7 The interaction of biomechanical and cognitive constraints in the production of children's drawing

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Research investigating the process of drawing has often been overshadowed by a focus on the end product of this process. However, it is important to acknowledge that various factors that shape the process also impact on the final drawing outcome. In this chapter, Braswell and Rosengren examine how biomechanical, cognitive and contextual factors shape how children and adults draw. For example, the physiology and structure of the fingers, hands and arms often influences the direction in which strokes are produced on a page. Numerous studies demonstrate the effect of handedness on drawing horizontal lines, for instance. Other research has demonstrated that cognitive factors shape where drawers begin figures and the direction in which strokes are produced. In some cases, drawers rely on relatively stable, procedural representations to guide the sequencing and placement of strokes for entire images. Contextual factors, such as writing systems, also play important roles in determining how individuals construct a drawing. They discuss these factors and how they interact using the TASC-based approach, which views development as driven by constraints internal and external to the individual.

DRAWING is a complex skill that emerges during the second year of life, changes significantly over the course of childhood, and involves both higher-order symbolic processes and a motor system capable of producing a desired representation in the real world. Much of the research on children's drawings has focused on the cognitive aspects of children's drawing, often with an emphasis on the final product of a drawing episode. This body of research has provided a relatively detailed account of what children draw, how these drawings relate to underlying mental representations, and how these drawings vary as a function of age and experiences (e.g. Cox, 1992; Goodnow, 1977; Kellogg, 1969; Willats, 1977).

Much less consideration has been given to the motor aspects of drawing. In part, this may be due to the fact that, at least in the United States, motor components and their development are viewed as less important and perhaps less interesting aspects of behaviour than cognitive processes (Rosenbaum, 2005). There has been some research, however, looking at certain motor components involved in drawing and writing that we will discuss shortly. Although it is generally acknowledged that cognitive and motor components interact in the production of a child's drawing, it is often difficult to tease apart the relative contribution of these different factors. It is also commonly assumed that even though biomechanical constraints clearly influence the quality of children's drawing the representational desire of the children is not occluded by these biomechanical constraints. The overall goal of this chapter is to explore more closely the role of biomechanical, cognitive and contextual constraints on drawing development.

One way to understand how certain constraints might influence the drawing process and its outcome is to examine them through the TASC-based approach proposed by Rosengren and his colleagues (Rosengren and Savelsbergh, 2000; Rosengren, Savelsbergh and Van der Kamp, 2003), which envisions development in terms of '*task*-related *adaptation* and *selection*, influenced by *constraints* both within and external to the child' (Rosengren and Braswell, 2003, p. 60).

Constraints involve environmental properties (e.g. gravity, friction), properties of the organism (e.g. handedness, size of hand) and task properties (e.g. the drawing goal, particular instructions for a drawing activity) (Newell, 1986; Rosengren *et al.*, 2003). While some researchers have proposed that culturally specified expectations and artefacts serve as additional forms of constraint (Van Roon, Van der Kamp and Steenbergen, 2003), these can be perhaps best thought of as additional forms of either environmental or task constraints depending upon how they influence the child's behaviour in a particular situation. For example, differences in the preferred direction of writing that are found across cultures may be viewed as an environmental constraint that impacts on drawing and writing in a global manner across individuals, sessions and particular tasks. The presentation of a particular drawing implement that is more common in one culture than another, as calligraphy brushes are to certain Asian cultures, may be best viewed as a task constraint that has more local and specific influences on how a drawing is produced. In this situation, the drawing is potentially more influenced by the implement itself, a task constraint, than by the larger cultural influences, although the larger culture determines in part the implement to be used.

