chose for a free-draw task was not correlated with the quality of their drawing products using any medium, so children do not appear to select a medium that is easiest to use or that allows them to produce high-quality drawings.

Given the cross-sectional nature of this study, it is impossible to determine the extent to which age-related differences were due to generational cohort effects. Unlike our adult participants, who likely had little (if any) exposure to touchscreen devices during their preschool years, our child participants live in a society in which nearly all young children have access to at least one mobile touchscreen device (Rideout, 2017). It may be that "digital natives" (i.e., children who grow up in technology-saturated environments; Prensky, 2001) will be more likely to choose to draw with a tablet computer, even as adults. Only time will tell whether the age differences observed in the current study persist over time.

Practical Implications

The need to better understand how touchscreens affect children's drawing is underscored by anecdotal reports suggesting that tablets are being used in educational, diagnostic, and intervention settings, perhaps because such devices are believed to be particularly motivating for children. For instance, many early childhood educators report using touchscreen technology in their classrooms (Blackwell, Lauricella, Wartella, Robb, & Schomburg, 2013), and touchscreen applications have been used with some success to help preschool-age children learn to write letters (Patchan & Puranik, 2016).

Similarly, a poll of occupational therapists reported that over half of the respondents used tablets and apps (i.e., mobile applications) in their clinical assessments (Yamkovenko, 2012). Reflecting the use of touchscreens in clinical practice, online resources have been developed to instruct occupational therapists on integrating tablet use in their clinical practice with different populations ("OT's with Apps," 2018) and provide guidelines for optimally matching touchscreen applications with client needs (Erickson, 2015; Ravenek & Alvarez, 2016).

While there appears to be increasing interest in using apps as an educational and intervention tool, minimal evidence exists regarding how tablets and associated apps are actually utilized in these settings with children. Furthermore, it is potentially problematic to use drawings produced on electronic media in either diagnostic or intervention settings prior to assessing the impact of different mediums on drawing output, as this could potentially invalidate the diagnosis or intervention. Our findings suggest that for young children, the type of medium used has relatively little impact on the quality of drawings that children produce, at least when they copy simple shapes. However, children may prefer drawing on a tablet computer than on paper, and (at least for younger boys) drawing with a finger on a tablet may be the best way to elicit drawings.

Limitations and Future Directions

The current findings should be interpreted in light of some limitations and directions for future research. One notable limitation is the homogeneity of the convenience samples; the child and adult samples are not representative of the general population, limiting generalizability of the findings. Another potential limitation is the reliance on a subjective coding scheme for evaluating drawing quality. Although interrater reliability was high, this approach was time-consuming. Future research may capitalize on more objective measurement methods, such as using a custom drawing application to calculate the deviance between a drawing prototype and copies produced by participants.

While increasing internal validity, the experimental nature of the study limits external validity. Future research would be needed to determine how children's drawings might differ across mediums in more naturalistic settings. For instance, the current protocol required children to draw the same images (copies of simple shapes) using each of the three mediums, constraining the specific types of differences that might be seen across mediums. It remains to be seen whether other differences would emerge in unconstrained free-draw tasks using each of the three mediums. Similarly, we opted for high internal validity by constraining the mediums (e.g., equating the color and thickness of lines produced with the market versus on the tablet; equating the size, shape, and weight of the marker versus stylus). Future research could examine how children draw using a wider range of mediums (e.g., finger-painting on paper; selecting a familiar writing implement).

Conclusion

Young children's growing access to touchscreen technology represents one of many contextual factors that may have direct and transactional influences on development (e.g., Bronfenbrenner & Ceci, 1994; Sameroff, 2009). Thus, researchers must gain a better understanding of the impact of touchscreens. In the short term, the impact of touchscreens on drawing has real-world implications, given the widespread use of touchscreen devices in early education (Blackwell et al., 2013) and clinical assessment and practice (e.g., "OT's with Apps," 2018; Yamkovenko, 2012). Our findings suggest that the use of tablet computers may increase drawing accessibility or motivation for younger children, with relatively little impact on the quality of drawings that are produced (despite effects for adults).

