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# THE ROLE OF
# CHUNKING AND SCHEMAS
# IN LEARNING FROM DRAWING

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DISSERTATION SUBMITTED IN FULFILLMENT

OF THE REQUIREMENTS OF THE DEGREE OF

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# DECLARATION

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature : ......................................................................

To my parents, Obaidellah and Suriati.

Thank you for believing in me.

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THE ROLE OF CHUNKING AND SCHEMAS IN LEARNING FROM DRAWING

# SUMMARY

Learning by drawing raises questions related to the organization and internal processing involved during graphical production. This thesis explores how and to what extent, spatial and semantic information influences learning through drawings. It investigates the roles of chunking and schemas in learning through drawings by manipulating the spatial and semantic content of the presented stimuli, which participants reproduced using different methods over repeated sessions. Over three experiments with adult participants, multiple measures were used, including: pause durations between drawn elements, numbers of reproduced objects, error rates, sequences of element production, and transitions among chunk patterns.

The first exploratory study investigated the effects of chunking in the drawing of a complex abstract diagram. Five participants reproduced a single stimulus in four types of tasks, which involved delayed recall, tracing, copying and immediate recall across 10 sessions. It was found that participants learned the diagram surprisingly quickly. They used chunking in order to aid the learning processes. This effect was most obvious in the delayed recall task and least so in the tracing. The analysis of the participants' sequence of chunk production revealed that they used a spatial schema to organise the chunks. This appears to explain their rapid learning.

The second study investigated the effects of semantic and spatial schemas in learning. Twelve participants drew four types of stimuli (i.e. no-structure, semantic, spatial and spatial-semantic) across six sessions. Learning was easiest in the presence of both spatial and semantic coding, followed by semantic coding alone. By contrast, it was most difficult when the stimuli had neither semantic nor spatial information. Contrary to the predictions, the spatial stimulus was far worse to learn than the semantic.

The third study manipulated the strength of the spatial and semantic information in the stimulus to investigate the effects on learning of the weak and strong organisation of information in the two types of schemas. Twelve participants performed four drawings (i.e. strong-semantic, weak-semantic, strong-spatial, weak-spatial) in four sessions. In line with the hypothesis, the findings revealed that the strong semantic stimulus is a better type of stimulus for learning than the weak semantic one. The opposite applies, however, to the strong and weak spatial stimuli. A detailed

analysis of the performance of these two stimuli showed that the weak stimulus had evoked a stronger schema than the strong stimulus, which reveals that spatial properties may contribute to the strength of a schema.

The concluding results of these studies proposed that even purely diagrammatic stimuli are likely to be encoded semantically, as well as spatially. Furthermore, learning based on spatial coding alone may be difficult to achieve, in contrast to learning based on semantic coding alone. The combined spatial and semantic coding, however, facilitates learning better than either coding alone. These findings suggest key features that need to be considered for diagrammatic presentations used for learning in scientific and technical domains.

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# PUBLICATIONS

A large proportion of Chapter 3 (Experiment 1) also appeared in the following published article:

Obaidellah, U.H. & Cheng, P-C.H. (2009). Graphical production of complex abstract diagrams: Drawing out chunks and schemas. In N. Taatgen & H. v. Rijn (Eds.), Proceedings of the Thirty-first Annual Conference of the Cognitive Science Society (pp. 2843-2848). Austin, TX: Cognitive Science Society.

# Chapter 1 Introduction

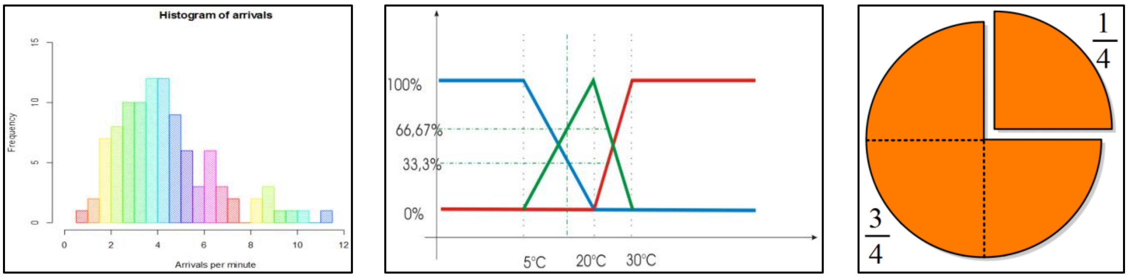
*While we draw we are drawn*
*(Latin proverb)*

## 1.1 Importance of the process of drawing

Drawings are powerful external representations used by all ages as a form of communication, in order to facilitate the understanding of ideas. Based on archaeological findings, drawings may have appeared before language and can be seen in caves, petroglyphs and pictorial languages from ancient civilizations (Gelb, 1963). Unlike with language, people do not need to share the same one in order to understand a basic graphical pattern; given that the underlying concepts, notations or symbols are understood. Indeed, someone who does not read a language may still be able to interpret drawings. Thus, the meaning of graphical elements can be arrived at without the necessity of being fluent in any language. Due to this significant advantage, the widely-known proverb “a picture is worth a thousand words” reflects the general view that drawing facilitates learning, problem-solving and inference-making.

A fundamental question that has been commonly investigated by previous researchers is what are the advantages that graphical materials have over textual materials in the process of learning. Findings from these studies agree that people generally learn better through the use of graphical materials, such as diagrams and pictures, than textual (Mandl & Levin, 1989; Mayer, 1997; Davenport et al., 2008). Although diagrams have their disadvantages, such as the need for the learner to apply prior conceptual understanding in order to assimilate graphical materials, which determines the success of making an inference, they do have their advantages as well. For example, diagrams may quickly communicate concepts better than words, as high density information is more succinctly conveyed in an organized manner and a limited space, (e.g. a few lines in a graph are more easily interpreted than the same information represented in the form of a table or text) (Fry, 1981; Larkin & Simon, 1987). This makes abstract problems ‘physical’ and ‘tangible’, and thus allows them to be easily conceptualized, which in turn promotes inference based on spatial reasoning, proximity, direction and distance (Tversky, 2008). This process enables diagrammatic information to be organized and re-organized, an approach often employed when using diagrams in domains such as science, engineering and design.

Information can be represented in many types of graphical elements. Fry (1981) proposed six categories of drawings in a ‘Taxonomy of Graphs’ according to the type of information presented. For instance, bar and pie graphs are examples of the quantitative graphs category that is used to represent numerical data. Danos & Norman (2009) recently extended these categories to offer more comprehensive pictorial devices, such as those shown in Figure 1.1 and Figure 1.2. These graphical formats provide educators with many options to choose from as a teaching device. Graphs and charts are common types of graphical material used for teaching, as shown in Figure 1.1. In an effort to examine its effectiveness, Ali and Peebles (2011) investigated graph comprehension using different methods of interaction (e.g. writing, thinking out aloud), while Peebles and Cheng (2001) studied graph-based reasoning and its effect on understanding and retrieving information from various types of graphs.




