Developmental Analysis of Drawing Sequences: How Young Children and Adults Organize Object Parts in Line Drawing

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Abstract

The drawing process (how we draw), together with its outcome (what we draw), provides valuable insights into the cognitive mechanisms and motor control underlying symbolic representation. To depict developmental changes in the drawing process, this study examined the drawing sequences of Thai-speaking adults and 4- to 5-year-olds during an object copying task. After segmenting the drawing process into discrete strokes and annotating each stroke with its corresponding object part, we extracted patterns distinguishing adults' and children's drawing sequences. Results indicated that when drawing a quadrangle part that forms the overall structure of an object (e.g., a chair's backrest), Thai adults complete it with multiple strokes, while children typically use one stroke. Moreover, when drawing objects with hierarchical structures (e.g., a tournament), most adults group parts of the same level, while young children tend to draw parts in physical proximity sequentially. This study proposes a method for analyzing developmental changes in drawing sequences and highlights key questions for future developmental research on drawing, object recognition, and symbolic representation.

Keywords: drawing; sequences; symbolic representation; developmental psychology; NLP

Introduction

The ability to process hierarchical structured sequence is claimed to be vital for the language processing of human beings (Friederici et al., 2006). The process of drawing, which is suggested to share neural networks with language, has also been reported to exhibit hierarchical structures (Makuuchi, 2010). In the currency study, hierarchical structure in drawing sequence is addressed by analyzing how individuals combine or segment specific object parts, specifically whether they group object parts in temporal contiguity rather than based on their spatial proximity. For instance, when drawing a human face from the front, people turn to draw both eyes continuously, followed by both eyebrows. In contrast, sequences such as drawing one eye and its corresponding eyebrows before moving to the other side are relatively rare. This tendency in drawing sequences may be explained by the ease of execution, but it could also be attributed to object recognition. One way to better understand the origins of this typical drawing sequence is to examine how it develops from childhood to adulthood. In the current study, understanding developmental changes in drawing sequences requires investigating at least two aspects: (1) the structure of the drawing outcome–how it can be segmented into meaningful parts, and (2) the structure of the drawing process–how the act of drawing is organized.

Research based on children's drawing outcomes has been conducted for over a century (Hurlock & Thomson, 1934; Strommen, 1988). Previous studies examining the objects depicted and the processing of drawn information have provided insights into the role of drawing in perception, memory, motor and social cognition (Fan, Bainbridge, Chamberlain & Wammes, 2023). Since the drawing outcome itself does not include segmentation information, the first step to approach the structure of drawing requires dividing the drawing object into multiple parts. Physically, any subset of an object could be considered a "part" of it (Singh & Hoffman, 2001). However, it is necessary to distinguish between an object's geometry unit and its semantic components. Unlike basic geometry units (e.g., circles and lines), semantic components of an object (e.g., eyes and eyebrows in drawings of a human face) reflect both how we visually parse objects and how we recognize the object based on conceptual knowledge. Our study focuses specifically on semantic components of objects, and the term "object part" will specifically refer to these conceptually meaningful elements in this paper (see the Method section for details). Previous research has demonstrated that these semantic components can be identified based on drawing outcomes. For instance, Wang, Polikarpova, and Fan (2021) developed a computational model that recognizes semantic components by analyzing common structural elements in a dataset of line drawings, using information regarding location and shape of each part. Their findings further support the role of conceptual knowledge in object recognition.

The semantic components of drawing serve as a bridge between objects in the visual world and their representation in visual conceptual knowledge. In this context research on missing object parts in drawings (Freeman, 1975; Dillon, 2021), and drawing inaccuracies (Cohen & Bennett, 1997) also offer valuable insights into how conceptual knowledge is formed and how it relates to the visual world. Furthermore, conceptual knowledge could be shared by both the individual producing the drawing and the observer recognizing it. From a developmental perspective, Long and her colleagues investigated the recognizability of children's drawings, analyzing drawing works from 4- to 8-year-olds based solely on conceptual prompts (e.g., the instruction "Can you draw a rabbit?"). The results of their annotation demonstrated that children's drawing of visual concepts become more recognizable and informative with age (Long et al., 2024).