In the long term, touchscreens may add to or displace more traditional forms of drawing and writing on paper, creating the potential for cascading impacts (for good or ill) on the development of drawing and writing specifically and fine motor skills generally. Such consequences may not be all bad if using a tablet makes drawing and writing more accessible to children with poor fine motor skills, providing opportunities to practice such skills. Indeed, touchscreen applications have been used successfully to teach young children to write letters (Patchan & Puranik, 2016), and one correlational study found that parents' retrospective reports of their infants' early, active touchscreen use (i.e., scrolling) were positively associated with infants' achievement of a fine motor milestone but not a gross motor or language milestone (Bedford, Saez de Urabain, Cheung, Karmiloff-Smith, & Smith, 2016). It remains to be seen whether such associations hold – or whether other unintended consequences exist – in prospective longitudinal studies of early touchscreen use.

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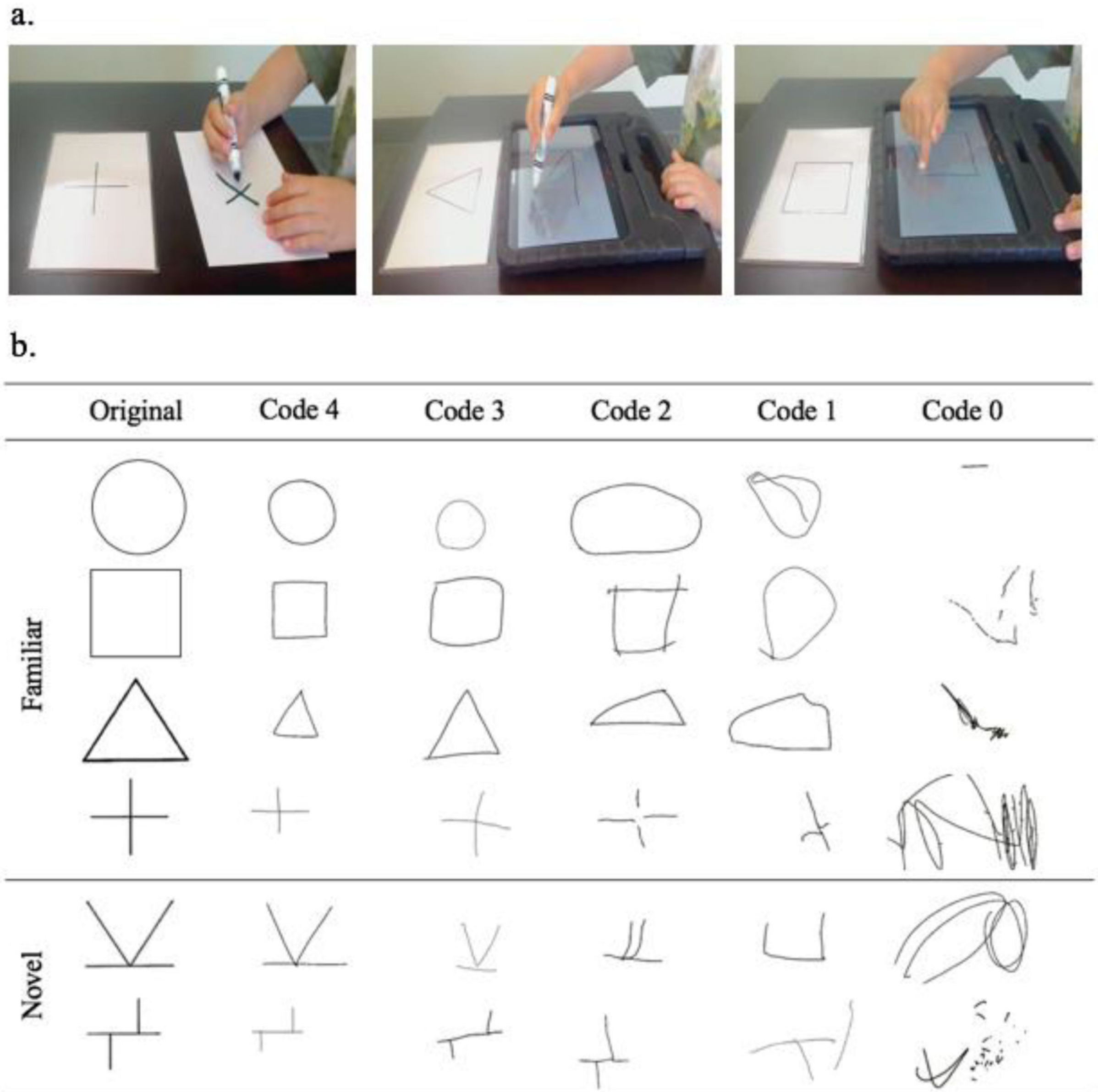

Figure 1.