(a) (b) (c)

Figure 1.1: Different types of graphs used in various domains, such as (a) histogram (statistics), (b) line graph (fuzzy logic), (c) pie chart (mathematics) [source: Wikimedia Commons]


(a) (b) (c)

Figure 1.2: Other forms of graphical material used in education: (a) children's picture book, (b) world map, (c) human anatomy diagram [sources: sesame street.org, justmaps.org, Wikimedia Commons]

As shown in Figure 1.2, other common types of visual representations used in education are pictures, maps and diagrams, to name but a few. These are used to supplement the prose in storybooks, textbooks and newspapers. There are different ways that diagrams are used across various domains in education. For example, in mathematics and physics, visual representations are commonly used to support the calculation of technical details, whereas in business management, the use of diagrams is essential in constructing and managing production. In brainstorming, mind maps are often preferred as a means to explore ideas. Moreover, medical students studying the human anatomy typically make full use of labelled anatomical charts to facilitate their learning.

The use of graphical representations offers an effective and efficient way of communicating information. The recognition of the potential benefits of graphical materials in education, as well as our dependence on visual information for learning, has led to the growing use of these kinds of materials and has emphasized the importance of research on drawing. As we will see in Chapter 2: Literature review, various studies have been dedicated to investigating the nature of drawing. In the domain of cognitive science, these studies explore the cognitive processes that involve graphical production, including how graphics are perceived, mentally processed and put on paper through motor actions. Each of these processes has received considerable interest. Many fundamental questions relating to drawing, however, have not been investigated. For example, it is unclear whether spatial or semantic information is more influential during the comprehension of graphical materials at the time of drawing. More specifically, until now, few investigators have studied the relative contribution of spatial and semantic information in learning with graphics.

In this context, we define spatial information as the use of graphical data based on spatial relations, such as regions, proximity, direction and distance, while semantic information relates to the use of meaningful concepts, such as categorisation, which utilizes the individual's knowledge about the world. Gattis (2001) raised an interesting question when she asked whether spatial cognition is important in abstract thought, such as in non-spatial tasks. More specifically, questions such as what is known about spatial cognition and how information relating to space is used in various tasks needs investigation. For example, what is the likelihood of people using spatial structures (e.g. spatial cues, such as distance and direction) in various tasks (e.g. finding directions, moving furniture, catching a ball)? This necessitates the evaluation of spatial schemas by observing the use of information on the location of objects, the movement of objects and the configuration of our environment, which affects how people learn to appreciate spatial concepts, such as linearity and directionality (Gattis, 2001). As Gattis emphasized, spatial schemas provide organizations in which the content is linked to improve memory. We are, thus, interested in testing this effect with drawings, as they are highly spatially determined. Further questions, such as how often and at what processing cost spatial schemas are used in the structure of memory, also motivate our interest in the present study.

In support of Gattis's view, Tversky (2001) proposed that many types of graphics are processed based on spatial schemas that may represent various formats of information or scales of measurement. Tversky further proposed that meaningful graphics are commonly evaluated on the basis of the Gestalt principles of perceptual organization, where elements are often grouped according to proximity (e.g. elements are often considered together if placed close to each other, rather than separated by distance). Considering this notion, we will investigate whether the drawing of abstract figures and non-conceptual objects supports this view.

From the semantic point of view, various studies particularly in *semantic* memory, have investigated the effects of meaning in learning. Semantic memory reflects the knowledge around us. This type of memory holds factual and generic conceptual information about the world and is unrelated to specific personal experiences. If the knowledge involves the memory of specific events, it is called *episodic* memory. Although Tulving (1972) has distinguished between these two types of memory and has proposed that each type operates within a different system, Howard and Kahana (2002) suggested that these two memories work together. During retrieval, semantic cues are strong when episodic cues are strong as well. Taken together, these forms of knowledge enable the meaningful assimilation of information. In an experimental study, Tulving and Pearlstone (1966) proposed that meaning plays a significant role in word-list learning, where retrieval of categorized items superseded that of random words. Although this effect is common in textual materials, such as word-lists, drawings have not received similar attention. We, therefore, aim to investigate the effects of semantic information in the process of drawing.

Given our interest in locating the effects of spatial and semantic schemas in learning with drawings, we are particularly inclined to examine how these forms of information are organized in the mental structure. Prior studies in this area have demonstrated the potential of information to be organized in a hierarchical format. Investigators who examined this notion in the field of spatial memory include Stevens and Coupe (1978), Mandler and Ritchey (1988) and McNamara (1992). In the field of semantic memory, similar views were proposed by Collins and Quillian (1970), Meyer (1970) and McKoon, Ratcliff and Dell (1985). As will become evident in the following chapters, their arguments permeate the present research.

## 1.2 Thesis aims

This thesis attempts to advance our understanding of how drawings might be used for learning and makes empirical contributions to this aim. A series of three experiments answer questions about whether the individual properties of either semantic or spatial information provide the greatest learning benefits over the use of both properties combined. These experiments serve as a method to evaluate the theoretical models from previous research, such as the hierarchical models of retrieval (Palmer, 1977; Cheng & Rojas-Anaya, 2008). The areas of interest in this thesis are drawings, chunking and schemas. In all of the experiments, drawing is used as a method to probe the nature of chunking, which relates to the underlying organization of information, known as *schemas*. The notion of hierarchical organization that stores units of information (*chunks*) at multiple levels is presented. In a wider context, this thesis investigates the effects of learning through drawing in relation to the use of semantic and spatial information. Issues concerning schemas, such as the notion of slot-fillers and the organization of information, are investigated in greater detail with respect to drawing data. In addition, we will investigate how rapid learning occurs and what factors facilitate learning as a result of knowledge acquisition from graphical materials.

The overall experimental strategy reported in this thesis consisted of iteratively trying to magnify the potential effects of schemas based on meaning and spatial information. The resulting evidence on the use of schemas shows that learning benefits from the drawing of abstract figures and non-representational diagrams. This finding contributes to the understanding of schemas, chunking, the structure of graphical organization in mental representations and learning through drawings. The results from the experiments identify the factors that may facilitate learning. These may be of importance to other fields, particularly in education, where learning materials could be re-assessed and improved in order to provide a more effective learning experience for students.

## 1.3 Overview of the thesis

This section will present a brief overview of the research undertaken for this thesis.