Constraints on behaviour do not work independently but interact in complex ways to produce specific behaviours. For example, the size of a child's hand and his or her grip strength influence the particular grip configuration that he or she might use when given a specific drawing implement by a parent or teacher. The child's grip configuration and the size and type of drawing implement (e.g. crayon, pen or marker) also interact to influence the frictional forces between the implement and the drawing surface (e.g. paper, chalk board or sidewalk). Certain combinations of grips, implements and surfaces may facilitate the drawing of highly detailed, complex figures that fit within a small confined space. Other combinations of grips, implements and surfaces may facilitate the drawing of less refined and less detailed figures that require a larger spatial area. Cognitive and cultural influences also interact in this process, influencing the choice of implements, surfaces and representations to be produced. In this chapter, we will examine various biomechanical and cognitive properties that serve as organismic constraints on the drawing process. We will also explore how these organismic constraints interact with task constraints and cultural constraints (particularly writing systems) during drawing development.

The impact of biomechanical constraints

Numerous studies have demonstrated the impact of biomechanical factors on the process of drawing. The underlying physiology, structure and movement of arms, hands and fingers all constrain how children and adults create images from individual strokes. Researchers examining these factors have examined the development of grip configurations, the influence of handedness, and how biomechanical factors influence stroke directionality. An assumption that appears to underlie much of this work is that various biomechanical factors are at different points in development relatively stable influences on the drawing process. We have argued, however, that much of the research on children's drawing and on children's cognitive development more broadly has ignored important aspects of *variability* (Rosengren and Braswell, 2001, 2003). Siegler (1996) has also argued that the failure to consider variability in children's behaviour has made it difficult to understand the process of developmental change. Likewise, Thelen and Smith (1994) have suggested that variability is inherent in any complex system and that variability may be a driving force underlying developmental change. In our own research (Braswell and Rosengren, 2000, 2002; Braswell, Rosengren and Pierroutsakos, 2007) we have shown that high levels of variability are characteristic of early aspects of children's drawing, and that the relative contribution of biomechanical and cognitive constraints varies as a function of a variety of factors, including drawing experience and different task constraints (Braswell and Rosengren, 2000, 2002).

The development of grip configurations

The manner in which children hold a drawing implement and how this changes with age has received considerable attention (Rosenbloom and Horton, 1971; Saida and Miyashita, 1979; Sasson, Nimmo-Smith and Wing, 1986; Thomassen and Teulings, 1983; Ziviani, 1982, 1983). Traditionally it has been suggested that the form of grasp used for an object or tool is determined primarily by maturational factors (Connolly and Elliott, 1972; Halverson, 1931). Researchers examining children's drawing and writing have described a developmental progression from less mature grasps involving the palm and fingers (palmar or power grips) to more mature grip configurations where the object is held between the thumb and first two fingers (tripod grasp; Rosenbloom and Horton, 1971; Saida and Miyashita, 1979). At the most advanced stage, children use a dynamic tripod, a grasp differentiated from the tripod by relatively small movements of the fingers and thumb. These small movements are thought to enable the drawer to produce fine details in drawing or writing. Traditionally, children were thought to acquire the final grip, the dynamic tripod, by about 5 years of age (Rosenbloom and Horton, 1971).

Even though researchers have generally emphasized the stability of grip configurations in children of the same age, a number of researchers have reported some degree of variability in the grip configurations used by different children (Blöte and Heijden, 1988; Blöte, Zielstra and Zoetewey, 1987). In these studies approximately 40 per cent of 5- to 7-year-old children were found to use a grip other than the dynamic tripod. This is not all that surprising if one conducts an informal survey of grip configurations commonly used by adults. A quick survey of pen grips used in any undergraduate class will demonstrate that many adults do not employ the standard dynamic tripod. Blöte *et al.* (1987) also report variability *within* individual children in the grip configurations they use in a particular drawing session. They found that while many 6-year-old children begin drawing with a tripod grip they sometimes shift to use a power grip over the course of the drawing session.

One reason for looking at grip configurations is that it has often been assumed that a child's grip configuration influences various aspects of drawing or writing. The results of these studies have been somewhat mixed. For example, Ziviani and Elkins (1986) found no relation between pen grips and writing speed or legibility in a sample of 8- to 14-year-olds. One possible explanation of this result is that children of this age have had extensive experience drawing and writing and that these participants primarily used variations of a single grip, the dynamic tripod. In another 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. We have suggested that one reason for these disparate findings is that the actual grip configuration may be less important than whether the child has adopted a stable grip.

