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THE ROLE OF CHUNKING IN DRAWING REY COMPLEX FIGURE

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Summary.—The study investigated the effects of chunking and perceptual patterns that guide the drawings of Rey complex figure. Ten adult participants (M age = 22.2 yr., SD = 4.1) reproduced a single stimulus in four drawing modes including delayed recall, tracing, copying, and immediate recall across 10 sessions producing a total of 400 trials. It was hypothesized that the effect of chunking is most obvious in the free recall tasks than the tracing or copying tasks. Measures such as pauses, patterns of drawings, and transitions among patterns of drawings suggested that participants used chunking to aid rapid learning of the diagram. The analysis of the participants’ sequence of chunk production further revealed that they used a spatial schema to organize the chunks. Findings from this study provide additional evidence to support prior studies that claim graphical information is hierarchically organized.

The process of drawing is increasingly of interest among educators to be adopted as a method to facilitate the learning experience. This is often practiced by teachers teaching early childhood education, when young children are introduced to doodling or drawing to communicate freely, particularly children with low literacy skills (Young & Barrett, 2001). There are many modes of drawing. For example, the tracing mode commonly requires the drawer to outline the figure, i.e., shown in dotted or faded lines. The copying mode requires the drawer to refer to a target figure while reproducing the reference figure as accurately as possible. Another mode of drawing can be referred to as recall from memory, where reproductions of the target figures are drawn based on recall of the previously seen figure, without any reference to the target figure at the time of drawing. Recall from memory drawing tasks are useful to test a learner’s understanding of a particular concept that a figure expresses.

An interesting question arising from drawing by using these various modes relates to the kinds of strategies people use to reproduce figures. A better understanding on how these different modes of drawings affect the strategy of reproduction will be able to explain the effectiveness of using these modes of drawing in education to benefit the learning process. Furthermore, if a figure is repeatedly drawn using these modes over a specified period, little is presently known about the kinds of effects they produce on how well the graphically learned materials are recalled, such as whether tracing (as compared to copying) is a better drawing mode that can be used to improve the rate of recall of a particular figure. The mental structures representing the knowledge acquired from graphical material remain unclear. Previous studies (Bower, 1970; Palmer, 1977; McNamara, Hardy, & Hirtle, 1989) on mental representation associated with semantic and spatial memory have collectively proposed that information of these types are hierarchically organized. In this type of mental representation, information such as ‘items to be remembered’ is categorized based on shared similarities such as functions or properties (i.e., apples and oranges are considered fruits, while roses and camellias are flowers). This mental representation comprises many levels, the most general information being the represented at the highest level and the most specific unit of information at the lowest level. These units of information are referred to as chunks (Miller, 1956), defined as a group of related information that shares related characteristics and normally appears in sets or small groups (Miller, 1956; Tulving, 1962; Chase & Simon, 1973; Buschke, 1976). For example, studies on semantic recall typically employ word association or categorization of word lists to assess the effects of semantic structure on retrieval. Thus, the highest level of the hierarchy consists of category names that correspond to larger categories (e.g., animal),

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and the lowest level consists of smaller category names (e.g., dog, bird) (Collins & Quillian, 1969, 1970). Mental representation of meaningful knowledge in this manner is referred to as a schema (Piaget, 1926; Bartlett, 1932); schemas organize the knowledge a person possess about the world, events, people, and action (Mandler, 1984; Brewer, 1999).

It would be interesting to know whether drawing actions are guided by a perceptual pattern or the existing chunks and schemas established by and cultivated from prior experience, such as those developed in childhood, have a greater influence on drawing. One approach proposed by Gestalt theory’s perceptual principles (Wertheimer, 1923) posits that units of elements are retrieved based on the principles of grouping together items according to shared characteristics such as proximity (i.e., items are spatially close together), similarity (i.e., items are similar in shape, color, or size), common fate (i.e., items appear to move in the same direction), good continuation (i.e., points for smooth curving lines are seen as belonging together following the smoothest path), closure (i.e., items are perceived as complete figures even parts of the information is missing) and symmetry (i.e., items are perceived as symmetrical that can be divided into an even number of symmetrical parts) (Wertheimer, 1923). Bartlett (1932), Egan and Schwartz (1979), Karmiloff-Smith (1990) and Palmer (1977) offered another approach. They reported that when people draw, they retrieve graphical components in groups of elements sharing similar functions akin to chunks (Bartlett, 1932; Palmer, 1977; Egan & Schwartz, 1979; Karmiloff-Smith, 1990). These functions serving similar purpose are not necessarily consistent in terms of the characteristics described by the Gestalt’s perceptual principles. This means, the elements of a chunk do not have to belong to a strictly Gestalt principle of groupings, such as whether all members of elements for a chunk share a symmetry pattern. For example, Egan & Schwartz (1979) who sought to provide evidence of expertise between skilled and unskilled participants on symbolic diagram reading reported that experts recalled symbols based on functional units sharing related operations, rather than if the appearance of the symbolic representation look similar. The study reported in this paper describes an experiment that supports the second approach. Elements retrieved in chunks of figures obtained from graphical material may be derived from an organized schema such as that described in a hierarchical structure (Palmer, 1977; Koedinger & Anderson, 1990).