### 1.3.1 Chapter 2: Literature review

This chapter reviews the literature in three areas that relate to the aims of this thesis. First, the chapter describes the relation of drawing to cognition. In this context, we discuss the use of drawing as a tool to investigate issues relating to learning and memory. In particular, we concentrate on a comparison between drawing and writing. The review then turns its attention to the use of drawings and diagrams in problem-solving. The discussion focuses on the mechanisms involved during the process of drawing with references to existing cognitive models of drawing. We also relate the process of graphical production to motor behaviour including the movement of the hands and fingers. In addition, we describe methods to evaluate drawing based on various techniques.

Research on chunking in drawings is then reviewed, highlighting the properties of chunks and the theories related to chunking. The effects of chunking found in previous drawing research are also discussed. It is unclear, however, whether the effects extend to more abstract drawing tasks. While chunks are often described as forming the mental structure, which previous investigators proposed to be hierarchically organized, there has been little engagement in the literature with drawing so far. The examination of the hierarchical structure is one of the main interests of this study. Finally, the review includes the effects of chunking from a motor-behaviour perspective.

The final section of this chapter reviews the literature on schemas, which relate to the semantic and spatial information that provides the background to the experiments presented in subsequent chapters. This includes a review of the role of semantic and spatial schemas, their definition, structure and representation, as well as a comparison between various schema theories. While the role of schemas in drawing is apparent from previously reported studies, evidence for the relationship between semantic and spatial schemas in drawings is still unclear.

We conclude this section by placing emphasis on the most relevant earlier work relating to this study. It is suggested that the benefits of employing spatial and semantic schemas in drawing must be highlighted in order to improve the applicability of drawings being used for learning.

### 1.3.2 Chapter 3: The role of chunking and schemas in drawing a complex abstract diagram

The first experiment investigates the effects of chunking based on the drawing of a single abstract diagram. Chunks are evaluated based on the likelihood of parts of the diagram becoming segmented into units of elements according to shared characteristics, such as those described by the Gestalt principles. This is followed by measures to establish whether chunks from an abstract diagram are hierarchically organized. The effects of learning with various modes of drawings (i.e. Tracing, Copying, Immediate Recall and Delayed Recall from memory) are analysed. The potential influence of spatial schemas on the process of drawing is also investigated. Further examination includes the order of drawing the complex abstract diagram.

The results indicate that parts of the Rey Figure abstract diagram were organised into units of elements within and between chunks according to putative patterns. In addition, there were traces of different learning outcomes for the different drawing tasks. The chunks of elements were also proposed to form a hierarchical structure of many levels. It was also found that the drawing of abstract diagrams might be influenced by meaning (semantic) and spatial information. This serves as the foundation for the following experiment. A large proportion of this experiment has appeared in a published article (see Appendix B).

### 1.3.3 Chapter 4: The effects of spatial and semantic schemas in learning

The second experiment manipulates the structure of the stimulus presentation in order to evaluate the use of spatial and semantic information in drawing. Comparisons are conducted between stimuli, which consist of both spatial and semantic information, semantic information alone, spatial alone and of neither. Therefore, the investigation evaluates learning performance from the most to the least structured stimulus, according to the prediction that this corresponds to the easiest and most difficult learning experience accordingly. More specific measures of learning are introduced, in addition to those used in Experiment 1 (Chapter 3). These measures use the participants' drawing data to examine the underlying mental representation of graphical elements in terms of how information is organized at different levels in a hierarchical structure for the types of the given stimulus presentation.

This experiment showed that the structure of stimuli presentation has an effect on learning in accordance with the provision of spatial and semantic information. It appears that different levels of cognitive processes are involved with learning different types of stimulus presentations, which have an influence on the information organization in the mental schema. It was not clear, however, how the relative contribution of different strengths of spatial and semantic information affected learning, (i.e. whether learning was equally easy for a strong semantic and a strong spatial stimulus). This will be investigated in the following experiment.

### 1.3.4 Chapter 5: The effects of spatial and semantic schemas of different strengths in learning

The final experiment compares learning with different degrees of semantic and spatial strength stimuli associated with the contents of the learned materials. These factors are predicted to have an influence on learning. In this experiment, the stimuli presentations are further manipulated to represent either weak or strong semantic, or spatial information that serves as cues during retrieval. A larger number of measures than those used in Experiment 2 (Chapter 4) is employed in this experiment, coupled with more detailed evaluation to assess the types of learning strategies participants employ to facilitate the process of knowledge acquisition. These measures provide a more comprehensive analysis of the structure of the underlying mental representation of the learned stimulus.

Findings from this experiment suggest that the different strength of semantic or spatial information present in learning materials influences learning. The speed of learning and the evaluation of the learning strategies used by the participants serve as supporting evidence for the effect of the stimulus presentation.

### 1.3.5 Chapter 6: General discussion and conclusions

The final chapter provides a summary of the empirical work comparing different structures of learning materials in association to semantic and spatial information.

It is suggested that effectiveness of learning is influenced by the mutual relationship between meaning and spatial content. A strong association between the semantic information and the contents in the learned material also provides enhanced learning. Nevertheless, to some degree, spatial information was also demonstrated to facilitate learning. It is further proposed that the effect on learning is influenced by the organization of information in the underlying mental representation. The use of strategies that facilitate learning is discussed in the context of semantic and spatial information. The limitations of the present study across all reported experiments are presented. The implications of applying the findings of this thesis are highlighted. Finally, this section makes recommendations for future research in the field of learning.

# Chapter 2 Literature Review

*Learning is a lifetime process,*
*but there comes a time when we must stop adding and start updating*
*(Robert Braul)*

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## 2.1 Introduction

This chapter will discuss the three main areas that serve as the framework for this research. These are: cognition and drawing, chunking in drawings and schemas. All of these themes relate to the effects of the structure of underlying mental representations, which is the overarching concern of this research. The main focus of this thesis lies in the significance of drawing as a tool to study the effects of the structure of mental representations. The following example demonstrates the interrelation between these three areas and the way in which they contribute to the research question.

The act of drawing a human figure requires the drawer to have a general knowledge of the properties concerning humans. During drawing the most common and sensible approach is to draw the human figure in clusters of related items, such as the pair of eyes, the pair of legs and the pair of hands. This activity demonstrates that drawing is driven by many cognitive processes, including the process of encoding and recoding from underlying knowledge representation, which in turn affects motor behaviour processing. Studies in these areas will enable us to grasp better the effects of drawing from the perspective of Cognitive Science. In this chapter, we will describe the issues related to drawing with respect to the effects of chunking and the representation of chunks in mental schemas.