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However, while previous research has examined object parts in drawing, investigation of drawing sequence–indicating organization of these object parts–remains largely unexplored. Research on grammar of action can be tracked by the 1950s, when Lashley (1951) suggested that the serial order of many skilled motor actions displays a syntax or general pattern. Furthermore, Greenfield and her colleagues have done a quantity of work discussing the emergence of "hierarchically organized sequential behavior" (Greenfield, 1991). For example, Greenfield and Schneider (1977) discussed the sequence and object combination strategy when building a presented tree structure using Constructo Straws by children aged from 3 to 11. Beagles-Roos and Greenfield (1979) examined how 4- to 5-year-olds build structure in two-dimensional pictures such as flowerpot models with different hierarchical complexity. With respect to construction of three-dimensional structures, Goodson & Greenfield (1975) examined how children aged 2 to 6 assembled a modeled construction using a set of provided blocks. Their work identified two distinct strategies–later named "uninterrupted" and "interrupted" strategies (Greenfield & Schneider, 1977). For instance, when building a bench composed of five blocks (two fundamental blocks, two nail-like blocks, and one bridge block), children using the uninterrupted strategy completed one subunit, secured it with the bridge block and then moved to the opposite side, following the spatial arrangement of the parts. In contrast, the interrupted strategy involved first positioning two fundamental blocks at the same level and placing the bridge block to connect them, before returning to each side to secure and complete the respective subunits (Figure 1). Analogizing the grammar of natural language, Goodson & Greenfield (1975) suggested that children's block constructions followed predictable, rule-governed patterns, similar to syntactic rules in language. Younger children tended to use simpler, linear sequences, while older children demonstrated more complex, hierarchical structures.

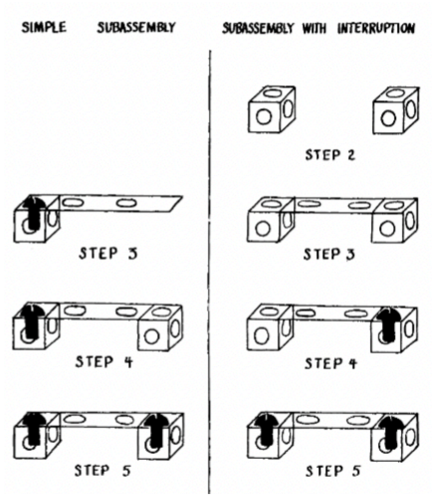


Figure 1: Action sequence patterns when constructing a bench (Goodson & Greenfield, 1975)

Prior research also indicates that drawing behaviors can be influenced by sociocultural factors (e.g., Japanese vs. the United States: Toku, 1992, 2001; the United States vs. China: Long et al., 2023; Australia vs. Vietnamese/Kampuchea: Brown, 1992) as well as by the writing systems of one's native language (e.g., Goodnow et al., 1973). While much of this work has compared Eastern and Western cultural groups, it is also important to consider variation within Asian populations. The present study focuses on Thai speakers–a population whose writing system exhibits relatively low similarity to the stimuli used in this study (for an overview of the Thai script, see Kasisopa et al., 2016)–in order to control for potential influences of experience with logographic writing systems such as Chinese and Japanese, on drawing sequences (e.g., some Chinese characters contain components resembling quadrilateral shapes in our stimuli).

Accordingly, previous studies have shown that children exhibit hierarchically structured action sequences when constructing models across a range of domains, and that the ways in which they combine objects develop throughout childhood. Building on this work, the present study investigates whether the process of drawing–as a form of symbolic representation–also demonstrates developmental changes from the preschool years to adulthood, as reflected in the organization of object parts in drawing sequences. Specifically, we aim to (i) introduce an experimental method for recording drawing sequences, (ii) apply feature extraction methods from the field of Natural Language Processing to identify characteristic drawing sequence patterns in Thai-speaking adults and children, and (iii) to highlight critical questions for future research on developmental change in drawing, object recognition and symbolic representation.

