Gregory S. Braswell
Department of Psychology
Illinois State University, Normal
IL 61790-4620
E-mail: gsbrasw@ilstu.edu

Karl S. Rosengren
Departments of Kinesiology & Psychology
University of Illinois
Urbana-Champaign, Urbana, IL
E-mail: krosengr@cyrus.psych.uiuc.edu

Sophia L. Pierroutsakos
Department of Behavioral Sciences
Saint Louis Community College
St. Louis, MO
E-mail: SPierroutsakos@stlcc.edu

Task Constraints on Preschool Children's Grip Configurations during Drawing

ABSTRACT: *Traditional accounts of motor development have described the development of grip configurations in terms of a global maturational change from immature to mature grips. We present data that demonstrate that the grip configurations of preschool-aged children are greatly influenced by task demands and are more variable than previous research has suggested. Grip configurations were most variable during free drawing. Three- to 4-year-olds with highly variable grips produced poorer quality drawings in a shape copying task than children with relatively stable grips. It is argued that the study of the development of drawing skills may best be captured by an approach which emphasizes the role of task requirements and various external and internal constraints which shape variability in grip configurations. ©2007 Wiley Periodicals, Inc.* Dev Psychobiol 49: 216–225, 2007.

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INTRODUCTION

Drawing is a complex motor skill that has long captured the attention of parents, teachers, and child development researchers. Much of the past research in this area has focused on what children draw, that is, the end product, rather than the drawing process itself. Indeed, vast quantities of children's drawings have been collected, which have led to detailed descriptions of what children at different ages draw (e.g., Cox, 1992; Eng, 1954; Gardner, 1980; Goodnow, 1977; Kellogg, 1969; Willats, 1977).

Despite the overwhelming emphasis on product over process, the act of drawing itself has received some attention by developmentalists. For example, Freeman (1977) has described the compositional strategies young children use to plan the construction of human figures. Others have outlined typical sequences of strokes used to create basic geometric shapes (Braswell & Rosengren, 2000, 2002; Gesell & Ames, 1946; Goodnow & Levine, 1973) showing that young children often use different sequences than adults in producing simple shapes. These accounts highlight differences in how children and adults produce drawings. Laszlo and Broderick (1985), in attempting to go beyond mere description, characterized children's shape copying with an information processing approach. They argue that children fail to copy figures accurately due to difficulties in planning movements, problems with detecting and correcting errors in ongoing movements, and undeveloped perceptual-motor abilities. They do not, however, discuss the nature of these undeveloped perceptual-motor abilities in detail.

In this paper we take a closer look at the processes involved in preschool-aged children's drawing, and in particular we examine how the manner in which a child holds the drawing implement influences his or her ability to copy shapes accurately. Most researchers acknowledge that motor components constrain drawing abilities to some degree, especially in the early stages of drawing development, but few studies have actually explored how specific motor components influence children's drawing.

The manner in which preschoolers hold a drawing implement has received considerable attention

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Correspondence to: G. S. Braswell
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(Rosenbloom & Horton, 1971; Saida & Miyashita, 1979; Sasson, Nimmo-Smith, & Wing, 1986; Thomassen & Teulings, 1983; Ziviani, 1982, 1983). Traditional accounts suggest that the manner in which objects or tools are grasped is determined primarily by maturational factors (Connolly & Elliott, 1972; Halverson, 1931). Researchers examining children's drawing and writing have charted a developmental progression from less to more mature grip configurations (Rosenbloom & Horton; Saida & Miyashita, 1979). Specifically, children's earliest attempts to grip a writing implement involve a palmar or power grasp, where the implement is held primarily between the palms and fingers. Then, as children mature, they gradually shift to a tripod grasp, holding the implement firmly between the thumb and first two fingers. Finally, children achieve what is known as the dynamic tripod, differentiated from the tripod by small movements of the fingers and thumb. These small movements are thought to enable the drawer to make fine details in their drawing. Typically, children acquire the dynamic tripod between the ages of 4 and 6 years (Rosenbloom & Horton). By this maturational account grip configurations are thought to reach maturity by about the age of six.