## 2.2 The role of drawing in cognition

Drawing is often regarded as an effective method for communicating ideas, used by both adults and children (Tversky, 2007). Many forms of drawing, such as sketches, maps, graphs and diagrams, are used to express thoughts that facilitate understanding. The effects of learning with drawing, therefore, are an interesting and important area for investigation. Substantial research has employed drawing as a tool to understand the nature of cognitive processes in areas such as the evaluation of cognitive development among children, the assessment of drawing difficulty due to neurological syndromes and the investigation of the cognitive components of drawing processes (van Sommers, 1984; Karmiloff-Smith, 1990; Guérin, Ska, & Belleville, 1999; Smith, 2002). Although such research has produced significant findings about the processes involved in drawing, along with their behavioural effects, studies on the internal representation of drawing activity are still meagre.

One of the fundamental issues in drawing research concerns what constitutes the organization of graphical information and how this information is accessed from the memory. This includes the potential format through which graphical knowledge is represented, namely whether this is done hierarchically or in unorganized networks. Understanding the format of graphical information representation allows us to investigate patterns of graphical organization and the factors that influence these patterns in mental representation. Semantic and spatial information are two potential factors that may influence graphical organization as they determine the strength of association between the objects and the location and position of the drawn elements as perceived by the participants. This affects internal graphical representation during encoding and retrieval. This thesis will investigate these factors in detail. The findings will enable us to evaluate the effects of chunks in drawings, retrieval consistency and the effects of drawing on learning, as well as the strategies employed during drawing.

The following sub-sections will provide a review of the literature on the relationship between graphical representation and language, the representation of drawings, the differences between drawings and diagrams, problem-solving by using diagrams, the processes of drawing, the effects of drawing in motor behaviour and the methodologies used for analysing drawings.

### 2.2.1 Drawing versus language

Drawing tasks have gained a central position in research on memory, as they have proven useful in probing the nature of cognition in certain circumstances such as child development and in evaluating drawing abilities among cognitively impaired individuals. This highlights the significance of drawing as a means to investigate memory-related issues and learning.

Drawing and language are both important forms of communication. Although they share some similarities, the conventions used in each form are different. For example, Freeman (1972) theoretically compared drawing with language. According to Freeman, both sets of conventions communicate meaning between individuals given that the respective signs and symbols used are well understood. The relation between the signs and objects signified, however, is different between the two. Language employs more straightforward conventions, in which sounds and shapes of letters (e.g. alphabet characters) have defined meanings, whereas graphics are founded on perceptual similarities that depend on factors such as size, form and orientation (e.g. four closed straight lines can form either a rectangular or a square shape). Freeman further pointed out that language differs from drawing in terms of the rules that govern the combination of signs and symbols. In the case of language, the rules are *firmly laid down*, but in drawing they are *minimally specified* or less constrained. This is because, in order to comprehend textual input, languages are required to obey the correct syntax. Failing to follow the relevant conventions of a language may result to an incomprehensible text. In drawing, however, understanding the final image is independent of the order in which its constituent parts were executed. For example, regardless of the order of drawing the eyes, the mouth, or the nose in a human face, people who perceive the outcome of the drawing will be able to evaluate and recognize it as a human face, given that a standard drawing of it was produced.

The unspecified rules that govern drawings have raised interest among researchers as to how drawings are perceived, encoded, structured and retrieved from memory. For example, research on drawing can reveal the relation between spatial information and geometric forms, the parts and whole of a figure, motor behaviour and drawing strategies. These areas will be examined in more detail in the following sections.

The consensus among investigators is that writing and drawing operate on different types of cognitive systems (Karmiloff-Smith, 1992; Brenneman et al., 1996; Adi-Japha & Freeman, 2001; Yamagata, 2007). Describing diagrammatic representations as information that is indexed in two dimensional locations, Larkin and Simon (1987) proposed that it is easier to understand the relations between information portrayed in diagrams than the same information presented in sentential format. This notion, which is supported by Koedinger and Anderson (1990), is used as the foundation for their theory of *diagrammatic configuration schema* designed to show how chunks of geometrical representation knowledge can be used to cue abstract planning for geometrical problem-solving.

This section has reviewed the differences between drawings and language emphasizing the advantages of learning in a graphical format. The following section will review the representation of drawings.

### 2.2.2 Representation of drawings

A variety of formats and formal structures can be used to represent objects. For example, a drawing of a chair can have a 2D or a 3D form from various perspectives. The understanding of these various forms and perspectives enables the drawer to control the level of sophistication when drawing a particular object. Willats (1985) suggested that *drawing systems* account for the spatial relationships between objects (e.g. the position of a table and a chair on paper), while *denotation systems* define the relationship between the drawn marks and the objects in the real world (e.g. the table drawn on paper relative to its actual counterpart, as seen by the drawer), and *projection systems* outline the shapes of geometry and their orientations (e.g. an oblique or isometric 3D cube). These systems contribute to how drawings are perceived from either viewer-centred or object-centred descriptions of the world.

Therefore, drawings can be based on different types of single, or combinations of multiple, drawing systems (e.g. *orthogonal*, *orthographic*, *oblique projections*). The experiments reported in this thesis will employ the *orthogonal* drawing system, which Willat defines as line drawings from a 2D perspective. Line drawings are chosen in this research because they are easy to handle in an experimental context and incorporate the spatial relationships between objects in a scene and parts of objects that belong to a single figure. Furthermore, it is easier to analyse line drawings of an object, as opposed to other drawing formats due to their potential higher level of complexity.

There are many types of drawings. Artistic drawings, such as creative portraits and design sketches, clearly have different functions than the well-structured diagrams of electronic circuits and Venn diagrams. The former express the artist's thoughts, which can generally be appreciated without having to understand specific rules or requiring specialized knowledge. On the other hand, the latter necessitates a reasonable understanding of the notations on the part of the reader, in order to facilitate the interpretation of meaning. Furthermore, the underlying drawing processes of these two types of drawings may also differ due to the requirements in understanding these graphical productions. The experiments in this research will employ well-structured diagrams. Their lower level of ambiguity will facilitate the analysis and interpretation of the results.

The following section will compare drawings and diagrams.

### 2.2.3 Drawing versus diagrams

Commonly, the term *drawing* refers to the process or activity of producing graphics on a medium (e.g. paper, tablet), while *diagrams* often refers to a symbolic (or abstract) graphical representation that requires specific knowledge for interpretation. The term *drawing*, however, also often refers to unstructured pictorial representations (picture devices) such as a picture, a sketch, a plan or an outline, produced by means of drawing lines on a surface. Examples of diagrams are an electronic circuit and UML diagrams, while a drawing can be a picture of a house or a sketch of a human face. Nevertheless, more often than not, diagrams and drawings are used interchangeably to refer to graphical representations. This is the definition that will be employed in this thesis.