We explored this hypothesis in a series of studies where we varied the types of implements that 3- to 4-year-olds could use and the particular tasks that they were required to perform (Braswell, Rosengren and Pierroutsakos, 2007; Rosengren, DeGuzman and Pierroutsakos, 1995). The tasks included simple shape copying, rapid line drawing and free drawing. The results of these studies showed that there is considerable variability in the manner in which 3- to 4-year-old children hold a drawing implement. We found that on average children switched between three different grip configurations over the course of the drawing sessions. We also found considerable individual differences in the stability of children's grips. The majority of the children exhibited no or only one overall grip change. Other children changed their grips almost constantly over the drawing session. These latter 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 and Lockman, 1998).

Although many of the children in our studies exhibited stable grip configurations, *all* of the children frequently changed their finger and/or thumb contact over the drawing sessions without varying their overall grip configuration. This type of variability in grip 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. Most studies examining the development of grip configurations have used a shape copying task that may lead to an overestimation of stability. For example, participants in Greer and Lockman's (1998) study drew horizontal and vertical lines. We suggest that free drawing places a variety of task demands on the child, increasing the likelihood that the child might need to adjust her grip in order to produce fine detail or large shapes.

We also found that more grip changes occurred while children were engaged in particular drawing tasks than when children switched between different drawing tasks. This result suggests that the majority of young children may have a preferred grip that is used to begin different drawing tasks, but that the demands of specific tasks lead children to vary their grip configuration.

Young children who varied their grip often were also found to produce less accurate copies of simple shapes than children who rarely changed their grip. One implication of these results is that it is not a particular grip, but the stability of the grip that enables children to copy shapes accurately. Another implication of these results is that the quality of children's drawings may not improve substantially until children have settled into relatively stable grip configurations.

Although we focused on task constraints in these studies and how these influence a drawer's grip configuration, additional studies are necessary for investigating other types of constraints. Likely candidates for important organismic constraints include hand size, hand strength and finger coordination. For example, hand size or strength may serve as an important constraint that interacts with the diameter or length of an implement. Young children are often provided with relatively large drawing implements based on the assumption that these implements will be easier for children to use given their relatively small hands and poorly developed fine motor skills. Large diameter implements, such as large, thick crayons, have a larger area of contact with the drawing surface than implements with a smaller diameter. The larger contact surface 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 need to alter his grip to a power grip in order to apply adequate force to the implement to produce a drawing. A child with relatively weak grip strength using a large crayon and perhaps using a power grip may produce relatively poor copies of shapes and draw relatively large objects lacking in details because of the interaction of these constraints and not because he lacks some representational capacity.

Providing a young child with a marker that produces much less friction on a surface may enable the child to use a non-power grip and potentially create a drawing with more precision. Thus, an implication of our work is that one must consider how the characteristics of the child interact with the characteristics of the implement and the drawing surface.

Stroke direction

Biomechanical factors seem to have a particularly important influence on stroke directionality (Van Sommers, 1984). Finger and hand flexion, which guide drawing implements inward or downward towards the body, allow for more efficient stroke production than finger and hand extension. Thus, adults and children typically draw vertical lines from top to bottom (although there are exceptions to this general rule to be discussed below). The production of horizontal lines is also strongly shaped by the biomechanics of the human body in that individuals tend to draw moving their hands and fingers away from the midline of the body. Thus right-handed drawers tend to draw horizontal strokes from left to right, and left-handed drawers tend to draw these lines in the opposite direction (Van Sommers, 1984). This phenomenon occurs in both children (Gesell and Ames, 1946; Scheirs, 1990) and adults (Van Sommers, 1984).

Directionality preferences have been noted in other types of strokes beyond the straight horizontal or vertical strokes discussed so far. Van Sommers (1984) found that most adults in Western societies draw circles in a counterclockwise fashion, although this tendency is slightly weaker among left-handed individuals. Other patterns may emerge during the production of other circular forms. Right-handed adults often produce upward spirals in a *clockwise* fashion (Thomassen and Tuelings, 1979; Van Sommers, 1984).