Van Sommers (1984) investigated the strategies used by adults when copying simple patterns. He developed a cognitive model of drawing positing that the process of drawing consists of an interaction between two hierarchical systems: the visual perception and the graphical production systems. Guérin, Ska, and Belleville (1999) accepted van Sommers’ (1984) model as a comprehensive cognitive model of graphical production that incorporated principles governing drawings from a mechanical (i.e., action) and cognitive (i.e., perceptual) point of view. Van Sommers (1984) proposed that drawing processes are influenced by graphic rules. One of the rules van Sommers (1984) described suggests that participants adopt common principles such as a preference for drawing in a counterclockwise direction when drawing a circle at a starting point above a virtual axis (e.g., top half of the circle such as going from 11 o’clock to 5 o’clock), whereas they use a clockwise movement when a starting point is on the lower half of the circle. This approach indicates that drawers commonly employ strategies that improve motor efficiency (i.e., the movement of the hand and fingers that influence drawing behavior), because the frequency of hand movements decreases with temporal and spatial accuracy. In response to this notion, Burke and Roodenrys (2000) and Vinter and Perruchet (2002) further proposed that in relation to learning from drawings, the factors that influence the effectiveness of a drawing task are the level of observation, the directionality of drawing movements, the size of the figure, and the average speed of hand movement. This means that the movement of the hand increases as the size of the figure to be drawn becomes larger. On this assumption, it is necessary for the drawer to apply selective attention, emphasizing drawing groups of preferred components chosen from the respective whole figure, when strategizing an efficient execution (Farran, Jarrold, & Gathercole, 2003). The selection of these parts, relative to chunks, may potentially rely on a hierarchical organization and schemas (Palmer, 1977; Koedinger & Anderson, 1990). Alternatively, the elements may be selected line-by-line irrespective of any grouping relations between the lines during the planning process, prior to the execution of any drawing actions. The present study will assess whether graphical elements may be retrieved in a hierarchical manner, predicted to consist of chunks, corresponding to the notion of schemas as suggested by Palmer (1977).

Palmer (1977) presented a framework for perceptual representation in the assessment of drawing tasks, such as verifying parts within a figure and synthesizing the figure from separate parts. Participants were asked to draw and rate simple straight-line figures in various configurations. He proposed that graphical
elements (i.e., simple, straight-line figures consisting of 16 segments) are processed in units that integrate hierarchically, forming a complete network of chunks (units of elements) which he defined as a schema. According to Palmer, the use of a schema is advantageous during information selection for further processing, including the analysis of the selected data and eye fixation on specific data of interest. Thus, a unified and coherent integration of visual-spatial properties is made up of a hierarchy of progressively more detailed and complex visual components from individual segmented patterns to complex figures. This hierarchy of visual-spatial properties provides a way to envision the organization of graphic information.

The use of chunks in the drawings of simple geometrical shapes has been reported by Cheng, McFadzean, and Copeland (2001) and Obaidellah and Cheng (2009). In a different experimental setting, Karmiloff-Smith (1990) found that children used chunks and schemas in their graphical productions when they were asked to draw usual and unusual (i.e., items the children usually see are defined by Karmiloff-Smith as existent and unusual items arrived from their imagination are defined as non-existent) sets of pictures (i.e., a house, an animal, or a man). For example, when instructed to draw a non-existent object, older children show a tendency to use chunks and schemas more noticeably as they are able to interrupt patterns of chunks (e.g., older children drew parts of a house while they were drawing a man) more easily than younger children (e.g., younger children drew a complete drawing of the house before adding the features of the man). This effect shows that younger children often perform whole parts of their drawings before they continue drawing a different part of a figure. Hence, with respect to drawings, the study reported by Karmiloff-Smith (1990) suggests that drawing in chunks of elements sharing similar characteristics could have been guided by the individual’s knowledge of the world, based on personal experience and principled understanding of a particular concept or event (i.e., a schema). Vinter and Picard (1996) reported similar findings. According to Vinter and Picard (1996), the effects of chunks were apparent when children (both younger and older) decomposed the objects into basic components (e.g., a house consists of a body, a roof, windows, and a door). Each of the components is formed by an integration of several elements. The errors in the drawings were: change of size, deletion, replication, changes of position or orientation of elements, modification of whole shape, assimilation to another object, and the ability to adopt a cross-category change (e.g., drawing wings belonging to the animal domain to the side walls of the house domain) from different domains in the middle of their drawing activity (i.e., inter-representation change). Younger children were more commonly observed to demonstrate intra-representational element-based changes, a condition where drawings occur within categories and within chunks (i.e., complete their drawings of all elements associated with the animal domain before they begin drawing elements associated with the house domain). In contrast, older children tended to show inter-representational whole-based changes, which indicate that they integrate and access components from different categories. Therefore, older children could manipulate the drawings by integrating different components from distinct categories more flexibly rather than only elements within a specific component from a single category.