Unlike previous research, we argue that it is important to consider variability in grip configurations. Research on drawing and cognitive development research more broadly tends to focus on the similarities found among same-aged children (Siegler, 1996). We focus, instead, on variability within and across children. Piaget (1967, 1971) acknowledged the role of variability in the development of children's reasoning, but until recently few researchers have devoted much attention to issues of variability in children's performance (e.g., Rosengren & Braswell, 2001, 2003; Siegler; Thelen & Smith, 1994). Siegler, for example, argues that our failure to consider variability in children's thinking has made it more difficult to understand the process of developmental change. Thelen and Smith argue that variability is inherent in any complex system and that systems might best be described in terms of factors which influence their stability.

Regarding motor development, past studies have found some variability in the grip configurations used by different 5–7-year-old children (Blöte & Heijden, 1988; Blöte, Zielstra, & Zoetewey, 1987), although examining variability was not the main focus of that research. In these studies roughly 40% of the children were found to use a grip other than the dynamic tripod. Blöte et al. (1987) also report some variability in the grip configurations of individual children, finding that many of the 6-year-old children began drawing with a tripod grip but shifted to more of a power grip (like the palmar grip) over the course of the drawing session.

Researchers have also examined whether grip configurations affect writing quality, assuming that individuals who use the dynamic tripod, the grip considered to be most mature and efficient, should produce the highest quality writing. For example, Ziviani and Elkins (1986) examined whether 8–14-year-olds' pen grips were related to their writing speed and legibility. They found no relation, but this may be due to the fact that the children they examined had extensive experience drawing and writing and that they primarily used variations of the dynamic tripod, the most mature grip. In a study of younger children, Martlew (1992) reported that 4- and 5-year-old children using a tripod grip produced higher quality letters than children using other grip configurations. These results suggest that earlier in development, grip configurations may play a more significant role in production than at later stages. We posit that variability within children's grips, rather than the grip configuration per se, may influence the quality of the final product. Stability in a grip configuration may indicate greater experience with using a drawing implement and may allow for more control of the implement. The actual grip configuration may be less important than whether the child has adopted a stable grip.

We propose the use of the TASC-based approach proposed by Rosengren and his colleagues (Rosengren, Savelsbergh, & van der Kamp, 2003) for understanding the role of variability in motor development. This approach views development as "*task*-related *adaptation* and *selection*, influenced by *constraints* both within and external to the child" (Rosengren & Braswell, 2003, p. 60). Although having a range of behaviors to select from is important—for example, many studies have demonstrated behavior becomes highly variable during developmental transitions (Goldin-Meadow, 2001; Thelen & Smith, 1994), it should be noted that variability is not always helpful to a child. It may be more efficient to stick to one (or a small handful) of behaviors when tasks and constraints are constant, instead of trying something new in the same or similar situations (Rosengren & Braswell, 2001).

The TASC-based approach clearly draws on the work of Thelen and Smith (1994) but differs in a number of ways. First, the TASC-based approach emphasizes the child's goal as an "organizing" constraint that drives behavior. That is, the child's goal serves as a "top-down" organizing constraint as opposed to a behavior emerging from the "bottom-up" as a process of self-organization. Second, we view higher-cognitive processes, such as representation, as important constraints for the production of certain behaviors. It is not clear how producing a drawing or writing one's name on a piece of paper can be described purely in terms of self-organization. Thus, we see higher order cognitive processes as playing a much more central role in the production of certain behaviors—for example, those behaviors that deal with symbolic production.

The TASC-based approach proposes that variability in the process of drawing and writing is driven by and limited by several types of constraints (Rosengren & Braswell, 2003; Rosengren et al., 2003). These constraints fall into three basic categories: *environmental* (including laws of physics and friction between writing implements and surfaces), *organismic* (i.e., traits of the organism, such as the biomechanics of the arm, hand, and fingers), and *task* (such as instructions given to a child or the particular requirements of a writing/drawing activity) (Newell, 1986). Researchers interested in variability have noted that behavior is highly context sensitive (Rosengren & Braswell, 2001), and in the present study we focused on task constraints which shape the contexts in which child use writing implements.

Similar research has focused on the impact of constraints on other aspects of the development of fine motor skills. For example, Van Roon, Van der Kamp, and Steenbergen (2003) identified several constraints on the development of spoon use in infants and young children. They note that task constraints (e.g., feeding oneself), physical properties of eating implements (e.g., size and shape of a spoon), organismic constraints (e.g., motor control), and cultural expectations (e.g., rules for eating properly) all interact together to shape grip configurations with spoons.