Methods

Object-copying Task

To maintain consistency in object representation and part structure of object parts across participants, we employed an object-copying task using line-drawn stimuli (Makuuchi, 2019) instead of a free-drawing task with linguistic prompts (e.g., Long et al., 2024).

The current study further adopted this task to examine the drawing process of native Thai speakers aged 4 to 5 and adults. Unlike language production, the final drawing does not inherently convey the sequence in which strokes were made, necessitating real-time recording of the drawing process. Specifically, measurement of pen pressure is required for dividing the drawing process to multiple strokes, and recording of point position is necessary to record the drawing contents.

Participants

A total of 74 participants took part in the study: 40 children (M = 4.9 years, SD = 0.7 years) and 34 adults (M = 18.9 years, SD = 0.3 years), all native Thai speakers.

Procedure, Stimuli and Equipment

Participants were asked to copy a series of line-drawn objects onto a sheet of paper placed in front of them on the table, drawing each object one at a time. The experimenter instructed them to replicate the object displayed on a screen, ensuring all parts were drawn as completely as possible. After an initial practice trial using an image of a tomato, the experiment commenced. Adults and 4- to 5-year-olds were required to copy 30 and 12 objects, respectively. The stimuli remained visible throughout the task, and participants were given unlimited time to complete each drawing.

The stimuli consisted of both common objects (e.g., a flower) and abstract geometric shapes (e.g., a fence-like pattern). The drawing process was recorded using a digital pen (Anoto DP-201) that captured pen position and pressure in real time. Participants used specialized paper compatible with Elian software (developed by Seldage Co.), allowing for precise tracking and replaying of the drawing process. To ensure consistency across participant groups, both adults and children completed the task using identical digital pen and specialized paper (Seldage Co.). This setup ensured a drawing experience comparable to using a standard ballpoint pen on paper. Using this setup, we recorded the coordinates and pressure of pen points as participants performed an object-copying task. This allowed us to segment the drawing process into discrete strokes.

Data Analysis

How people find parts and how people describe them could be different issues (Singh & Hoffman, 2001). Hoffman and Richards (1984) argued that the mechanisms for identifying object parts are more fundamental and that parsing visual objects relies on general computational rules.

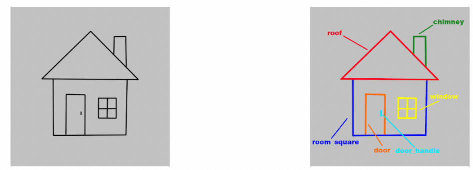
In our study each object in the experimental stimuli was segmented into meaningful object parts, which serve as fundamental units for analysis. By annotating which object part each stroke represented, we obtained a sequence of object parts that emerged during the drawing process.

Drawing sequences are represented as ordered lists of object parts, analogous to sentences or phrases in natural language. This structural similarity allows for the application of Natural Language Processing (NLP) and text mining methods to analyze drawing sequences (see the section "Extraction of Drawing Seuquence Patterns"). To investigate developmental changes, we conducted a logistic regression analysis to determine which object part co-occurrences distinguish adults' and children's drawing sequences. This approach enabled us to extract sequential patterns characterizing differences between the two groups. Details of the data analysis process are outlined below.

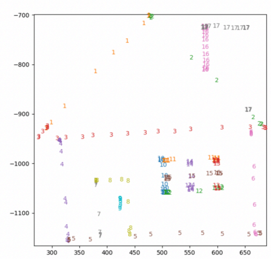
Mapping Drawing Strokes to Object Parts

The first step in preprocessing involved annotating the corresponding object part for each stroke. As illustrated in Figure 2, the object "house" was segmented into meaningful units such as "roof", "door" and "chimney". The drawing process recorded by the digital pen was exported as a dataset containing timestamps, coordinates, and pen pressure data. Figure 2c presents a plot of an example drawing, where each stroke is color-coded and labeled with its chronological order (e.g., points marked with "3" constitute the third stroke).