Although Palmer (1977) suggested that while a simple graphical diagram consists of three levels, the potential number of hierarchical levels in a complex diagram is unclear. Further, no studies (Palmer, 1977; van Sommers, 1984; Karmiloff-Smith, 1990) have investigated the selection and order of execution of parts from the whole figure in drawing strategies for different types of drawing tasks, such as tracing, copying, and recall from memory. It is important to discover how these drawing tasks facilitate a drawer’s learning from diagrams. The drawing mode, whether tracing or copying, which facilitates learning the most is still unknown (Gonzalez, Anderson, Culmer, Burke, Mon-Williams, & Wilkie, 2011). Improved understanding will enable proper complexity of graphical materials used for learning, particularly in educational subjects such as physics and chemistry. In addition, at present, little is known about how graphical elements are stored mentally and retrieved with respect to drawing mode. Although, van Sommers (1984) successfully demonstrated that common drawing practices (i.e., a sequence of graphical productions such as the anti-clockwise approach when writing the letter ‘O’ among right-hand writers) are generally applied among individuals regardless of age, gender, and cultural background, it is presently uncertain if this generalizes to relatively complex diagrams.

The main purpose of this study is to determine if drawings based on different modes (i.e., tracing, copying, immediate recall from memory, and delayed recall from memory) are more likely driven by strict perceptual patterns or by an influence of chunks and schemas. The previously discussed research (Cheng, et al., 2001) used simple and straight-line figures as stimuli. In this study, a more complex figure was employed as a stimulus to compare drawing strategies to those used for simpler diagrams (Palmer, 1977; van
Sommers, 1984) are presented. The goal was to investigate the types of strategies (i.e., order of elements drawn) used to reproduce the complex figure in different drawing modes. Data from ten adult participants who reproduced the Rey figure in four modes of drawings across ten sessions producing a total of 400 trials were analysed. As previously discussed, the participants may adopt any or a combination of the following potential strategies: (1) drawing patterns in an arbitrary order based on Gestalt principles, e.g., selection of drawn elements based on symmetry before those elements in close proximity; (2) drawing lines that maximize motor efficiency; (3) using some kind of hierarchical structure. Finally, if a hierarchical structure is used, it was of interest how the elements of the figure would be represented in the hierarchy. Hence, the motivation is further developed by investigating which of these strategies show the strongest influence in the drawing protocols.

**Hypothesis 1.** Drawers will recall and reproduce graphical elements of a figure in chunks that are derived from an organized schema in the form of a hierarchical structure.

**Hypothesis 2.** If chunking strategies are adopted, the production of the drawings will be more consistent, demonstrated by regular patterns of chunks (i.e., each chunk consists of the same collection of elements), and will reduce the number of transitions between elements as compared to higher transition counts when no chunking strategies are used (i.e., elements were drawn randomly) or if irregular chunk patterns are drawn.

**METHOD**

**Participants**

Ten adult (6 men, 4 women) undergraduate and postgraduate university students participated in the experiment. Their ages were between 21 and 30 years ($M=22.2$ yr., $SD=4.1$). Eight of them were right-handed and two were left-handed. Eight participants had normal vision, while two of them had corrected-to-normal vision. All had sufficient fundamental experience with drawing scientific figures, as all of them had science education backgrounds. There were no specific criteria for the selection of their participation. However, the pool of participants was focused on trained drawers (i.e. university students) as we were interested to investigate our research aims among normal and healthy adults. Thus, the university community serves as an ideal choice for this. None of them had memory, drawing, or motor impairments as demonstrated by successful drawing of simple shapes prior to the experiment. Each participant received a small monetary reward for their participation.