In contrast to previous characterizations of children's grip development with respect to drawing or writing, we expected that the grip configurations of young children at the beginning of drawing development would be highly variable while performing a series of different drawing tasks. In this manner, we expected the early phases of children's use of drawing implements would be similar to that found by Connolly and Dagleish (1989) who reported that 11-month-old children in the early stages of spoon use exhibited a wide range of different grips.

Task constraints, as described above, should play a unique role in shaping how preschoolers grip writing implements. We expected that different drawing tasks would create different demands for the children and that they would alter their grip configurations to meet these demands. Our tasks consisted of copying four simple shapes, rapid drawing of horizontal and vertical lines, and free drawing. The shapes were included so that the quality of the children's drawings could be compared to performance based on standard drawing assessments (Cox, 1992, p. 162). We included rapid drawing tasks to examine whether preschoolers would adopt a different grip configuration while performing tasks that required more powerful strokes. We expected that children might adopt a power grip in order to meet this task demand. The free drawing task was included to examine whether children would change their grip configuration as they worked on different aspects of a picture. We expected that children might use a power grip for relatively large aspects of the picture, shifting to a precision grip for fine details.

Overall, we predicted that preschool children would vary their grip configurations to meet the demands of different tasks and more generally that their grip configurations would be characterized by variability rather than stability. Specifically, we expected that young children would utilize a variety of grip configurations as they explored the perceptual-motor workspace of drawing. Using a wide range of grip configurations may allow children to adapt to the demands of different drawing or writing tasks.

In addition to investigating the nature and variability of children's grip configurations, we also examined whether these were related to the quality of children's shape copying. We predicted that children who used less mature grip configurations and/or exhibited high levels of variability in their grip configuration would produce poorer quality shapes than children with more sophisticated grips or less variability.

METHOD

Participants

Eighteen children between the ages of 37 and 50 months of age ($M = 44$ months) participated in this study. An equal number of boys and girls participated. The children were from a laboratory preschool at a large Midwestern university. The majority of the children were from white, middle-class families. Three of the children who participated in the study were of Asian descent, and three children were originally from South America. All children spoke and understood English. We did not try to account for hand preference with this sample, because hand use is not entirely stable in children of this age range. Gesell and Ames (1947) suggested that many children do not settle into a preferred hand until much later in childhood. A number of children in our sample changed drawing hands over the course of the drawing session.

Procedure

The following procedure was approved by the university research ethics board. An experimenter tested the children individually at a child-sized table in a section of the classroom that had been cordoned off from the rest of the room. The entire procedure was recorded using a video camcorder. The camcorder was mounted on a tripod and positioned across from the child in a location that allowed viewing of both the child's hand and drawing.

Children were told that they were going to be asked to perform different drawing tasks. Children were shown pictures of four shapes (a circle, a cross, a square, and a triangle), one at a time, in random order, and asked to draw each one using a graphite pencil (10 cm long with a diameter of 1.8 cm). The pencil was placed at the midline in front of the child. Computergenerated shapes—approximately 10.16 by 10.16 cm—were presented, centered, on single sheets of 21.59 by 27.94 cm paper one at a time. There were no instructions given to the child regarding the size of the drawing. The shapes remained in view while the children copied them. After the children had completed the shape copying task they were asked to: (1) make as many vertical lines as fast as they could on the paper; (2) make as many horizontal lines as fast as they could on the paper; and (3) make a picture of anything (free drawing). These last three tasks were presented in random order. In order to maximize children's interest in the task a large variety of different colored papers were provided for the children. The children were asked to make each drawing on a new sheet of paper.

The children found the drawing tasks to be quite enjoyable; they drew for an average of 5.4 min ($SD = 2.3$ min) with a range of 3.2–11.1 min. Drawing time was assessed from the point of initial contact with the paper until the child left the drawing table.

Coding of Changes in Overall Configuration

The videotapes of the children's drawing activity were coded independently by two of the researchers using a Panasonic AG7350 videocassette recorder equipped with frame by frame capabilities which enabled continuous monitoring of the grip configurations. The videotapes were coded for a number of different types of changes related to the overall grip configuration and to changes within a specific grasp. Coders recorded the children's original grip configuration and any subsequent changes in their overall grip. We also examined the position of children's hands on the writing implement, the orientation of the implement in their hand, and any hand switching.