Directionality preferences based on handedness appear not only in the production of single lines but also in the construction of entire figures. For example, directionality differences were demonstrated in the order in which 3- to 11-year-old children completed unfinished pictures of human figures (Glenn, Bradshaw and Sharp, 1995). Thus it appears that directionality differences based on handedness apply to isolated horizontal strokes as well as to more complex figures.

There has been mixed evidence regarding age-related differences in the impact of biomechanical constraints on stroke directionality. Van Sommers (1984) and others (e.g. Braswell and Rosengren, 2000; Gesell and Ames, 1946) have demonstrated that children typically draw circles (proceeding clockwise) differently than adults (proceeding counterclockwise), for example. Van Sommers (1984) found few differences in directionality preferences based on age for drawing horizontal or vertical strokes, yet other studies (e.g. Braswell and Rosengren, 2000; Goodnow and Levine, 1973) have noted increases across age-groups in directionality preferences when drawing isolated, straight lines. Glenn, Bradshaw and Sharp (1995) found that their youngest right-handed participants typically finished figures from right to left. These preferences were unstable among 4- to 7-year-olds (suggesting that these children were in a state of transition), and were reversed among 9- to 11-year-old right-handed participants. Left-handed participants typically drew components in the opposite direction from right-handed participants, although this preference was not as strong. In one study, we found that older children and adults were more likely to copy pictures of a human face and a house with a sun from left to right than younger participants (Braswell and Rosengren, 2000).

There is no established explanation for this age-related change in directionality preference, although certain cognitive constraints may inhibit biomechanical factors in early childhood but not in adulthood (Braswell and Rosengren, 2002). It may be that the biomechanics of the arm, hand and fingers have a greater impact as individuals become more efficient and practised in their drawing efforts. It also may be the case that certain tasks requiring speed or repetition are more greatly influenced by biomechanical rather than cognitive factors.

The impact of cognitive constraints

Biomechanical constraints alone do not drive drawing production. There are various cognitive factors that also shape the manner in which children and adults draw. For example, a large body of research has examined the extent to which adults and children rely on mental, procedural representations to guide the sequencing and placement of strokes. Some researchers have suggested that drawers tend to follow set sequences when drawing common images like cubes and human forms (Phillips, Hobbs and Pratt, 1978; Phillips, Inall and Lauder, 1985; Stiles, 1995). Others have questioned the rigidity or uniformity of set procedures and have demonstrated that children and adults often vary how they draw a variety of images, including well-practised ones (Braswell and Rosengren, 2000; Van Sommers, 1983, 1984).

Karmiloff-Smith's (1990, 1992) theory of 'representational redescription' has served as the foundation for many researchers who have studied the use of stable drawing procedures. According to this view, a child is only able to alter a procedural representation for drawing once that procedure is mastered and the child is able to reflect upon the representation. Thus young children often have trouble interrupting how they draw well-practised figures (e.g. human forms and houses) in order to add novel features (Karmiloff-Smith, 1990; Zhi, Thomas and Robinson, 1997). However, this rigidity can be alleviated by the presentation of graphic models (Picard and Vinter, 2005; Zhi *et al.*, 1997), by giving explicit instruction (Barlow, Jolley, White and Galbraith, 2003) or by training children to break down procedural representations into smaller parts (Picard and Vinter, 2006).

The process of drawing may be driven in part by more general cognitive constraints that apply to any figure, whether simple or complex, well-practised or novel. Goodnow and Levine (1973) identified four principles that drive where simple figures are started and the direction in which strokes are produced. Drawers may start at the leftmost point of a figure, at the topmost point, with the top of a vertical line, or with the top of a left oblique line (if one is part of the shape). The first of these principles (starting at the topmost point) overrides the second (starting at the leftmost) point when there is a conflict within a particular figure. Certain start position principles also guide the production of circles, ellipses and other curved figures. Adults typically start at the top of circular forms (Braswell and Rosengren, 2000; Goodnow and Levine, 1973; Meulenbroek, Vinter and Mounoud, 1993; Van Sommers, 1984). Van Sommers (1984) and others have argued that start positions are guided by cognitive constraints, rather than biomechanical ones, because handedness has little effect on where one starts to draw.