In the domain of problem solving, Purcell and Gero (1998) have noted the similarities between the use of diagrams and drawings. One of the central similarities they describe is that diagrams and drawings are both associated with re-interpreting the graphical representation in question. Re-interpretation in this context denotes the process of recognizing the features of the object (either a figure or diagram) to be drawn. For example, drawing a figure requires the drawer to recognize its constituting elements in order to execute it successfully. Similarly, interpreting a diagram necessitates a sufficient level of understanding of the relevant graphical notations in order for inferences to take effect. Both cases of re-interpretation provide cues that enable access to underlying knowledge (conceptual, abstract and perceptual), which is then integrated into the diagram or drawing. For example, perceptual knowledge is associated with the physical properties of figures represented in drawings. Purcell and Gero have also noted similarities in the sequential process of solving a problem (e.g. the development of an evolution system for biological problems vs reasoning for design problems). The final similarity described by Purcell and Gero is that in each case there is a marked difference in the extent of information used in diagrams and drawings between experts and novices.

Given the similar definition of diagrams and drawings, the following section will review the reasons why understanding information in graphical format is easier than that represented in textual format in the context of problem-solving.

### 2.2.4 Problem-solving with diagrams

In their classic publication on the differences between diagrammatic and sentential representations, Larkin and Simon (1987) showed that diagrams are more advantageous than sentential representations. The explanation behind that was that the latter (sentential) presents data structures that appear to be in an ordered sequence, while the former (diagrammatic) represents elements of information in 2-dimensional locations. The three major reasons why diagrammatic representation is more computationally efficient than sentential, as proposed by Larkin and Simon are: (1) *locality* – diagrams group related information which reduces the search process during problem-solving, (2) *avoiding the need or effort to match the symbolic labels* – diagrams can be used to group elements of information according to spatial location; hence, the use of symbolic labels is not necessary or if it is, the effort of matching information to symbolic labels is significantly reduced, (3) *support for perceptual inferences* – certain aspects of processes are more easily recognized in diagrams in the form of notations and symbols (e.g. the ‖ symbol, which denotes equal length, shown in the middle lines of a square pattern), as opposed to the equivalent list of sentences describing the diagram (e.g. A and B are two points that produce a line. C and D are two points that produce a different line. Both are components of a square shape. Both lines are of equal length).

Koedinger and Anderson (1990), however, argued that diagrams are not necessarily advantageous. They reasoned that: (1) although diagrams group related information, other necessary information may not be grouped together, (2) it is essential to mark diagrams to facilitate interpretation and reasoning, although symbolic object labels are not as important, (3) perceptual inferences are easier to understand because they are more practiced and people tend to have more experience in this type of representation than in drawing symbolic inferences.

The computational processes for diagrams generally require less time than sentences. Not all diagrammatic representations, however, are advantageous to everyone because the reader must have sufficient understanding of the notations. Failing to comprehend the features of a diagram results in their less effective functioning. If this is the case, the use of diagrams in facilitating learning decreases, as reported by Klahr (1978) and Diezmann (2000a, 2000b).

If diagrammatic features are understood sufficiently, they can be proven effective for problem-solving, reasoning and learning (Kosslyn, 1989; Lohse et al., 1994; Scaife & Rogers, 1996). This has been demonstrated in the domains of chemistry (Davenport, Yaron, Klahr & Koedinger, 2008), engineering (Ullman, Wood & Craig, 1990), mathematics (Koedinger, 1994) and physics (Larkin, McDermott, Simon & Simon, 1980; Larkin & Simon, 1987; Bauer & Johnson-Laird, 1993; Rogers, 1999; Cheng, 1999; 2002). For example, Davenport et al. (2008) studied the effectiveness of learning using diagrams facilitated by instructions. They evaluated the learning outcomes using their proposed framework, which investigates the factors (i.e. learning objective, diagram design and cognitive processing of learning) that influence the effectiveness of diagrams. Their findings revealed that learning is heavily influenced by the conceptual details available on the diagram and the learner's previous knowledge on the topic.

Due to the potential advantages diagrams and drawings may offer for learning, it is important to study the effects of using them.  Previous studies, which used drawing to probe the nature of learning, were conducted by Lansing (1984), Taylor and Tversky (1992) and Walker et al. (2006). Lansing (1984) emphasized the importance of studying the development of mental representations in relation to drawing. Taylor and Tversky (1992) took a more empirical approach in studying the effects of map learning using drawing. They compared their findings to a study on the same topic, based on recall from memory. In a different study, Walker et al. (2006) investigated the factors that influenced drawing performance. These factors are the idiosyncratic view or angle of the object, novel shapes, colours and categorical representations.

At this point in the review, we have become sensitised to the importance of learning with diagrams and drawings and their ability to reveal details about the underlying internal processes. This research will further investigate the effects of learning from drawing, by examining the underlying internal graphic representations. A variety of studies have investigated the mechanisms of drawings, as will be presented in the following section.

### 2.2.5 The mechanisms of drawing

How is graphically perceived information reproduced on paper? What kinds of processes occur in the mind during graphical information processing? These are the fundamental questions that have incited considerable interest in research concerning drawing processing. Notable investigators, whose work sets a benchmark in this area, are Gesell and Ames (1946), Goodnow and Levine (1973), Ninio and Lieblich (1976), Golomb and Farmer (1983), Farah (1984) and van Sommers (1984, 1989). Research in this area focused *inter alia* on the procedures of drawing, such as stroke direction, assembling smaller parts into more complex figures and finding common drawing strategies between normal and brain-impaired children and adults.

For example, Goodnow and Levine (1973) claimed that drawing by copying is governed by rules that determine the starting point and direction of the strokes. These rules, which form 'the grammar of action,' are claimed to be adequate in describing the strategies used to draw various designs consisting of combinations of horizontal and vertical lines, which form squares, triangles and intersecting horizontal and vertical lines. Ninio and Lieblich (1976) provided experimental evidence to verify Goodnow and Levine's theory. The proposed theory by Goodnow and Levine, however, is not comprehensive, as it does not account for other factors, such as motor action, perception or thought.

Building on this limitation, van Sommers (1989) was the first researcher to present a comprehensive cognitive model of graphical productions incorporating the principles that govern drawings from a mechanical (action) and cognitive (perceptual) point of view. Based on the model for face processing proposed by Bruce and Young (1986), van Sommers (1989) extended the model for graphical output and introduced a drawing model consisting of two hierarchical systems of drawing for visual perception and for graphical production.