Grip Configuration. Children's grip configurations were coded as: (1) palmar; (2) digital; (3) modified tripod; and (4) tripod. These categories were based on coding used by previous researchers (Connolly & Dagleish, 1989; Connolly & Elliott, 1972; Rosenbloom & Horton, 1971). Examples of these grip configurations are presented in Figure 1. The modified tripod and the tripod grips are distinguished by variations in the finger positions and/or by the number of fingers contacting the writing implement.

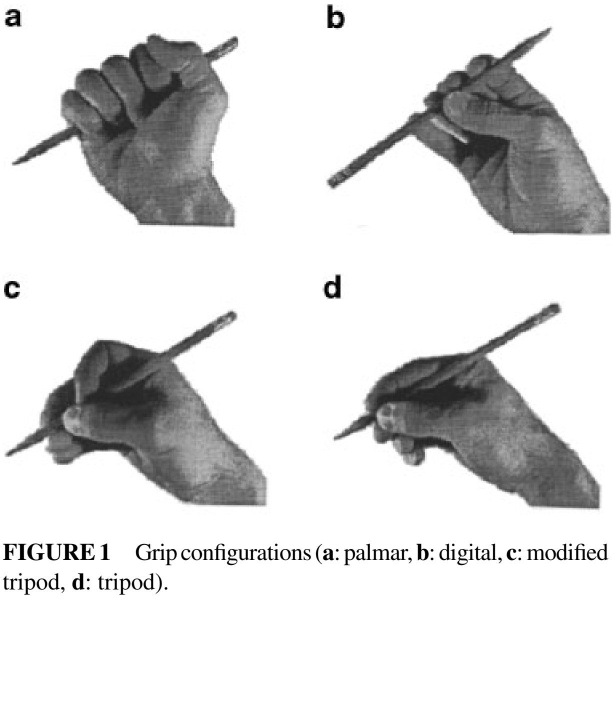

FIGURE 1 Grip configurations (**a**: palmar, **b**: digital, **c**: modified tripod, **d**: tripod).

In past research, investigators have also coded whether children utilize a dynamic tripod grasp. The dynamic tripod is distinguished from the tripod by relatively fine movements of the finger and thumb. However, past researchers have coded children's grip configurations from still photographs (Rosenbloom & Horton, 1971; Ziviani, 1983) or from observations as the children drew (Saida & Miyashita, 1979), and they may not have been able to observe relatively small movements of the child's fingers and thumb that would indicate more dynamic control of the writing implement. The frame by frame capabilities of our video recorder allowed us to assess more clearly the existence of these movements and whether they were restricted solely to the tripod grasp. We therefore did not code the dynamic tripod grip as a different grip but examined whether dynamic movements were made in any of the overall grip configurations. This was because these movements are believed to be involved in the production of fine details and are thought to emerge only after children have adopted the dynamic tripod (about 6 years of age; Rosenbloom & Horton).

Grip Position. Past accounts of children's drawing have suggested that children initially hold the pencil far from the writing tip and with age move their hand closer to the writing tip (Martlew, 1992; Rosenbloom & Horton, 1971). Children's grip positions were coded as low, middle, or high. These codes correspond to the location of the child's hand on the writing implement with respect to the writing tip. The low position refers to a hand position close to the writing tip and the high position to a hand position at the opposite end of the writing implement. The middle position was used to code any instances where the child's hand was not clearly in either of these locations.

Orientation. The orientation of the pencil in the child's hand was coded as ulnar or radial (Connolly & Dagleish, 1989). An ulnar code was given if the tip of the drawing implement extended from the ulnar side of the hand (see Fig. 1a). A radial code was given if the tip of the drawing implement extended from the radial side of the hand (towards the thumb, see Fig. 1b).

Hand Switching. We recorded whenever children switched the implement from one hand to the other and actually drew with other hand. Hand switching was not coded if a child passed the implement back and forth between his or her hands but did not draw anything.

Coding of Changes within Grip Configuration

In examining the videotapes of the children's drawing sessions it became obvious that participants often did not change their overall grip configuration but often made a number of more subtle changes (e.g., number of fingers in contact with the implement). Although researchers (Ziviani, 1983; Ziviani & Elkins, 1986) have examined a number of changes within grip configurations for children between 6 and 14 years of age, these more subtle changes have not been described in detail for younger children. As with the overall grip, we examined children's original configurations and any subsequent changes which occurred.

Number of Fingers. We coded the number of fingers initially contacting the pencil and any subsequent changes. If a finger was not visible in the video image the finger was not counted as making contact.