(a) Drawing object presented (b) Object parts segmentation



(c) Drawing sequences expressed in strokes



(d) Drawing sequence expressed in object parts

Stroke Number	Object Parts
…	…
3	roof
4	room_square
5	room_square
6	room_square
7	door
8	door
9	door_handle
…	…

Figure 2. Preprocessing steps for the object "house"

In some cases, two specific issues arose: (i) A single object part was drawn using multiple strokes, and (ii) A single stroke contained multiple object parts. To address (i), we distinguished cases where an object part (e.g., the "room_square") was drawn in one continuous stroke versus multiple strokes (Figure 2d). Regarding (ii), we updated the stroke numbering to ensure that each stroke corresponded to a single object part. For example, if a participant drew the "roof" and then the "room_square" within the same stroke, the third stroke would be labeled as "roof" and the fourth as "room_square", preserving only the relative order of object parts in the final dataset.

Three independent annotators evaluated the object part each stroke represented. Discrepancies among annotations were resolved through discussion. Strokes classified as unrelated "points" or "lines" were excluded from further analysis. If consensus could not be reached on a stroke, it was labeled as "unrecognizable". If more than three strokes in a single drawing were deemed unrecognizable, the entire drawing was excluded from the dataset.

Extraction of Drawing Sequence Patterns

By drawing an analogy between word co-occurrence in sentences and object part co-occurrence in drawing sequences, we applied NLP techniques to extract meaningful patterns. We conducted a logistic regression analysis, where object part patterns served as explanatory variables and participant group (adults vs. children) as the response variable. For this analysis, we limited co-occurrence patterns to pairs of object parts, although similar methods could be applied to sequences of three or more parts. We fitted a logistic regression model with an L1 regularization term (penalty = “l1”, solver = “liblinear”) implemented in the scikit-learn package. Unlike L2 regularization, L1 regularization can shrink some coefficients exactly to zero, retaining only predictors that contribute to prediction. The regularization parameter (C), which controls the inverse strength of regularization, was fixed at 1 following preliminary analyses. We did not standardize count features so that coefficients retain the unit-count interpretation. Coefficients were interpreted as log odds ratios. Positive coefficients indicate higher likelihood of the corresponding object-part pattern appearing in children’s drawings, and negative coefficients indicate higher likelihood in adults' drawings.

Results

In this section, we present representative characteristics of drawing sequence patterns in adults and children, focusing on how they organize object parts in their drawing order.

Segmentation Tendency

Thai adults and young children demonstrated differences in segmentation when drawing object parts with quadrilateral shapes (e.g., the “room_square” part of a house; see Figure 2b). As shown in Figure 3, the logistic regression analysis identified the co-occurrence pattern “room_square → room_square” with a coefficient of -1.43. This corresponds to an odds ratio of 0.24, indicating that each additional occurrence of this pattern in a drawing sequence decreases the odds that the sequence belongs to the young children group by 76%. These results suggest that Thai adults tend to segment the “room_square” into multiple strokes, whereas 4- to 5-year-olds typically complete it in a single stroke.

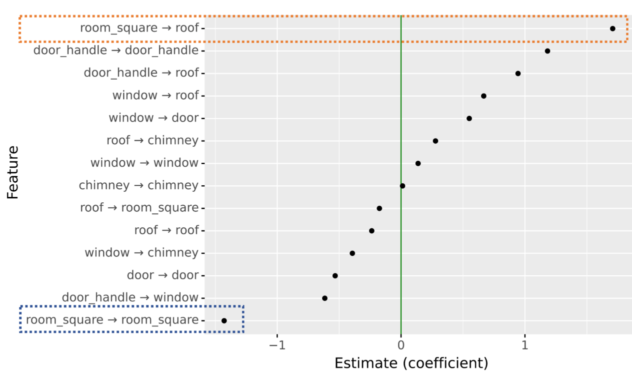


Figure 3. Distinct drawing sequence patterns for the “house” object in adults and children

A similar tendency was observed in the drawing sequence of a “chair”. The logistic regression analysis revealed a negative coefficient (-3.3) for the object part pattern “back → back” (Figure 4b), indicating that this pattern was more characteristic of the adult group than children group. Specifically, 33 out of 34 adults segmented the back part of the chair into multiple strokes (Figure 4c), whereas only one out of 36 children exhibited the same segmentation pattern. A chi-square test confirmed a significant difference in segmentation tendency between the two groups ($\chi^2 (1) = 62.2$, $p < .0001$).