The first processing system for visual perception, as shown in Figure 2.1, has three features:

(1) Three stages of visual processing from common types of visual inputs based on Marr's model (1982) are used to describe the perceptual processing of copying. The perceptual system, which describes how the eyes recognize an input (e.g. figures), operates in 2D. This is complemented by information on the association between the edges of the figure in view-specific position or 2½D. An association between the information perceived in 2D and the information for the edges of the figure coupled with the corresponding axis then serves as 3D input

(2) Visual representations are incorporated to account for materials from memory ranging from abstract designs to familiar objects

(3) Two types of inputs are distinguished via the phonological and semantic systems, visual and auditory, to categorise drawings based on name, definition, association, touch or sound.

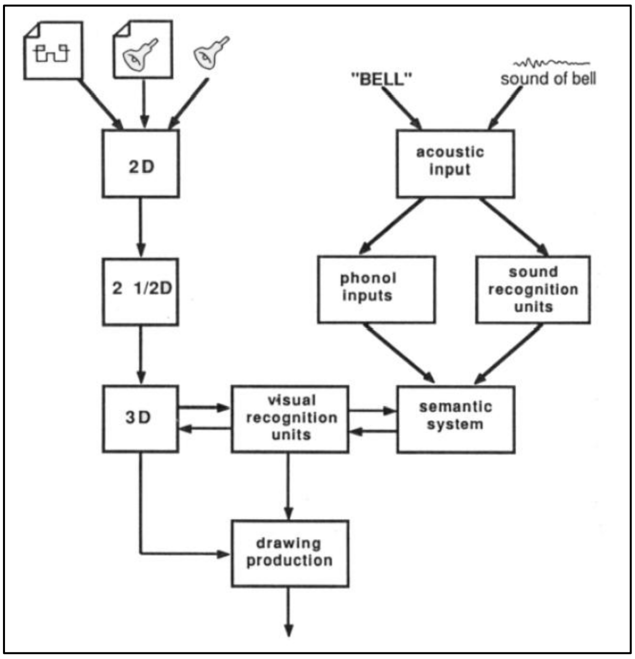



Figure 2.1: van Sommers' (1989) perceptual system model of drawing production

The second processing system or graphic output system, as shown in Figure 2.2, encompasses five hierarchically organized graphics production components. The components and their functions, according to the order presented in the model, are: (1) *depiction decision*: the drawer selects the characteristics of the drawing (e.g. context, state of the object, orientation, viewpoint, level of detail), (2) *chunking*: the process of segmenting drawings into parts that can be semantically driven depending on the function and meaning of the drawing either (i) hierarchically or (ii) line-by-line, despite the organization of the actual picture, (3) *contingent planning*: a process akin to problem-solving, yet distinguished from routine planning, which selects and ranks the segmented parts to enable reproduction in an appropriate and conventional order (e.g. drawing the disc of the sun before its rays, or a human body before the arms and legs), (4) *articulation and economies*: the physical movement of the drawer's hand and fingers, which determines ease and preference of stroke direction in line drawing (i.e. opening, starting position, rotation order, circle production and direction of the hand - the majority of right-handed drawers share a common preference on directionality, order and starting point of the drawings), (5) *motor programmes*: the programming and execution of hand movements to determine factors such as speed, accuracy and symmetry in the intended drawing.

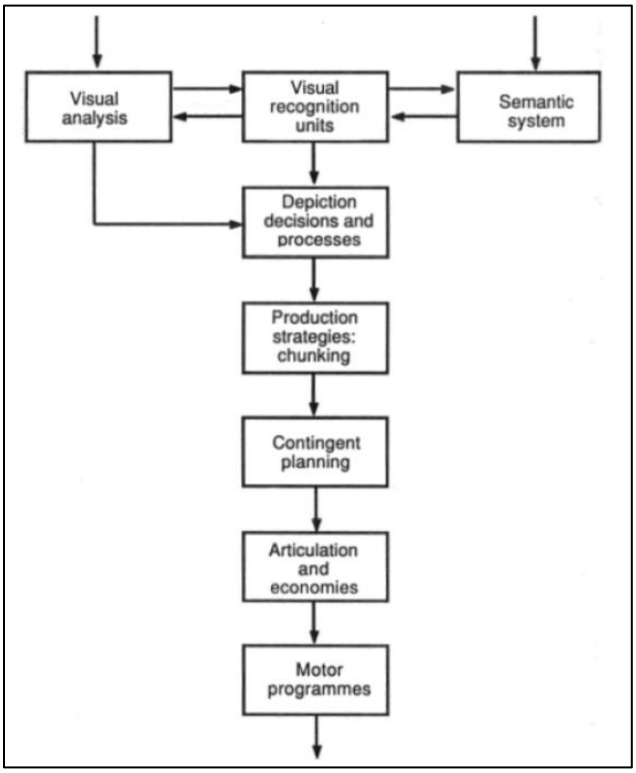



Figure 2.2: van Sommers' (1989) graphic output system model composed of five sub-models

Van Sommers' comprehensive model of drawing is supported by experimental data gathered from observation and tape recordings. Furthermore, the model is well-linked to existing cognitive, neuropsychological and cognitive neuropsychological literature (Marr, 1982; Farah, 1984; Bruce & Young, 1986). Van Sommers' model, however, lacks support in the current developmental literature on drawing. For example, it provides limited explanations of the degree of influence of semantic or spatial knowledge on task demands, knowledge of pictorial devices and the relations of internal factors, such as the hierarchical organization of graphical elements in drawing tasks. Although this thesis does not introduce a new model, it relates its findings to two components of the van Sommers' model.

The two sub-models that are relevant for the present study are *depiction decision* and *chunking*. In the former (i.e. depiction decision), which is based on stored visual representations that are important for the recognition process, van Sommers emphasized the role of the semantic system in drawing. He demonstrated the semantic effects on drawings by asking participants to copy ambiguous figures presented with different labels (e.g. cocktail glass with cherry or man with a telescope), as shown in Figure 2.3.