(a) Child copying a familiar shape using a marker on paper (left), the stylus on a tablet (middle), and their finger on a tablet (right). (b) Original shapes used in the shape-copying task (left column) and exemplars of drawings receiving each quality code (decreasing quality from left to right); a score of zero indicated an uncodable drawing.

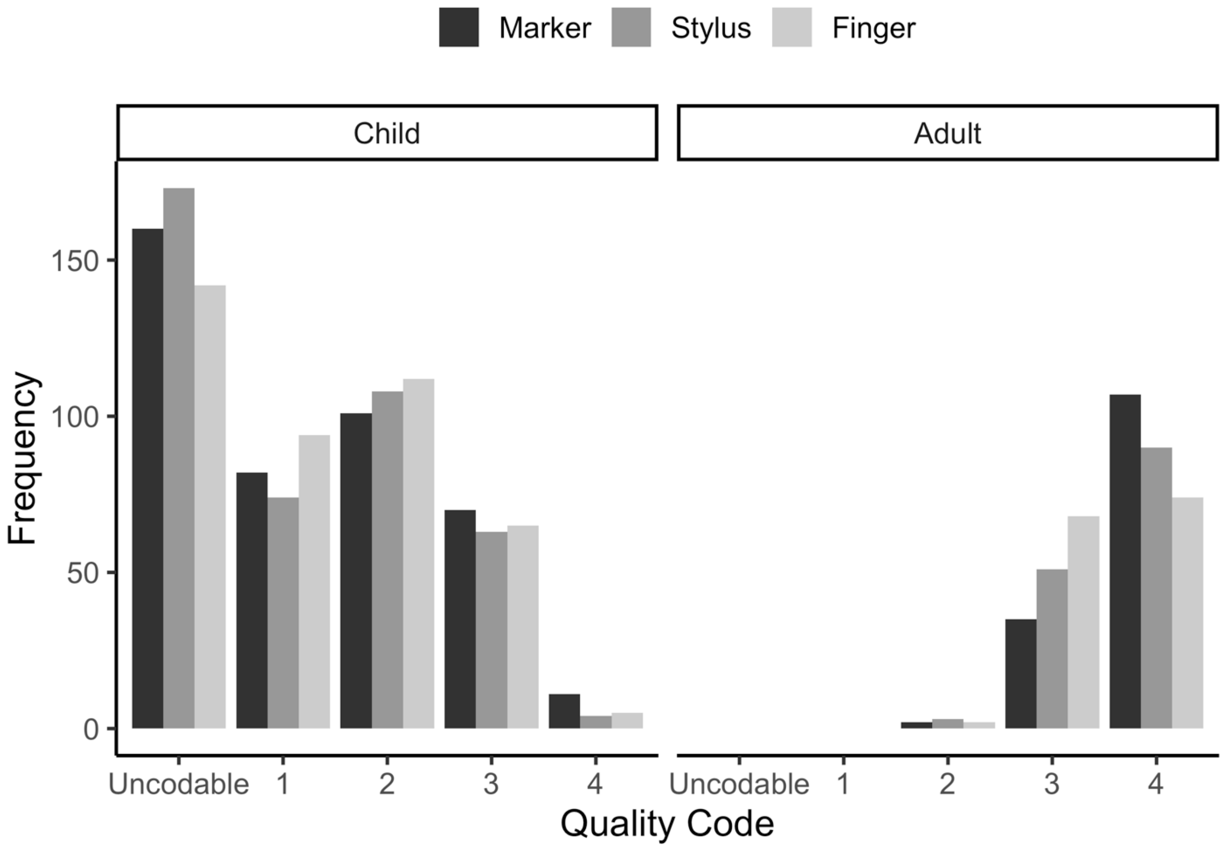

Figure 2.
Frequency of each quality score for children (left, $N = 73$) and adults (right, $N = 24$) as a function of medium.