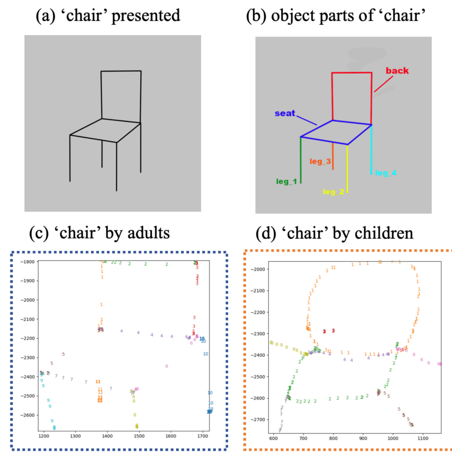


Figure 4. Object part segmentation and samples of drawing sequence of the object “chair”

Combination Tendency

Some line drawing objects in our stimuli, such as “tournament” and “tournament of semicircles” (Figure 5), contain hierarchical or recursive structures. Within these objects, if object parts belonging to the same rank are treated as units at the same hierarchical level, and if drawing sequences directly reflect the object’s hierarchical structure, then parts within the same rank should be produced consecutively during the drawing process. For example, when drawing a “tournament”, “rank1_3” and “rank1_4” should be completed before processing to “rank2_2”. Likewise, “rank1_1” and “rank1_2” should be drawn consecutively, either before or after “rank2_1”.

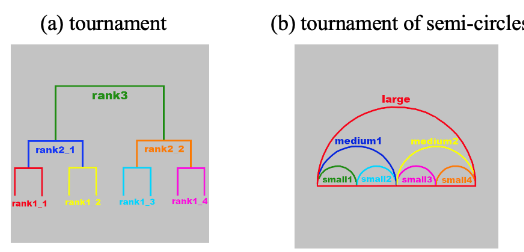


Figure 5. Object part segmentation in “tournament” and “tournament of semicircles”

The logistic regression analysis identified serial sequence patterns that were more likely to appear in children’s drawing sequences, specifically “rank1_3 → rank2_2” and “rank2_1 → rank1_2” (Figure 6). The regression analysis suggests that young children more frequently transit between different hierarchical levels when drawing the "tournament" object, whereas adults tend to complete object parts within the same level before progressing to another.

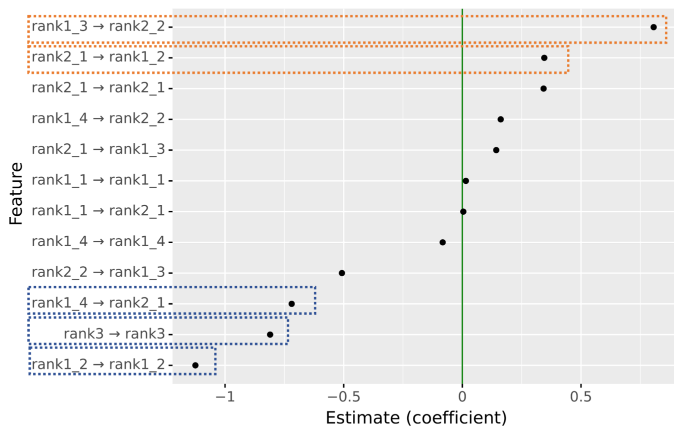


Figure 6. Distinct drawing sequence patterns for the "tournament" object in adults and children

Furthermore, the co-occurrence sequence pattern "rank1_4 → rank2_1" had a negative coefficient, indicating a higher occurrence rate in adult drawings. This suggests that adults are more likely to draw object parts within the same hierarchical level sequentially. Figure 7 shows representative examples of recorded drawing sequences produced by adults and children. Similarly, in the regression analysis of the "tournament" object, the pattern "rank3 → rank3" was more prevalent in adult drawings, consistent with the previous finding that adults segment quadrilateral-shaped parts into multiple strokes, whereas children complete them in one.