Thumb Position. We coded the manner in which the child's thumb contacted the implement (pad contact involving the surface of the finger where the finger-print is located, side contact, contact higher than the first joint, no contact) and its location relative to the first finger (in pad to pad opposition, with thumb closer to the writing tip, with thumb farther from writing tip).

Index Finger Contact. Index finger contact with the writing implement was coded as pad contact, tip contact, side contact, or no contact.

Middle Finger Contact. The middle finger contact with the writing implement was coded in the same manner as index finger contact.

Index Flexion of Proximal Joint. The flexion of the proximal interphalangeal joint of the index finger was coded as either flexed more than 90 degrees or flexed less than 90 degrees (Ziviani, 1983). Flexion of this joint is thought to reflect the amount of force being applied to the writing implement. Less flexion in this joint indicates more force is being applied to the implement.

Index Flexion of Distal Joint. The distal interphalangeal joint of the index finger was coded as either flexed or extended. Extension of this joint typically indicates that greater force is being applied to the implement.

Quality of Drawing

Two independent coders used a four point scale to assess the quality of the children's drawn shapes from their actual drawings. An accurate copy of the drawing was coded as 1. A discernible, but not very accurate copy of the target shape was coded as 2. If the drawing was discernible as a shape but not as the target shape, then it was coded as 3. If no shape was distinguishable or the marks appeared as scribbles, then the drawing was coded as 4. Examples of participants' drawings that fit each of these categories appear in Figure 2.

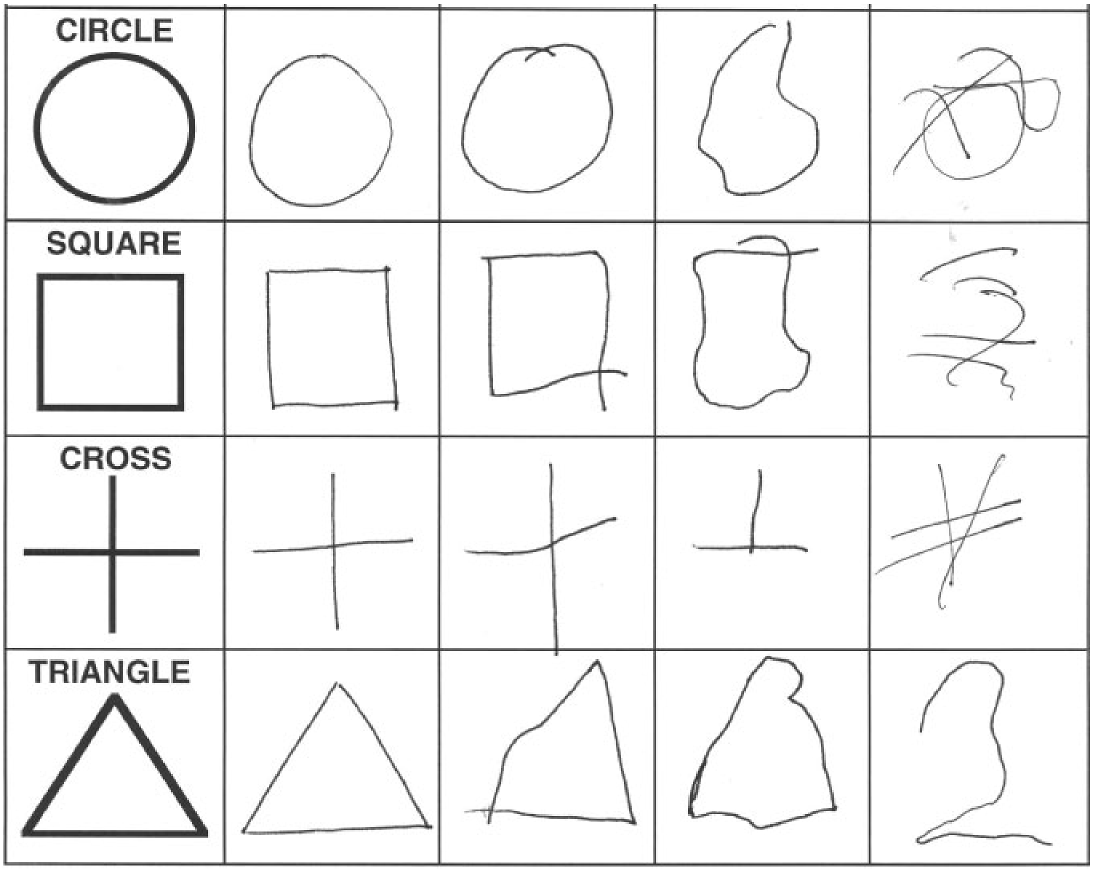

FIGURE 2 Examples of participants' drawings of shapes, varying by quality.