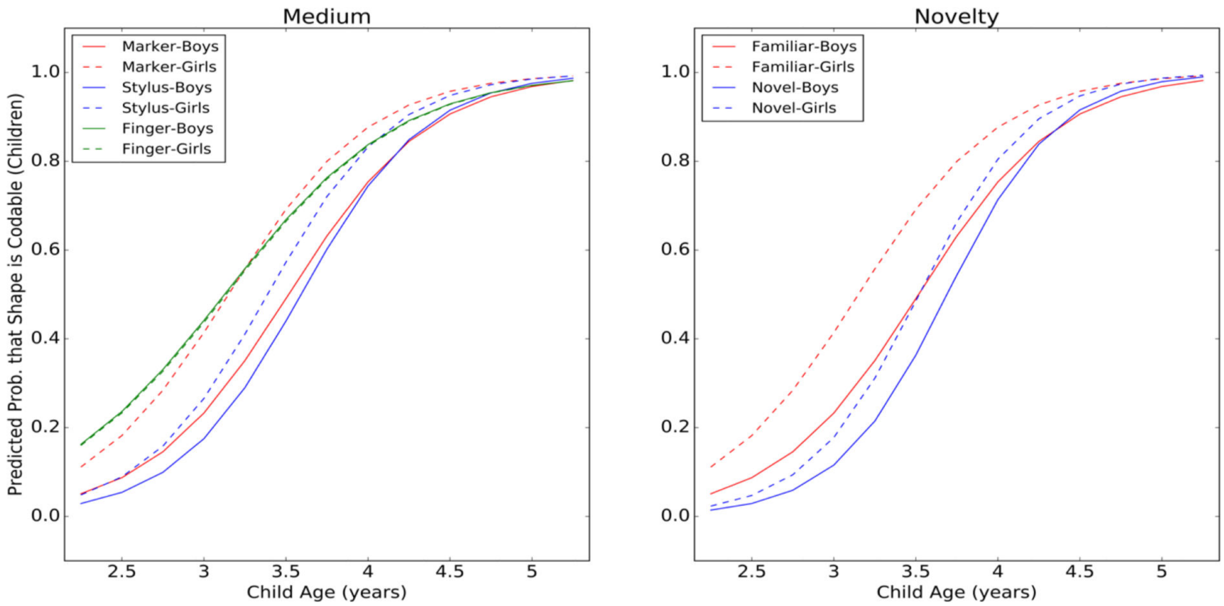

Figure 3.
Predicted probability of a codable shape for children as a function of age, gender, and medium (left) or novelty (right) ($N = 73$).

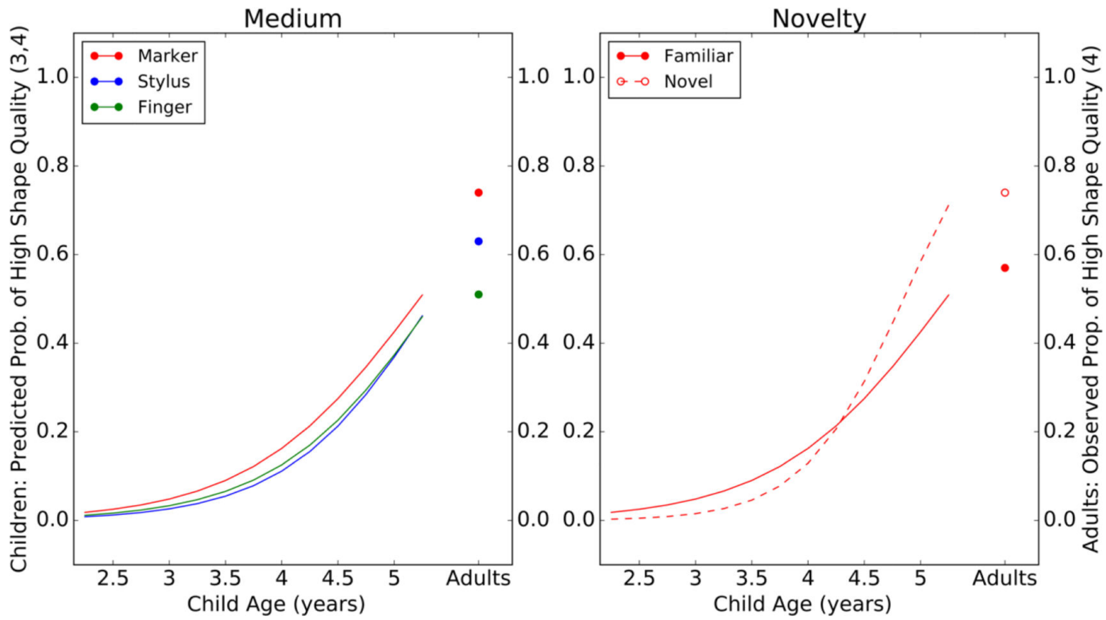

Figure 4.

Predicted probability of high shape quality for children as a function of age and medium (left) or novelty (right) (N = 59). The observed value for the adult group (N = 24) is shown for comparison.