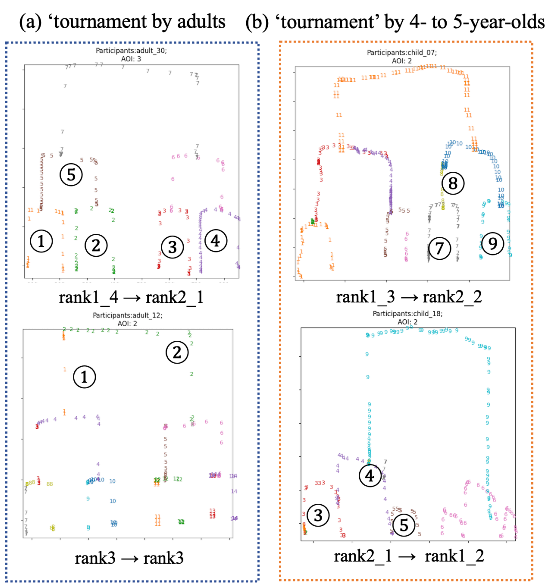


Figure 7. Sample drawing sequences for "tournament"

4- to 5-year-olds exhibit a tendency to alternate between object parts from different hierarchical levels. However, this tendency is less evident in their drawings of the "tournament of semicircles" (Figure 5b). In the children's dataset, the sequence "rank1_1 → rank2_1" was observed in "tournament" drawings, but analogous patterns (e.g., "small1 → medium1") were absent in "tournament of semicircles". These findings suggest that children tend to group and draw spatially proximate object parts together. In "tournament of semicircles", because object parts at the same hierarchical level are also adjacent, children tend to follow a level-based drawing sequence.

Directionality of Drawing

The organization of object parts also reflects the directionality of drawing sequences. For example, in the "house" object, the regression analysis identified the sequence pattern "room_square → roof" as more likely to appear in children's drawings (Figure 3). This suggests a bottom-to-top drawing direction when constructing a "house". Moreover, in the analysis of drawing sequences of the "tournament", the pattern "rank2_2 → rank2_1" had a higher occurrence rate in children's drawings (Figure 6). This suggests a right-to-left drawing direction when constructing the "tournament" object.

Discussion

This study proposed methods for representing and recording drawing sequences based on pre-specified object parts. Furthermore, we developed techniques for extracting sequence patterns that distinguish the drawing processes of adults and 4- to 5-year-old children. Our preliminary findings, based on drawing sequence data from Thai-speaking adults and young children, revealed the following tendencies: (i) when drawing quadrilateral-shaped parts which constitute the global structure of an object, Thai-speaking adults tend to segment these parts into multiple strokes, whereas children typically complete them in a single stroke., (ii) when drawing objects with hierarchical structures, adults are more likely to complete all parts at the same hierarchical level before moving to other parts, and in contrast, children's drawing sequences are more influenced by the physical proximity of object parts, and (iii) directional tendencies such as left-to-right and bottom-to-top sequences, are more commonly observed in young children's drawings.

As a case study, these findings underscore the importance of investigating the developmental processes underlying drawing sequence. However, there exist some limitations in our analysis methods. Our analysis of drawing sequences was based on the unit of "object parts", which are meaningful components of line-drawn objects. The role of semantic understanding in children's drawing development has long been a topic of interest, particularly regarding object recognition, representation, and conceptual knowledge (Freeman, 1975; Freeman & Janikoun, 1972; Willats, 1981; Cohen et al., 2000). Prior research also suggests that semantic meaning influences visual learning and object-copying tasks (Lee, 1989). In our study, it remains to be verified whether children recognize individual object parts (e.g., "chimney" or "door_handle" of "house" in Figure 2) while copying drawings. Because our analysis of object parts relied on annotations provided by third-party coders, it is possible that these annotations did not always correspond to the object parts that participants themselves intended to draw. The inability to recognize which object part each stroke represented also caused high data exclusion rates, particularly in the young children group. Incorporating self-report methods–such as asking children to identify which part they drew after completing the object-copying task–may help improve the robustness of our data analysis. Furthermore, the feature extraction method we proposed is based on logistic regression, which restricts its applicability to comparisons between two age groups. Future work should refine and extend this method so that it can accommodate three or more developmental stages, enabling a more fine-grained analysis of developmental changes in drawing sequences.