**Material**

All drawings were performed on a Wacom Intuos graphics tablet with a special inking pen. An A4 paper was taped on the graphics tablet in a landscape orientation and participants were required to draw a large figure on the blank sheet. A specially written program, TRACE (Cheng & Rojas-Anaya, 2004) was used to capture all drawing actions, extract pen positions, and compute pause durations between the drawn elements. The single stimulus adopted from the original Rey figure as shown in Fig. 1(a) was printed in black ink on a white sheet for all tasks in this experiment. Modifications such as blank spaces introduced at the ends of all lines were used to enable recording of the pauses that occur during the transitions between drawing strokes.

**Measures**

Four types of tasks were chosen. A Tracing task was administered to assess the effects and extent of chunking employed in drawings when little effort was necessary during retrieval. A possible approach taken in the Tracing task is to draw consecutive elements based on the nearest-neighbor strategy as an economical drawing method. To test whether parts of a figure are drawn in groups of related elements based on Gestalt principles, a Copying task was used to evaluate whether the process of copying parts of a figure would
change over time or the retrieval of the elements would exhibit a recurring and consistent pattern between and within individuals. An immediate recall task was used to study the effects and accuracy of retrieval from memory after recent exposure to the stimulus. A delayed recall task was used to study how coherently and precisely a figure could be reproduced following a delay as long as 24 hours.

As shown in Fig. 1(a), the Rey-Osterrieth Complex Figure (hereafter called the Rey Figure) was adopted with a few modifications (i.e., gaps in between lines, break longer lines into shorter ones) for the technique called Graphical Protocol Analysis (Cheng & Rojas-Anaya, 2008). The method measures the pause durations between the drawn elements, i.e., the time between the end point of the last drawn line and the starting point of the successive line. Graphical Protocol Analysis was employed as this method uses pauses as an indication of chunk boundaries, similar to other methods such as the standard reaction time, qualitative scores of drawings, and verbal protocol analysis (Egan & Schwartz, 1979; Karmiloff-Smith, 1990; van Mier & Hulstijn, 1993). The Rey Figure was chosen because of its extensive use in established empirical psychological studies related to memory tests. This relatively complex figure comprising 56 lines in various putative groups of elements is a suitable stimulus to assess the hypotheses.

Fig. 1. (a) Modified Rey Figure, (b) Default pattern, (c) L1 and L2 pauses.

Graphical Protocol Analysis is an improved method of analyzing drawing behavior compared to the standard reaction time technique, as data recording is accurate and the analysis is simpler: drawings are done on a graphics tablet to capture natural drawing actions, with accurate measurement of drawing and pause timing. A number of writing studies employing Graphical Protocol Analysis have demonstrated a coherent temporal pattern indicating the structure of chunks in memory during tasks such as writing number sequences, word phrases, and mathematical formulae (Cheng & Rojas-Anaya, 2005, 2006, 2007). The chunk patterns are indicated by statistically significant differences between the duration of the pauses at different hierarchical levels, and were observed in all of the above tasks (Cheng & Rojas-Anaya, 2008). Specifically in drawings, this method is adequate for the investigation of the internal mental representations when drawing simple geometric patterns (Cheng, et al., 2001). The present study will apply the Graphical Protocol Analysis method for all drawing activities obtained from more complex graphical stimuli.

As shown in Fig. 1(c), the two types of pauses examined in this experiment were coded as (a) L1-element within patterns, defined as the pauses measured between successive elements of the same pattern; and (b) L2-element between patterns, defined as the pause between the last line of a pattern and the first line of a different pattern. To facilitate and standardize the process of scoring the participants’ drawings, as shown in Fig. 1(b), the Rey Figure was decomposed into 13 patterns according to specific grouping criteria where each was named (e.g., gill, fin, eye, brow) following the terms used to describe the anatomy of a fish. These criteria, otherwise known as coding schemes, largely similar to the categorization criteria of Osterrieth (1944), Lezak (1983), and Corwin and Bylsma (1993), were developed to test the consistency of the sequence of the elements drawn by the participants (i.e., consistency of drawing patterns for both between and within participants) and to provide rules to resolve ambiguities in scoring confusing drawings such as whether an element or pattern is drawn by mistake, thus, should not be considered (e.g., if a participant...
draws a flag at the tip of the fin pattern) or should be accepted as part of the closely related pre-defined pattern (e.g., if a participant draws a slanting line instead of a straight vertical line to represent the element of the brow pattern).