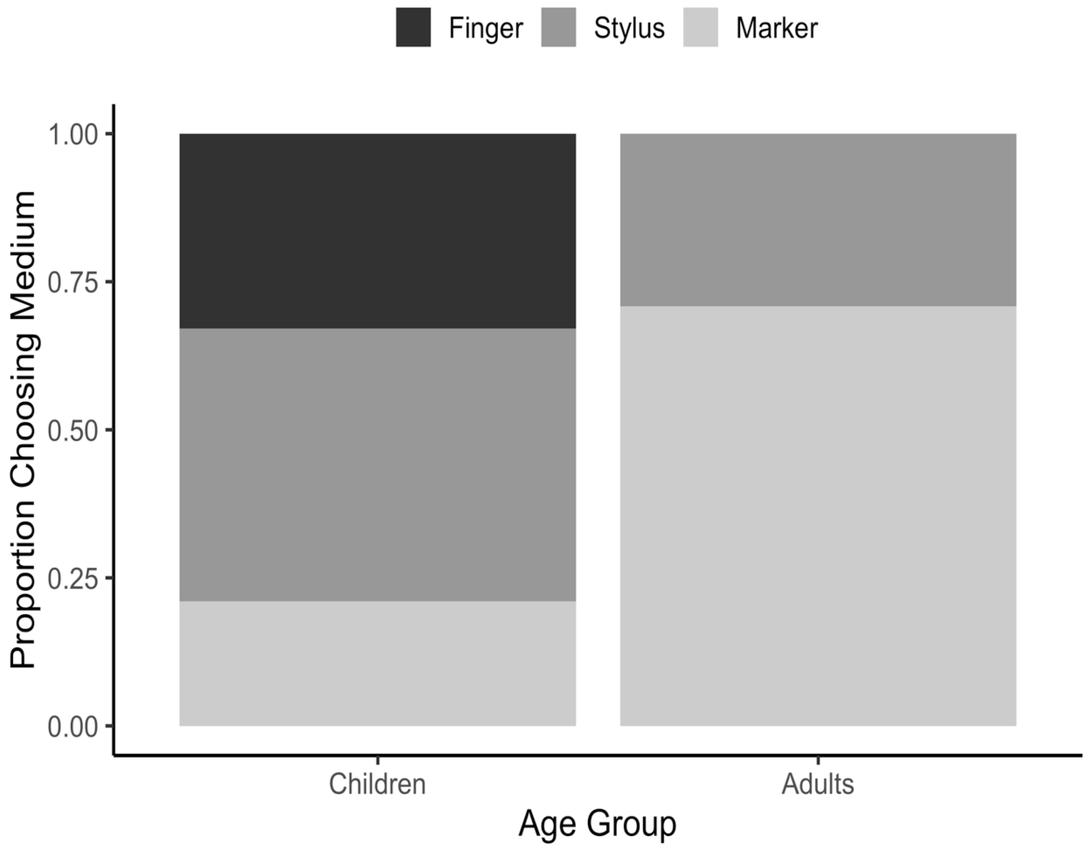

Figure 5.
Proportion of children and adults who selected each medium during free draw.

Table 1

Zero-order Correlations (and First-order Correlations Controlling for Age) Between Child Characteristics and Drawing Outcomes

			Hand Strength		Motor Achievement		Drawing Frequency		Drawing Enjoyment		Drawing Duration	
	Age	Gender	Grip	Pinch	Fine	Gross	Trad.	Elec.	Trad.	Elec.	Trad.	Elec.
Proportion of drawings that were codable												
Marker	.53*	.27 (.25)	.38* (.10)	.34* (.14)	.62* (.53*)	.05 (.15)	.43* (.31*)	.24 (−.04)	.06 (−.15)	.26 (.12)	.49* (.35*)	.20 (.13)
Stylus	.58*	.25 (.22)	.35* (.02)	.31* (.08)	.67* (.59*)	<.01 (.10)	.34* (.18)	.26 (−.05)	.09 (−.13)	.36* (.24)	.50* (.35*)	.13 (.04)
Finger	.42*	.20 (.17)	.27 (.04)	.33* (.18)	.61* (.54*)	.15 (.24)	.41* (.31*)	<.01 (−.28)	.17 (.03)	.14 (.01)	.58* (.49*)	.11 (.04)
Average quality of codable drawings												
Marker	.69*	−.08 (−.22)	.31* (−.15)	.52* (.32*)	.51* (.36*)	<.01 (.14)	.34* (.15)	.27 (−.13)	.40* (.25)	.25 (.05)	.69* (.60*)	.31* (.27)
Stylus	.69*	−.07 (−.22)	.28 (−.21)	.45* (.22)	.50* (.35*)	.05 (.21)	.17 (−.11)	.17 (−.29*)	.32* (.14)	.25 (.06)	.52* (.35*)	.13 (.01)
Finger	.74*	.06 (−.04)	.28 (−.26)	.49* (.26)	.56* (.43*)	.07 (.26)	.26 (.01)	.30* (−.14)	.34* (.15)	.35* (.19)	.50* (.31*)	.18 (.07)