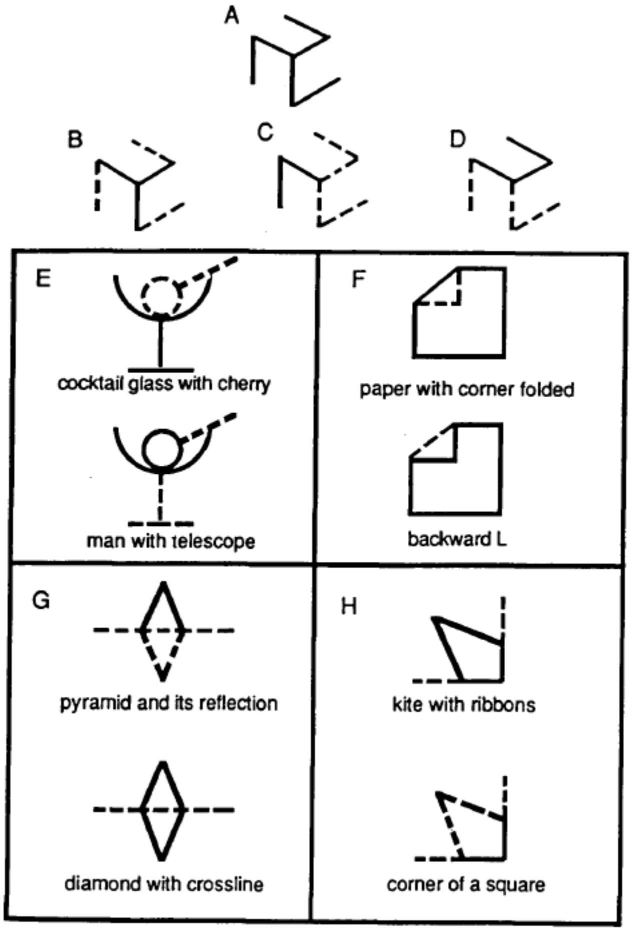



Figure 2.3: Ambiguous figures with alternative captions. Solid lines indicate early strokes, dashed lines represent later strokes [source: van Sommers (1989)]

There seems to be a strong association between semantic interpretation and geometric forms, which influences the strategy of production, as demonstrated in the examples given in Figure 2.3. Meaning plays a role in how graphics are executed. Van Sommers (1984) experimentally demonstrated that the semantic interpretation of a figure determines the order in which the lines of a drawing will be executed (i.e. which lines become the frames and which the details). For example, participants who were asked to draw a 'folded paper', as indicated by F in Figure 2.3, frequently drew a five-sided polygon before inserting the inner right-angled elements. Alternatively, participants interpreted a 'backward L' by first outlining the letter L with an additional stroke across the internal angles. Therefore, the perceptual properties and functional description of an object influence, to some extent, the end product of the graphical representation. No clear indication, however, has been given in previous research about the degree to which semantic knowledge affects drawing execution and performance. As much as meaning is important to convey the graphical description, it is presently unclear whether the relationship between semantic information and the objects to be drawn has a role in shaping drawing processes, such as perceptual planning, conceptual analysis and the construction of mental representations.

In regard to the second sub-model (i.e. chunking), van Sommers refers to the Rey Figure and predicted that in theory components of the abstract diagram should be chunked in an organized hierarchical order. This prediction is based upon the identification of common units of the graphical elements, which are extracted from the Rey Figure (e.g. rectangles, diagonals, crosses, lines), as described by Rey (1941) and Osterrieth (1944). Nevertheless, van Sommers did not describe in more detail the relations between the different hierarchical representations of the chunks, namely how these chunks are organized in the mental schemas. Phillips, Inall and Lauder (1985) further suggested that learning to draw denotes the acquisition of a new graphical description, which is eventually stored in the long-term memory, indicating that schemas have a central role in this context. Furthermore, as proposed by Gombrich (1977), the process of drawing would be impossible without appropriate *schemata*, which were referred to as *graphical descriptions* by Phillips et al. (1985). Therefore, the knowledge of drawing, including how graphical elements are organized and accessed, plays a crucial role in drawing processes. Therefore, this research will attempt to perform an in-depth investigation of the effects of chunking using the underlying schema representation of graphical information acquired from drawings.

Various drawing models have built on the van Sommers model. Contributions have been made on the improvement of the input and output processing of the visual representation (Shawe-Taylor, 1993), as well as the interactions of components for mental imagery, spatial processing, and the control of movement in the cognitive and motor processing of drawing (Smith, 2002).

Other models, which characterise drawing processes, were less detailed than van Sommers' as the definition of the cognitive and motor components were distinctly described. For example, van Galen (1980) discussed the motor programs of drawing and the retrieval of motor patterns from memory, such as the selection of the appropriate sequence of motor actions from memory followed by the execution of these movements. Roncato et al. (1987) proposed a model, which accounts for differences in copying tasks used to analyse information processing for drawing-impaired individuals and normals. On the other hand, the model proposed by Thomassen and Tibosch (1991) suggests that drawing operates purely on the basis of rule selection.

This section has reviewed drawing models and the general processes involved during graphical production. This bears a relation to hand and finger movement coordination discussed in the following section.

### 2.2.6 Drawing and motor behaviour

Drawings are used in research related to motor behaviour, which investigates geometrical properties, such as velocity, trajectory and curvature of drawn lines in the area of kinematics, kinetics and dynamics (Lacquaniti et al., 1983; Viviani & Schneider, 1991; Blank et al., 2000; Pellizzer & Zesiger, 2009). Although the terms for these geometrical properties are different, it appears from these studies that the central interest lies in the investigation of motor processes, such as the movement of the hand and fingers that influence drawing behaviour. For example, Blank et al. (2000) examined the effects of drawing movements between dominant and non-dominant hands, by asking participants to draw circles and lines of different sizes. This type of stimulus was chosen to accommodate either the finger-wrist or the elbow-shoulder movement. The analysis focused on the frequencies of movements during drawing and it was found that the number of hand movements increased with temporal and spatial accuracy, and the economy of the drawn figure. Other studies revealed a consistent relationship between the speed of drawing (velocity) and the geometrical properties of the curvature and trajectory (Lacquaniti et al., 1983; Viviani & Schneider, 1991; Pellizzer & Zesiger, 2009). The consensus from the findings of these studies is that, generally, over time and with practice, drawing movements become faster, a view consistent with the Power Law of Learning theory (Newell & Rosenbloom, 1981; Anderson, 1995).

Other drawing research focused on learning from motor practices (Burke & Roodenrys, 2000; Vinter & Perruchet, 2002). In particular, research in this area investigated the effects of learning from drawing. It was proposed that the factors that influence learning are the level of observation, the directionality of drawing movements, the size of the figure and the average speed of hand movement. This research essentially debates whether unconscious learning, termed as *implicit* learning, affects drawing behaviour. For example, Vinter and Perruchet (2002) proposed that implicit learning acquired after practice is capable of modifying drawing behaviour, such as the starting position and movement direction.

What are the possible motor strategies involved in performing a drawing task? One potential approach is that a drawer would need first to visually recognize the figure to be drawn. Upon recognition, the next step would be to generate a plan of action, which Laszlo and Bairstow (1985) identified as a precursor to the motor program. Prior to execution, the drawer should consider the factors described above (i.e. starting point, direction, speed of drawing movement). It is only after these considerations that the decision for the appropriate motor program is taken. Examples of motor program parameters, which necessitate further consideration, are the selection of the number of motor units to be used, the activation of the specified motor units and the order of motor unit execution. All of these procedures lead to the success of the drawing task from a motor strategy point of view. The level of detail of the motor processing depends on the complexity of the figure. It is, thus, expected that a more complex figure would require more advanced motor programming, as confirmed by van Mier and Hulstijn (1993). The aforementioned model for the execution of motor processes is coherent with that proposed by van Sommers (1989) and is based on the comparison of general processes in the production sequence. As van Sommers did not discuss the motor programmes sub-models in any detail, it is, thus, possible, to integrate the described procedures to this final component of the van Sommers graphic output system model.