Goodnow and Levine (1973) also identified three principles which guide stroke directionality: drawing horizontally from left to right, drawing vertically from top to bottom, and using threading. The third principle involves drawing components of a figuring without lifting the drawing implement. As discussed above, biomechanical forces largely determine how isolated horizontal and vertical lines are drawn. However, threading involves overriding these tendencies and may be guided by cognitive constraints, such as planning considerations.

Developmental patterns have been identified in the use of these cognitive constraints. Following the start principles described above appears to increase with age (Braswell and Rosengren, 2000; Goodnow and Levine, 1973), although there is some variability prior to adulthood in terms of where children choose to start basic figures (Braswell and Rosengren, 2000). Start principles for circles also change, with children typically starting at the bottom and adults typically starting at the top (Braswell and Rosengren, 2000; Meulenbroek *et al.*, 1993; Van Sommers, 1984). In addition, the use of threading follows an inverted U-shaped trajectory, increasing then decreasing with age (Braswell and Rosengren, 2000; Goodnow and Levine, 1973). These developmental patterns may arise owing to a variety of factors, including increased planning ability, becoming literate, and changes in the biomechanical factors described earlier in this chapter. For example, Van Sommers (1984) suggested, 'It is natural to assume that [start position changes are] associated with learning to read and write, but it is possible that there is also an independent discovery being made by each child that graphic work is more straightforward if starting position is consistent with preferred direction of stroke making' (p. 20).

The impact of task constraints

Instructions given to participants and other facets of drawing tasks may complement or override the biomechanical and cognitive constraints discussed above. Van Sommers (1984) conducted several studies that demonstrated the impact of task constraints. In one study, he found that stroke directionality preferences can be manipulated when drawing arrows. Many right-handed adults drew from right to left when drawing arrows that point to the left, thereby overcoming the usual bias towards drawing horizontal lines in the opposite direction. In another study, Van

Sommers noted that the order in which adults drew two letters depended on whether the instructions were 'draw A in front of B' versus 'draw A behind B'. Thus task instructions can also shape the order in which larger graphic units are produced.

The manner in which children and adults produce individual strokes is also shaped by the larger image. That is, a particular drawing task may require a drawer to override general biomechanical or cognitive constraints that govern the production of simple lines. When connecting strokes to already drawn lines, individuals often 'anchor' the new strokes to the old ones. Anchoring involves starting new strokes (e.g. radials) at a previously drawn line (e.g. a circle) and drawing away from that previously drawn line. The evidence for developmental shifts in anchoring is mixed. Van Sommers (1984) found that anchoring was common among children and adult drawers when drawing radials at the bottom of a circle (e.g. when drawing rays on a sun), although the same participants tended to draw radials towards a circle near its top. This approach coincides with biomechanical factors that drive the preference for drawing vertical strokes from top to bottom. Four- and five-year-olds in one of our studies, however, typically anchored radials at the tops *and* bottoms of circles, completely overriding biomechanical considerations (Braswell and Rosengren, 2000). It may be that younger children anchor more because they lack the fine motor control of older individuals and because anchoring helps ensure accuracy (see Thomassen, 1992; Van Sommers, 1984). This demonstrates yet another way in which task parameters affect the drawing process.

Instructions for tasks that involve copying *ambiguous* figures appear to have a particularly strong impact on the drawing process. Van Sommers (1984) asked adult participants to copy a series of images that could be described in different ways. For example, one image was described as either a man holding a telescope or as a cocktail glass with a cherry. Participants tended to follow a certain sequence of strokes when interpreting the image as a man (starting at the top with the head) and tended to follow a different sequence when interpreting the image as a cocktail glass (starting in the middle with the sides of the glass). Meanings attributed to images impact the drawing process even with children as young as 6 years, although this effect seems to be stronger among older drawers (Vinter, 1999). In sum, the work of Van Sommers and others demonstrates the significance of particular task constraints on graphic production.