Reliability

Two of the experimenters (including the second author) coded the videotapes. Reliability of the coding was assessed by calculating percent agreement (number of agreements divided by agreements plus disagreements) on all aspects of data from six participants (33% of the sample). The average intercoder agreement ranged from 85% for index flexion at the distal joint to 100% agreement for orientation. Percent agreement for the overall grip configuration was 93%. The reliability of the quality coding was 92%.

RESULTS

The results will be described in terms of three questions: (1) to what extent are children's drawing grips marked by variability? (2) do children alter their grip configuration in response to different tasks? If so, what is the nature of these changes? (3) is the quality of children's drawings related to either the grip configuration or variability of children's grips? Preliminary analyses revealed no gender differences in the overall number of changes, the number of grasp changes or the number of changes within a particular grasp. Thus, girls' and boys' data were combined in all subsequent analyses.

Degree of Grip Variability

Children varied their overall grip configurations relatively often and made numerous variations within grips as well. We first examine changes in overall grip patterns and then examine the nature of variability found within particular grip configurations.

Variability in Overall Grip Configuration. Changes in overall grip configurations were relatively common among the children ($M = 3.1$ grip changes, $SD = 1.5$). There were large individual differences on this measure with nine children exhibiting few overall grip changes (six had no changes, three had one change) and nine children exhibiting two or more grip changes. One child changed his overall grip 27 times over the course of his drawing session. For children who varied their grip, most changed their grip between two or three different configurations, while two children changed their grip between all four configurations.

In order to determine if there was a consistent pattern in grip changes over the course of the drawing session, we examined children's initial grip (the one used when initially contacting the paper) and the final grip used in the drawing session. Half of the children began drawing using the modified tripod ($n = 9$) or the tripod grip ($n = 7$). The remaining two children began drawing with the digital grip. The majority of children ($n = 12$) ended the drawing session using the same grip as they started using. All of these children started or ended the drawing session with either the tripod or modified tripod. Of the remaining six children, three children shifted to using a more sophisticated grip and three children shifted towards using a less sophisticated grip over the course of the session. These data suggests that for most of the children in this study the tripod and modified tripod grips were the most suitable for the tasks in which they participated.

We also examined the frequency of position changes, orientation changes, and hand switching. These types of changes did not occur very frequently. For example, children maintained a relatively stable hand position during drawing ($M = 1.8$ changes in position, $SD = 3.8$) and rarely changed the orientation of the implement ($M = .3$ changes in orientation, $SD = .7$) during the entire procedure. Only 3 of the 18 children changed hands while performing the drawing tasks. This is a higher percentage of hand switching than reported by Connolly and Elliott (1972) who found that only 4 of 49 preschool children switched hands during a painting task. They, however, studied children between 32 and 60 months of age and found that hand switching decreased as a function of age. Also, the differences between the present sample size and that of Connolloy and Elliot's study may limit this comparison.

Variability within Grip Configurations. Children made a lot of changes within their grips while maintaining the same overall grip configuration ($M = 22.6$ changes, $SD = 19.1$, range $= 6$ to 63). Twelve of the 18 children exhibited small finger movements commonly associated with the dynamic tripod. These movements were found equally in the tripod and modified tripod grasps ($n = 6$ in each instance).

Task Effects on Grip

A 7 (drawing task: square, circle, cross, triangle, horizontal lines, vertical lines, free drawing) × 2 (change: within tasks, across tasks) repeated measures ANOVA revealed that significantly more changes (both between different grips and within specific grips) occurred in the free drawing task than in any of the other 6 tasks ($F(6,72) = 6.6$, $p < .001$, Tukey HSD used for post hoc analyses). No difference was found in the overall number of changes in the remaining five tasks.

Of the three children who switched hands, two of these children switched four times during the free drawing task, while the remaining child switched both during free drawing and while moving from drawing the square to free drawing.