**Procedures**

Experiments were conducted in independent sessions with each participant. They were initially given instructions about the tasks they were required to perform. Each participant completed 10 sessions with four tasks (i.e., Tracing, Copying, Immediate recall, and Delayed recall from memory) producing a total of 400 trials. The description of the tasks were: (1) Copying, in which the figure was reproduced on a blank piece of paper with the original figure placed next to the blank sheet; (2) Tracing, requiring replication of the figure printed in faded grey lines; (3) Delayed recall, a reproduction of the figure based on recall from memory. The target figure was presented prior to both of the copying and tracing tasks; (4) Immediate recall, in which the goal was to reproduce the figure based on recall from memory, after the copying and tracing tasks. The participants initiated the experiment with a practice task to familiarize themselves with drawing on a graphics tablet.

In the first session, all participants began with the Tracing task followed by the Copying task and the Immediate recall task. In the even-numbered sessions, the participants drew the figure in the order: Delayed recall, Copying, Tracing, and Immediate recall. In the odd-numbered sessions, the participants followed the order: Delayed recall, Tracing, Copying, and Immediate recall. Only the Copying and Tracing tasks were counterbalanced to reduce the possibility of an order effect, so that the results are less likely affected by the order of the stimulus presentation as the participants may develop a regular strategy applied in all the drawing activity if the same stimulus ordering were given in all 10 sessions. The Delayed and Immediate recall tasks were not counterbalanced as we were particularly interested to find if recall performance are statistically different prior and after executing both Tracing and Copying tasks.

In all drawings, participants began by writing a hash (#) to enable recognition of the time at which the figure is begun and to ensure drawing and thinking processes were underway. There was no time restriction for the duration of the drawings. The participants drew until they had nothing else to draw. They were given an option to end the session for the particular drawing task after being if they had anything else to draw. Most participants did not recall more elements. There was delay of at least one day, but no more than two days, between the Immediate recall task and Delayed recall task in the subsequent session. The inclusion of 10 sessions was meant to provide an opportunity for the participants to complete their learning process, so as to be able to perform chunking effectively.

**Results**

**Pause Analysis**

During drawings, a few of the participants made mistakes by drawing broken lines. The frequency of this kind of mistake was recorded as errors at the time of data pre-processing. The errors were divided into three categories according to the level and type of errors committed. For example, a structure error was defined as a type of error that was made when a participant produced lines that were too short, too long, or misplaced elements that could occur at the level of the entire pattern (i.e., drawing the eye pattern in the wrong location) or a single element of a pattern (i.e., drawing a single short line for the box pattern). However, the frequencies of these errors were very few (e.g., less than five in each session when aggregated across the participants) to qualify for a statistics test. Thus, given that these data were removed from the other data for analysis, the pauses used for analysis were due to changes between elements, and not the broken lines of a particular element. This coding is based on the experimenter’s observation as participants did the drawings. For example, the participants correctly traced over the original faded lines as can be seen in the hardcopies of the tasks. Thus, the pauses the participants establish were due to changes from one element to another and not during the drawing of that particular element.
As shown in Fig. 2, across all modes of drawing for all participants and sessions, the L1-within pattern pauses were shorter (within the range of 387–649 msec.) than the L2-between patterns pauses (695–1833 msec.). The L2 pauses were more variable. A test of equal variance on the pauses showed that the variances were unequal for the L1 and L2 pauses, \( F_{1,718} = 78.1, p < .001 \). A repeated-measures analysis of variance (ANOVA) used to examine whether differences exist between the L1 and L2 pauses for all drawing tasks investigated three main effects (i.e., task type, pause level, session) and four interaction effects (i.e., task type \( \times \) pause level, task type \( \times \) session, pause level \( \times \) session, task type \( \times \) pause level \( \times \) session). The kinds of data acquired for the analysis in this experiment are of type scale data (i.e., ratio).