Despite the above limitations, our research exhibits some essential questions for future research regarding children's drawing development, especially related to symbolic representation. For instance, in addition to familiar objects, our study included stimuli with recursive and hierarchical structures (e.g., "tournament"). Prior research has examined the cognitive processing and generation of recursive patterns (Dedhe, Piantadosi, & Cantlon, 2023; Ferrigno et al., 2020). Integrating drawing sequence analysis with recursive pattern research could provide further insights into how children process complex structures. Additionally, studies suggest that understanding the relationship between whole objects and their constituent parts is crucial for word learning (Soja, Carey, & Spelke, 1991). Our findings indicate that 4- to 5-year-olds frequently draw a house in a bottom-up manner, which differs from adults' typical top-down drawing sequences but aligns with real-world construction experiences. This indicates that drawing direction may reflect children's knowledge or experiences with physical objects. Future research should explore the connections between sequential structures in language, drawing, and object-related knowledge.

As drawing is a form of symbolic representation, its function in social communication is particularly relevant. The Winnicott squiggle game exemplified the communicative power of drawing (Caldwell & Robinson, 2016; Berger, 1980; Huey, Lu, Walker, & Fan, 2023), while interactions during drawing activities help shape the interpretation of visual objects (Hawkins, Sano, Goodman, & Fan, 2023). The close relationship between drawing production and recognition has been highlighted in previous research (Landsmann & Karmiloff-Smith, 1992; Long et al., 2024).

In our experiment, participants were instructed to copy a given line drawing (e.g., "Please copy this face"). However, many young children appeared to interpret the stimuli as symbolic prompts rather than as strict templates for reproduction. That is, they treated the task as an invitation to draw a "face" in their own way, rather than replicating the given image. While this symbolic interpretation created challenges for the object-copying task–leading to high exclusion rates during preprocessing–it also provides insights into how children conceptualize and recognize drawings (Long et al., 2024). The addition or omission of object parts may reflect underlying cognitive processes related to conceptual knowledge (Karmiloff-Smith, 1990). Moreover, studying how children's drawings are interpreted by others is crucial for understanding the social function of drawing (Hawley-Dolan & Winner, 2011; Asaba & Gweon, 2022). Future research could examine how drawing sequences evolve during social interactions (e.g., communication, evaluation, or imitation).

Beyond stroke-based segmentation and object-part sequencing, other measures may further illuminate the drawing process. Prior studies have examined initial starting points and drawing direction in both spontaneous and instructed drawing tasks, identifying tendencies such as top-to-bottom and left-to-right sequences (Gesell & Ames, 1946; Kellogg, 1969; Goodnow & Levine, 1973; Pemberton, 1987). When drawing complex objects composed of basic shapes, it remains an open question whether these fundamental directional principles persist or adapt.

Additionally, visual observation strategies play a key role in chunk decomposition (Roller & Cheng, 2014), and gaze frequency has been linked to drawing accuracy (Cohen, 2005). In object-copying tasks, the duration before initiating drawing is influenced by object complexity and recognition processes (Makuuchi, 2019). Investigating observational and cognitive activities during drawing may yield further insights into object representation and drawing development.

As an initial step, this study focused on Thai-speaking participants (see the Methods section for details on participant selection). A crucial next step is to compare drawing sequences across different linguistic and cultural groups. Prior research has explored the relationship between language processing and hierarchical sequence structures (see Introduction). Investigating how drawing sequences relate to language structure in diverse populations–particularly in light of typological variation (Dryer & Haspelmath, 2013)–may provide deeper insight into the cognitive mechanisms underlying drawing development.

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