The impact of cultural constraints

Cultural contexts play an important role in constraining the drawing process. In particular, writing systems constitute an important context that shapes how children and adults draw. The direction in which written characters and strings of text are produced may affect start position, threading preferences and stroke directionality. For example, Wong and Kao (1991) found that children of various ages in Hong Kong adhered to many of Goodnow and Levine's (1973) start position principles, especially starting at the topmost and leftmost points, to a greater extent and at earlier ages than children in English-speaking, Western samples.

Likewise, several differences in start position and threading preferences were found in a comparison of US and Hebrew-speaking Israeli 4- to 7-year-olds and adults (Goodnow *et al.*, 1973). Israeli participants were less likely than US participants to start with vertical components of shapes but more likely to start with horizontal components. Also, Israeli participants were less likely to thread figures than US participants. Goodnow and her colleagues (1973) suggest that these differences reflect variations in the properties of letters and how writing instruction varies across these cultural communities.

Stroke directionality preferences are shaped in part by writing systems, as well. Hebrew-writing Israeli children (between kindergarten and 8th grade) tend to draw horizontal strokes from left to right, whereas Arab-writing Israeli children were more likely to draw from *right to left* across grades (Lieblich, Ninio and Kugelmas, 1975). Interestingly, Goodnow *et al.* (1973) did not find horizontal stroke directionality preferences between Hebrew and English writers. The manner in which individual letters are produced seems to have a greater impact than the overall direction in which text is produced (Lieblich, Ninio and Kugelmas, 1975). Hebrew and Arabic are both written from right to left, yet individual Hebrew letters are constructed from left to right as are Roman letters. Arabic letters are written from left to right, however. Thus writing systems can overlap with or override biomechanical constraints on the drawing process, depending on the particular system.

The interaction of biomechanical and cognitive constraints

Although we have described biomechanical and cognitive factors separately as organismic constraints, these factors do not operate independently from each other. Sometimes biomechanical factors impact one aspect of drawing (e.g. line directionality) and cognitive factors impact another aspect (e.g. start position). In many cases, start position determines line directionality. The direction in which one draws a circle is driven by where one starts the circle (Meulenbroek, Vinter and Mounoud, 1993). Other parameters, such as the speed of drawing, appear to impact line directionality. Adults typically produce circles in a counterclockwise fashion when drawing slowly and deliberately, but they will draw circles *clockwise* when drawing rapidly (Thomassen and Teulings, 1979). It may be that counterclockwise circle production is driven by cognitive constraints that are more powerful when one is drawing more carefully (Goodnow *et al.*, 1973; Thomassen and Teulings, 1979).

Planning considerations often appear to override biomechanical preferences, as can be seen with anchoring. Anchoring involves drawing new strokes outward from previously drawn lines. This technique is primarily used to ensure accuracy (Thomassen, 1992; Van Sommers, 1984), although there are many potential instances when it may conflict with biomechanical constraints. We explored this issue (Braswell and Rosengren, 2000) in a study of 4- to 7-year-olds and adults who were asked to copy a picture of a house with a sun and a picture of a smiling face with hair. We examined the use of anchoring to produce hairs at the top of the face picture and the rays around the sun in the other picture. Interestingly, the degree to which both hairs and rays were anchored declined across age. In fact, many older participants anchored the rays around the bottom of the sun and drew rays inward around the top of the sun. These participants demonstrated a preference for top-down stroke production. One possible explanation for this pattern is that younger children rely upon anchoring because it is likely to improve accuracy. Older individuals produce these lines more automatically, relying to a larger degree on biomechanical constraints to produce the lines.

The relative impact of biomechanical and cognitive factors may shift over developmental time, as well. We (Braswell and Rosengren, 2002) asked 4- to 6-year-old children and adults to copy a series of shapes with both hands. Adults produced shapes in a mirror fashion across hands. For instance, horizontal components were drawn left to right with the right hand and right to left with the left hand. Children tended to use similar production strategies across hands. Therefore these cognitive constraints appear to be more salient in early childhood. Certain cognitive factors may have a greater impact as children start learning to draw shapes and they need to plan carefully where a particular line or segment must go. Certain biomechanical factors may have a greater impact later in life as drawers become more efficient and practised. Still the interplay between biomechanical and cognitive factors is evident at any age.