The test showed all main effects were significant: task type \( F_{1.63,14.66} = 5.72, p < .05 \) using the Greenhouse-Geisser estimates of sphericity \( (\eta = 0.54) \) with effect size \( \eta = 0.39 \); pause level \( F_{1,9} = 89.39, p < .001 \) using Sphericity Assumed \( (\eta = 1.000) \) with effect size \( \eta = 0.91 \); and session \( F_{2.47,22.23} = 4.27, p < .05 \) using Greenhouse-Geisser estimates of sphericity \( (\eta = 0.31) \) with effect size \( \eta = 0.32 \). The degrees of freedom for the F values indicate the minimum number of variables that may vary independently after being applied with restrictions. These results indicate that the pauses differed between Tracing, Copying, Delayed recall, and Immediate recall tasks across the sessions and type of pause, consistent with Fig. 2. The Bonferroni post hoc tests revealed a significant difference between the pauses where the L2 pauses were longer \( (p < .001) \). All interactions were significant: task type \( \times \) pause level \( F_{1.59,14.26} = 7.86, p < .05 \); task type \( \times \) session \( F_{24, 216} = 2.40, p < .001 \); pause level \( \times \) session \( F_{2.25,20.26} = 4.23, p < .05 \); task type \( \times \) pause level \( \times \) session \( F_{2.24,216} = 1.69, p < .05 \), showing that when compared between L1 and L2 across the sessions, all modes of drawing had significantly different pause lengths. Further analyses were done on L2 pauses to find if differences occur between the types of tasks. However, the Bonferroni post hoc tests only showed a significant difference between Tracing and Copying \( (p < .05) \) although significant effect was found for the task type \( F_{1.61,14.52} = 6.73, p < .05 \) using the Greenhouse-Geisser estimates of sphericity \( (\eta = 0.54) \) with effect size \( \eta = 0.43 \). The findings from these analyses supports the hypothesis, that the patterns of elements are potentially grouped and retrieved as chunks, and the kinds of chunk patterns used by the participants are similar to those defined in the coding scheme described earlier.

![Fig. 2. The within and between pattern(s) pauses for all modes of drawing.](image)
Pattern Transition Counts

It was predicted that there would be fewer transitions between elements for the different patterns if participants were using chunks during recall drawing of the Rey figure. This was shown by a transition matrix where the number of transitions between elements of the same type and elements of different types were computed based on the drawing sequences of the figure in each session. The differences in the total number of transitions between elements of each pattern and the ideal number of transitions for the particular pattern were calculated, where no difference suggests that participant’s chunking schema would be similar to that defined in the default pattern as shown in Fig. 1(b). The ideal transition was the maximum number of transitions occurring between elements in the pattern without any jumps to other elements from a different pattern, e.g., four transition counts between any 5 lines of the gill pattern (Fig. 1(b)).

The one-tailed, paired t test comparisons between the tasks revealed significant differences between the Tracing and Copying tasks \((p = 0.03)\), Copying and Delayed recall tasks \((p = 0.005)\), Delayed recall and Immediate recall tasks \((p = 0.004)\). Other comparisons produced non-significant results. As shown in Fig. 3, the transition between the patterns’ decreases across sessions for all types of drawing modes indicates the possibility of the chunking structure becoming stable and coherent over time. The lower mean (aggregated across sessions) for Copying \((M = 6.8)\) than Tracing \((M = 7.7)\), further suggests a more structured drawing procedure applied during the Copying task. Similarly, the Immediate recall \((M = 7.2)\) showed lower number of transition count than the Delayed recall \((M = 7.9)\) tasks. Thus, findings from the transition matrix analysis suggest that participants are inclined to draw similar-looking elements in smaller groups, which are then combined into larger units to construct a complete Rey figure drawing.

![Fig. 3. Transition count for each pattern for all drawing modes.](image)

Nearest Neighbor Technique

In order to get a sense of what the transition count would be if chunks were not used for drawing, a method called the nearest neighbour drawing strategy was examined. This method which minimizes pen movements between lines using a strategy that selects the next line to be drawn by: (a) finding the undrawn line whose centre is the closest to the pen at the end of the just completed line; (b) moving the pen to the end of the selected line closest to the pen. The strategy was applied to the diagram using five different starting points, producing the transition count of top left 22, top right 27, right 21, bottom left 22, and centre 27, for a mean transition count of 23.8. Figure 3 shows that the number of transitions, i.e., the mean of all the session between 7 and 8) dropped approximately 1/3 of the value of the nearest-neighbour strategy.
(23.8) by the third session in all modes. Hence, values less than this seem to indicate the use of chunks. A $t$-test comparison between the first and last sessions produced a significant effect for all modes except Tracing, indicating that chunks were progressively used over time.

**Drawing Strategy**

An inspection of the pattern of drawings showed that some patterns were often drawn together where majority of the participants commonly demonstrated a sequence of drawing groups of elements; these groups will be called the frame group, inner group, and outer group. Figure 4 shows the drawing pattern as mapped on the Rey figure.