Although we expected the rapid drawing tasks would require greater force and thus perhaps would lead to use of a more forceful grip (i.e., the palmar grip) our results did not support this prediction. Children typically used the same grip in the rapid drawing task they had used previously and rarely changed their grip during these tasks.

Next we examined whether changes in grip configuration were more likely to occur while children were engaged in the drawings tasks or when they were switching from one task to another. No significant difference was found in this comparison for the overall number of grip changes, $t(17) = 1.4$, n.s. Children produced an average of 2.2 grip changes ($SD = 1.2$) while engaged in the drawing tasks (i.e., while drawing a circle or a square). Children made an average of .9 grasp changes when changing between tasks ($SD = .3$). However, when we examined changes within particular grip configurations we found that more of these changes occurred while children were engaged in a particular drawing tasks ($M = 17.4$, $SD = 18.4$) than when children were switching from one drawing task to another ($M = 5.2$, $SD = 2.6$, $t(17) = 2.9$, $p = .01$). Table 1 shows the mean and standard deviations for variations in the within grasp measures examined both within and across tasks.

Quality of Drawing

The children's drawings were of relatively poor quality ($M = 2.9$, $SD = .6$, 1 = high quality, 4 = low quality, with 3 indicating drawings that are discernible as shapes but not as the target shapes). A repeated measures ANOVA revealed no significant differences in the quality of the different drawings ($F(3, 51) = 2.6$, n.s.). We summed children's quality scores across the four drawings to obtain an overall quality score. These scores could in principle range from 4 (high quality drawings for each of the 4 shapes) to 16 (poor quality drawings for each of the 4 shapes), but the actual range of scores ranged from 8 to 14 ($M = 11.5$, $SD = 1.8$).

Relations between Drawing Quality and Grip Variability

To determine if grip variability and drawing quality were related we performed two types of analyses: Spearman rank order correlations and Chi-square. The first of these analyses confirmed that children who made more changes as they switched from one drawing task to another were significantly more likely to produce drawings of relatively low quality than children who made few changes as they switched from one task to another. This was true for both changes in overall grip configuration ($\rho = .47$, $N = 18$, $p < .05$) and changes within particular grip configurations ($\rho = .71$, $N = 18$, $p < .001$).

For the Chi-square analysis, we categorized participants with drawing scores between 8 and 11 as producing drawings of relatively high quality ($n = 9$) and categorized participants with drawing scores of 12 or higher as producing drawings of relatively low quality ($n = 9$). A score of 16 would indicate a low-quality rating for all four shapes. Furthermore, children who varied their grip often (2 or more changes, $n = 9$) were characterized as high on variability and children with stable grips (0 or 1 grip change, $n = 9$) were characterized as low on variability. The Chi-square analysis confirmed that children who rarely changed their grip produced higher quality drawings than children with many grip changes (χ^2 (1, 18) $= 5.6$, $p = .02$).

Table 1. Frequency of Within Grasp Changes

Type of Change	While Performing Particular Tasks	While Changing Tasks
Thumb position	6.2 (9.3)	1.8 (1.4)
Number of fingers	2.2 (4.9)	.7 (1.0)
Index finger contact	.7 (1.2)	.3 (.5)
Middle finger contact	.9 (1.6)	.4 (.8)
Proximal joint flexion	1.3 (2.8)	.7 (1.3)
Distal joint flexion	5.9 (6.4)	1.3 (1.4)**

$^{**}p < .01$.

DISCUSSION

The results of this study show that there is considerable variability in the manner in which preschoolers hold a writing implement. Participants varied their overall grip configuration an average of three times over the drawing session. There were considerable individual differences on this measure, however, ranging from many children exhibiting one or no grip changes to one participant changing his grip constantly over the drawing period. These results suggest that for some preschoolers their grip configurations are relatively stable. For other preschoolers, their grip configurations were characterized by a high degree of variability, suggesting that no single strategy had been selected. These children may be in a transitional state, and it is likely that, if they were followed over time, we would find that they would settle into a particular grip configuration (see Greer & Lockman, 1998).