Note: Only children 3 years and older are included because of the low rate of codable drawings among the youngest children. Columns are child age; gender; grip and pinch strength (directly observed); fine and gross motor achievement (parent reported using ASQ-3); aggregated parent-reported drawing frequency with traditional and electronic drawing materials, parent-reported enjoyment of drawing with traditional and electronic materials, and parent-reported duration of drawing episodes with traditional and electronic drawing materials. Rows are the proportion of drawings (out of six) that were codable for each medium and the average quality of codable shape drawings for each medium. Degrees of freedom range from 47–50 for age and hand strength, and from 26–32 for parent-reported motor and drawing variables. N = 48 to 50 for directly observed variables (age, hand strength); N = 28 to 32 for parent-reported variables (motor achievement, drawing). Cells shaded with lighter gray are for significant zero-order correlations that become nonsignificant after controlling for age; cells shaded with darker gray are for significant first-order correlations that remain significant after controlling for age.

* $p < .05$

Table 2

Fixed Effects from Final Mixed Logit Models Predicting the Probability of a Codable Drawing (Left) and a High-Quality Drawing (Right)

	Model 1: Codable Drawing			Model 2: High-Quality Drawing		
Predictor	***B (SE)***	***t*-ratio**	**OR (95% CI)**	***B (SE)***	***t*-ratio**	**OR (95% CI)**
Intercept (β_{00})	0.54 (0.29)	1.86	1.72 (0.96, 3.06)	−1.69 (0.53)	−3.21 **	0.19 (0.06, 0.53)
Age (β_{01})	2.31 (0.22)	10.70 ***	10.07 (6.55, 15.50)	1.36 (0.30)	4.54 ***	3.89 (2.14, 7.10)
Gender (β_{02})	0.85 (0.39)	2.16 *	2.33 (1.07, 5.09)	−0.47 (0.55)	−0.85	0.62 (0.21, 1.89)
Stylus (β_{20})	−0.13 (0.19)	−0.66	0.88 (0.61, 1.28)	−0.58 (0.48)	−1.21	0.56 (0.22, 1.43)
Stylus * Age (β_{21})	0.31 (0.21)	1.45	1.36 (0.90, 2.07)	0.19 (0.34)	0.57	1.21 (0.63, 2.34)
Stylus * Gender (β_{22})	−0.31 (0.24)	−1.29	0.73 (0.46, 1.18)	0.14 (0.50)	0.30	1.16 (0.43, 3.11)
Finger (β_{10})	0.63 (0.22)	2.81 **	1.88 (1.21, 2.92)	−0.59 (0.41)	0.13	0.55 (0.26, 1.18)
Finger * Age (β_{11})	−0.44 (0.19)	−2.30 *	0.64 (0.45, 0.94)	0.45 (0.53)	0.86	1.06 (0.47, 2.39)
Finger * Gender (β_{12})	−0.86 (0.29)	−3.02 **	0.42 (0.24, 0.74)	0.45 (0.53)	0.86	1.57 (0.56, 4.43)
Novelty (β_{30})	−0.36 (0.31)	−1.16	0.69 (0.38, 1.29)	−0.21 (0.53)	−0.40	0.81 (0.29, 2.28)
Novelty * Age (β_{31})	0.64 (0.20)	3.26 **	1.89 (1.29, 2.78)	1.03 (0.33)	3.15 **	2.80 (1.47, 5.31)
Novelty * Gender (β_{32})	−0.34 (0.37)	−0.92	0.71 (0.34, 1.47)	−0.60 (0.45)	−1.34	0.55 (0.23, 1.32)

Note: The dependent variables were dichotomous indicators of whether each of the children's drawings was codable and whether each codable drawing was high quality (score of 3 or 4). The within-subject predictors were medium (marker as reference condition, stylus and finger conditions entered as dummy-coded variables) and novelty (0 = familiar, 1 = novel). The between-subject predictors were child age (years, mean-centered) and gender (0 = male, 1 = female). OR = odds ratio. CI = confidence interval.

* $p < .05$.

** $p < .01$.

*** $p < .001$.