![Diagram of drawing strategy](image)

**Fig. 4** Most common pattern of drawing produced by the participants.

<table>
<thead>
<tr>
<th>Example 1: A1Tr</th>
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<tr>
<td><img src="image" alt="Matrix for A1Tr" /></td>
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<th>Example 2: S1Cp</th>
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<th>Example 3: N1IM</th>
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<td><img src="image" alt="Matrix for N1IM" /></td>
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In a fashion similar to the pattern transition counts, pattern group transition count were performed at the aggregated group level in which applying the nearest neighbour technique for pattern groups produces counts in the range of 6 to 16, giving an approximate mean of 13. Figure 5 represents the mean of the group transition count for each mode of drawing (a relatively constant count, 4–6), showing that the pattern group transition count is substantially less than that of the nearest-neighbour strategy. Thus drawing in groups (i.e.: chunks) may have a larger influence, except in the Tracing task (between 6-10 transition counts). The paired-samples t test between the first and the last sessions for the Tracing task was statistically significant (p < .10). Similar results were also found for the other tasks.

A closer inspection of the sequence of patterns revealed that patterns from the frame group were always first to be drawn in every diagram for all tasks and without exception. (Figure 4a shows an example of a few of the participant’s drawing performances that matched Fig. 4.) Twenty-three lines constitute the patterns of the frame group. The mean number (and range) of elements produced in the frame group before drawing any other groups in the Tracing, Copying, Delayed and Immediate Recall tasks were 15.4 (11–21), 18.8 (14–21), 19.5 (18–22) and 19.1 (16–21), respectively. This suggests that the frame group of patterns had a primary role in all tasks, including the Tracing task, only to a lesser extent than the others. A multiple t-test comparison was performed due to limited number of data for this particular analysis to merit more advanced statistical analysis. This is because only the mean value aggregated from all participants was found suitable to access the early dominance of the frame group in the participants drawing strategy. A t test (corrected with Bonferroni) with comparison of the group transition count between the tasks across all sessions only
produced a significant effect for the Tracing vs Copying ($p < .001$); Tracing vs Delayed recall ($p < .001$); Tracing vs Immediate recall ($p < .001$); and Copying vs Immediate recall ($p < .05$). Thus, the group transition counts were comparable across Copying, Delayed recall and Immediate recall tasks, but not in the Tracing task.

**DISCUSSION**

The findings of this experiment based on 400 trials (10 sessions, 4 tasks, 10 participants) provided convergent evidence that drawing abstract diagrams is potentially more influenced by chunks and schemas than an absolute dependence on perceptual patterns or Gestalt principles throughout all drawing procedures. Although the drawn groups of elements conform to the Gestalt principles such as closure, similarity, and proximity, the participants did not show a consistent pattern for the use of these principles. For example, if the symmetry principle were consistently used across the productions, the participants would have drawn all patterns in a symmetrical fashion (i.e., drawing from the right side before the left). On the contrary, drawings were more commonly found in the order of frame, inner, and outer groups, suggesting a stronger influence of chunks than Gestalt principles. This reduces the necessity to conform to the methods described by these principles, hence, enabling a more flexible approach to drawing. This strategy is consistent with Bouaziz and Magnan (2007) who studied drawing of different complex diagrams where figures are drawn from the outside shape to the inside. Picard and Vinter (2005) who also found similar findings (i.e., larger elements drawn before smaller ones) concluded that drawing progressions are highly influenced by perceptual properties (i.e., size) more than the conceptual properties (i.e. meaning of parts).

The strong and robust temporal chunk signal observed in other writing and drawing tasks using the Graphical Protocol Analysis method (Cheng, *et al*., 2001; Cheng & Rojas-Anaya, 2005, 2006, 2007, 2008; van Genuchten & Cheng, 2009, 2010) was also clearly found in this experiment. Although the magnitude for the pauses ($L1 \approx 500$ msec., $L2 \approx 900$ msec.) found in the current experiment was larger than that reported by Cheng, *et al.* (2001) in drawing simple geometric figures ($L1 \approx 400$ msec., $L2 \approx 600$ msec.), the difference may be due to the greater complexity of the stimulus and the larger physical size of the drawing.

Consistent with the findings from tasks such as recall of chess items, drawing electrical circuit diagrams, listing of words, and listing of programming keywords (Chase & Simon, 1973; Buschke, 1976; Reitman, 1976; Egan & Schwartz, 1979), the longer $L2$ pauses than $L1$ pauses across all tasks provided further indication that the participants treated the patterns as chunks at least in drawing complex abstract diagram such as the Rey figure. Further, the selection of patterns was consistent with the existing Rey figure scoring criteria (Osterrieth, 1944; Lezak, 1983; Corwin & Bylsma, 1993).