Although half of the children did exhibit relatively stable grip configurations, all of the children made changes within particular grip configurations. For example, it was relatively common for children to change their finger or thumb contact with the writing implement. Overall, there was an average of 23 changes per child within particular grips. The stability of children's grip configurations varied as a function of the task performed. Children were most likely to change their grip in some manner during free drawing than during any of the other tasks. This result is of interest because most studies examining the development of grip configurations have only used a shape copying task. For example, participants in Greer and Lockman's (1998) study drew horizontal and vertical lines (and the authors noted that grip variability was not connected to these very rudimentary drawing tasks). We believe that the free drawing task places a variety of demands on the child involving the production of both large forms and fine details, thus increasing the likelihood that the child might need to adjust their grip. The finding that more grip changes occurred while children were engaged in particular drawing tasks than when children switched between tasks suggests that the majority of the children have a preferred grip that is used to begin different drawing tasks, but that the demands of specific tasks can cause the child to vary their grip configuration.

Another important finding in this investigation is that preschoolers who vary their grip often produce less accurate copies of simple shapes than children who rarely vary their grip. This result suggests that greater consideration of various motor factors which contribute to overall drawing quality is warranted. This is particularly true for assessment of young preschool children's drawings. One implication of this result is that the quality of children's drawings may not improve substantially until children have settled into relatively stable grip configurations.

The conclusions from past work clearly emphasize the dominance of grips as a function of age. However, close examination of the data from past work suggests that there is considerable variability. The present study highlights that there is considerable variability in preschoolers' use of different grip configurations and even within a particular grip configuration, that these variations are task-dependent, and importantly that preschoolers who show a lot of variability in their grip configurations produce poorer quality of drawings than children who have adopted a relatively stable grip configuration.

Overall, the present results suggest that young children vary their grip configurations to meet the demands of particular tasks. Rather than being fixed, rigid configurations that develop solely due to underlying maturational changes, grip configurations appear to be quite flexible. We suggest that it is useful to examine the process of drawing from a TASC-based perspective. According to this view, variability in grip configurations is adaptive and provides children with a repertoire of strategies to handle a variety of drawing tasks. This variability is also constrained by the various internal and external constraints examined here.

Although we focused on task constraints and how these influence a drawer's grip configuration, additional studies are necessary for investigating the other types of constraints (i.e., organismic and environmental) which are central to the TASC-based approach. For example, more detailed analysis of the motor components is necessary to identify specific organismic constraints that govern the development of children's grip configurations. Likely candidates for such organismic constraints include hand size, hand strength, and finger coordination. For example, hand size or strength may serve as an important organismic constraint when also considering the diameter or length of an implement.

Future studies can also establish the effects of environmental constraints on preschoolers' grip configurations. Parents and teachers often provide young children with relatively large drawing implements based on the assumption that these implements will be easier for children to use given their relatively poor fine motor skills. However, implements with a large diameter typically have a larger area of contact with the drawing surface than implements with a smaller diameter; in many cases this environmental constraint creates relatively large frictional forces between the implement and drawing surface. In order to overcome these frictional forces, a child using a relatively large implement, such as a large crayon, may adopt a grip configuration that enables them to apply more force to the implement, such as the palmar grip.

Constraints on motor skills may drive drawing production at two particular places in development. First, these constraints may serve to strongly guide children's behavior during the earliest acquisition of drawing skills. At this point, between about 18 months and 3½ years, children can generally recognize simple shapes and figures but have great difficulty reproducing them. While it is likely that memory, attention, and the ability to plan a series of movements influence the quality of children's drawings, we suggest that these components are likely to play a greater role as children begin to draw figures of increasing complexity. The second place where constraints on motor skills might serve a particular important function is in the acquisition of expertise in making precise renderings. In order to produce nearly perfect copies of existing works highly skilled movements of the hand and arm must be made. At this more advanced stage grip configurations may play a lesser role because the grip patterns may be highly stable. At this point control of the hand and arm may serve to separate the expert from novice.

As the discussion above makes clear, drawing is a complex skill that requires the interaction of a large number of components. These include motor components, such as grip configurations and hand and arm coordination, perceptual components, such as attention, and cognitive components, such as memory, planning, and knowledge of the subject being drawn. This is by no means a comprehensive list of the components involved in the production of drawings. We suggest, however, that in order to understand the development of children's drawings and in order to consider using children's and adults' drawings for diagnostic purposes, we must begin to examine drawing and its development in terms of the interaction of multiple constraints. Children's drawings are not an exact match of representations in their heads (Braswell & Rosengren, 2000; Kosslyn, Heldmeyer, & Locklear, 1977; Van Sommers, 1984). Rather, drawings are a product of a complex process involving the interaction of motor, cognitive, and task components.

NOTES

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