Summary and conclusion

Both biomechanical and cognitive factors constrain the drawing process. The biomechanics of the arm, hand and fingers play a significant role in the directionality of strokes. Hand size and finger strength interact with implement size and friction. Cognitive constraints, such as start position principles and planning considerations (e.g. threading), also guide how children and adults draw pictures. Individuals may also be influenced by procedural representations which dictate how well-practised figures are produced. Although both biomechanical and cognitive constraints clearly shape how we draw, it is important to keep in mind that these two types of constraints do not work in isolation.

Multiple sources of evidence demonstrate that biomechanical and cognitive constraints interact in various, complex, ways. Some planning considerations, such as anchoring, may sometimes conflict with (if the previous stroke is below or to the right of the new stroke) and sometimes match (if the previous stroke is above or to the left of the new stroke) biomechanical constraints. Also, the meaning assigned to an image may override or match directionality preferences based on anatomical structure (e.g. drawing arrows that face right or left). The parameters of the drawing task (e.g. pitting speed against accuracy) and the cultural milieu (especially in terms of writing systems) in which one becomes an experienced drawer provide other contexts in which these various constraints interact. Together these and other factors help shape the interplay between constraints on drawing behaviour.

We argue that in order effectively to understand the development of children's drawings and in particular if we are to consider using children's and adults' drawings for diagnostic purposes, we must examine drawing and its development in terms of the interaction of multiple constraints. Children's and adults' drawings do not exactly mirror mental representations, but are filtered through a production process where biomechanical and cognitive constraints interact (Braswell and Rosengren, 2000; Kosslyn, Heldmeyer and Locklear, 1977; Van Sommers, 1984). One may not be able to draw exactly what one sees (or visualizes mentally) because of the challenges of holding drawing implements, planning considerations for placing strokes, the effects of well-practised routines for drawing (e.g. for people, houses, etc.), task parameters and cultural biases (e.g. writing systems, artistic styles, stock imagery). Drawings are best viewed as products of a complex process involving the interaction of motor, cognitive and task components.

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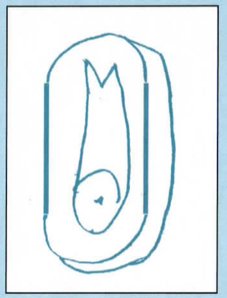
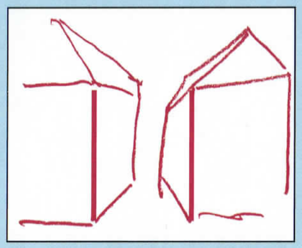
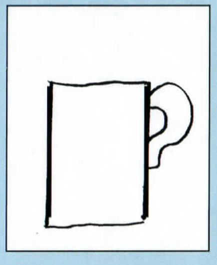
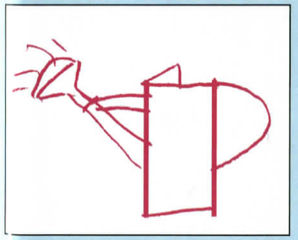
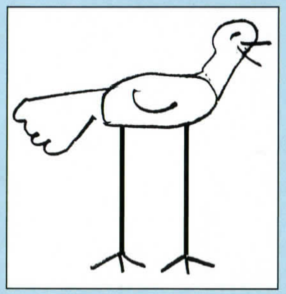
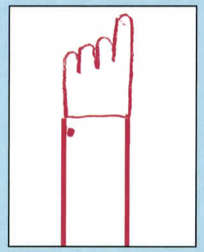
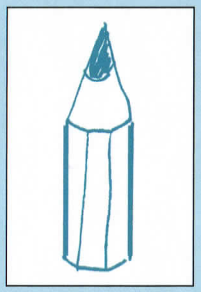
Drawing and the Non-Verbal Mind

A Life-Span Perspective

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