As evident from the transition matrix analysis, the relatively low pattern transition count also supports the claim for the causal role of chunks in the drawings, as patterns were drawn in whole before moving on to the next. This was indicated by the smaller pattern transition count across the sessions for all tasks, as compared to that estimated by the nearest-neighbour drawing strategy. These results strengthen the claim that chunks were used in the Copying, Delayed recall, and Immediate recall, which produced transition counts 6 times less than the value of the nearest-neighbour strategy. This finding suggests that participants deconstructed the diagram into patterns based on perceptual similarity, an activity consistent with the Gestalt principles. Consequently, this strategy supports the dynamic mental organization of the individual patterns where the order of retrieval may change during each recall session. Given this condition, there is an indication that spatial schemas may have a larger role to play than semantic information, as a more rigid and consistent drawing sequence would have been adopted if semantic information were largely employed during the reproduction.

The early dominance of the frame group suggests that a drawing strategy based on a spatial schema or template (Gobet & Simon, 1996) is used. Drawing the frame group first would provide spatial location cues for the retrieval of particular chunks. An advantage of this strategy is that it enables the working memory to function effectively because only selected patterns appear more salient during drawing. Thus, attention to each group is given serially. This is consistent with the notion proposed by Miller (1956), where the capacity of the working memory to process information at any one time is in the range of 7±2 units. Retrieval ought to be quicker as attention is reduced to limited information at any one time. This is consistent with the shorter pauses of the last session, in comparison to the first, for all tasks except Tracing.
The higher number of group transition counts that occur in the Tracing task compared with the other tasks suggests that the three groups (i.e., frame, inner, outer) have a lesser role in Tracing, indicating that drawing of the patterns could have occurred more randomly across the groups. Further, the nearest-neighbour strategy for the group patterns provides evidence that the complex abstract diagram is hierarchically structured in four levels. The lower value for the group transition count for all tasks, especially for the frame group, had an influential role in all tasks, although less in the Tracing task. The Copying, Immediate recall, and Delayed recall tasks may require the participants to access the underlying mental representation of chunk organization to a greater extent than the Tracing task. Thus, the highest levels may consist of the whole diagram, while the second level consists of three group patterns (i.e., frame, inner, outer), followed by associating patterns for each group (i.e., box, body, fin, nose for the frame) and the individual line segments for each pattern at the lowest level. The four levels of hierarchy support Palmer’s (1977) prediction that more levels are used for complex stimuli. This finding is consistent with van Sommers’ (1984) theoretical prediction that the Rey figure is mentally organized in a hierarchical manner. Similar claims have been reported by McNamara (1992), Palmer (1977) and Cheng and Rojas-Anaya (2008).

The group transition count may further suggest the use of breadth-first search strategy, although the participants may fall back to the depth-first search in order to retrieve any missing patterns from the drawings, if any lines were forgotten during the initial production. Although the Tracing task produced different outcomes than the other tasks, the present study can not specify the chunk organization representation for each task. Thus, whether or not recall tasks have more structured hierarchical organization than copying task warrants further investigation.

In support of the discussed measures, learning improved over time as indicated by decreasing L2 pauses and confirmed by significant comparison between the sessions and the drawing tasks. Decreasing transition counts for the patterns further indicates that chunks become more organized, an effect consistent with practice. Based on observation, the rapidity of learning of drawing near perfect version of the diagram by session 3, consisting of 13 patterns and 56 lines across the tasks, is remarkable as compared to that expected given the complexity of the diagram.

The results from this study illuminate a question posed by Gonzalez, et al. (2011) on whether copying or tracing produces better learning outcomes. Gonzalez predicted that a longer training period would improve performance for copying, but also impair performance for tracing, due to the repeated use of the same stimulus. However, the present study showed that repeated sessions with the same stimulus for different tasks produced different results, at least between copying and tracing. If learning of the Copying task affected the learning of the Tracing task, other learning measures would produce comparable results. Further results from this study, however, showed that the Tracing and Copying tasks are significantly different in terms of the lengths of pauses, number of transitions between patterns and groups, and the early dominance of the frame group within the drawings. We propose that steeper learning curve for Copying may be due to the more effective use of chunks than the more limited use in Tracing. This is because dependency of the participants on existing outline available throughout the drawing session in the Tracing task reduces their reliance on chunking that involves heavier processing from the memory.

A potential alternative measure of analysing patterns of chunks is by measuring the regularity of the recalled elements and comparing the patterns across the repeated sessions. The present findings can be further tested on more practical applications in specific scientific and technical domains involving conceptual knowledge, such as learning and drawing electronic circuit diagrams in physics. The present study has limitations since all participants had experience with drawing scientific diagrams, the selection of the participants may cause some bias. It is uncertain whether similar findings of the early dominance of the frame group patterns over the outer and inner group patterns as proposed in this study would be produced among novice drawers.

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