In summary, motor behaviour has a significant role to play in the physical process of transmitting graphical information from the mind to a graphical medium. Although this study will not attempt to investigate the effects of motor behaviour in the same detail as that employed in the hand movement or kinematics research, it will attempt to make general observations on whether drawing outcomes become faster in conjunction with greater learning. In this section, we have described the importance of motor processes in drawing. The following section will elucidate the methods for analysing graphical productions.

### 2.2.7 Methodology for studying drawings

Various methods have been used to study and evaluate graphical productions in the context of learning from drawings, such as cognitive development, problem-solving, expertise and motor processes of drawings. These methods can generally be regarded as either qualitative or quantitative analyses. Qualitative measures entail observation of the drawing outcomes and verbal protocol analysis, while reaction time, kinematic analysis and graphical protocol analysis are examples of quantitative analysis.

Qualitative measures emphasize the accuracy of graphical reproduction, namely whether the drawn elements are in the correct scale in terms of dimension and shape, or whether they are consistent with those presented on the stimulus. In most of the drawings, scorings of qualitative measures, such as second judge or inter-judge agreements, are normally employed to confirm the reliability of the judgment on the graphical productions. This method was used by a large number of researchers, who studied drawings, including Bartlett (1932), van Sommers (1984) and Karmiloff-Smith (1990). For example, Karmiloff-Smith (1990) observed children's graphical production by categorizing the outcomes according to the requirements of the drawing task (e.g. existing house, man or animal; non-existing house, man or animal). Nicholls and Kennedy (1992) evaluated the drawings with two judges by classifying the final output according to the frequency of the drawings into their defined categories. Willats (1977), however, did not use inter-judge agreements in his inspection for classifying the drawings. Alternatively, Cohen (2005) reported using verbal protocols in the drawings analysis of spatial visualization tasks. Nevertheless, although these measures revealed findings for learning development, they were insufficient to explain the underlying internal representations. In addition, although Koedinger and Anderson (1990), who also used verbal protocol analysis, showed some evidence of mental representation processes in the problem-solving capabilities of experts, their underlying research interest was more focused on the ability to solve geometric theorem problems, rather than evaluating the process of retrieving graphical components from the underlying mental representations. Therefore, quantitative measures, which emphasized the use of temporal information from the drawing data, offer the possibility to reveal more information concerning the underlying attributes of internal representation, compared to qualitative measures, which are mainly based on observations and hypotheses.

Reaction time, which is defined as the interval of time between the stimulus on set and the beginning of a response, is a type of quantitative analysis commonly used to evaluate graphic productions. This method normally uses stop-watches or computers to record the temporal data. Egan and Schwartz (1979) referred to this method as inter-response time (IRT) in their research, which sought to provide evidence of expertise between skilled and unskilled participants on symbolic diagram readers. A similar technique was also reported by van Mier and Hulstijn (1993) in an experiment involving the copying of letters, figures and patterns, all of which consisted of the same number of strokes, number of pen lifts, direction of the first stroke and symmetry. Although the IRT technique had successfully revealed predicted findings, which suggested the processes of retrieval and mental organization of the specified information, the accuracy of this method for analysing drawings was debatable. This is because the IRT, as proposed by Egan and Schwartz (1979), is computed by the nearest estimation of time between the symbols of the drawings from the recorded time based on pictures taken by the experimenter after each symbol was placed on the answer sheet. Furthermore, van Mier and Hulstijn (1993) redefined reaction time as 'initiation time' in order to reduce the effects of motor programming and to accommodate the differences between perceptual processing and motor programming. This was done so that the recorded time course would be closer to the time taken up by thinking. 'Initiation time' was computed by finding the time difference between the double strokes and single stroke of the specified drawing task (there were four sets of stimuli, each consisting of the same number of strokes), as it was predicted that doubling the number of strokes would increase the initiation time in accordance with the complexity of the stimulus.

On a different analytical scale, yet still in the area of qualitative measures, a number of researchers have recognized kinematic analysis (hand and arm movement analysis) as a plausible measurement for drawing (Thomassen, Meulenbroek & Tibosch, 1991; Blank, Miller & von Vofl, 2000; Gonzalez et al., 2011). Findings from this technique, however, were not sufficient to evaluate the underlying mental representation of graphical information.

Nevertheless, in employing this method of analysis, Gonzalez et al. (2011) reported that either copying or tracing tasks may potentially facilitate learning with drawings as a result of the use of repetitive drawing practices.

Other research on drawing protocols has used experiment specific techniques, such as ‘goodness of parts within figures’ and ‘bushiness’ to compare the drawn outcomes in reference to the models or the actual stimulus (Palmer, 1977; Koedinger & Anderson, 1990). These findings provided insights on the underlying mental representations. They are, however, specific to problem-solving and perceptual representation, rather than investigating the effects of drawings in relation to spatial (e.g. spatial properties, such as regions and proximity) and semantic (e.g. meaning, such as categorical membership) information. This is because the focus of this work lies on the problem-solving skills of experts and the processes that operate in their proposed theory of graphical representation. Therefore, this thesis will extend the research of Palmer (1977) and Koedinger and Anderson (1990), by evaluating the effects of spatial and semantic information on the underlying mental representation of drawings. Furthermore, this thesis will also generalize the outcomes of the internal representation of graphics using data from normal adults, rather than experts or those encountering drawing difficulties.

The final technique for review is known as the graphical protocol analysis (GPA). In conjunction with the use of a graphics tablet, this method, which has been employed in a number of drawing and writing tasks, has proven that the analysis of internal representations is possible. The GPA analyses the temporal signal in which patterns of pauses occurring between written or drawn elements are digitally captured using a computer’s clock (measured in milliseconds). This ensures an accurate recording of pauses between the pen up and pen down moments during the drawing actions. An advantage of the GPA over the standard reaction time technique is that it employs simple and artificial stimuli. This is because GPA uses a modern and economical approach to capture accurate and rich data during the naturalistic act of drawing using a pen. The GPA method has been applied to experiments that have required participants to write and recall number sequences (Cheng & Rojas-Anaya, 2005), write familiar and unfamiliar word phrases (Cheng & Rojas-Anaya, 2006), copy mathematical formulae (Cheng & Rojas-Anaya, 2007) and write sentences (Cheng & Rojas-Anaya, 2008; van Genuchten & Cheng, 2009, 2010). Specifically in regard to drawings, this method had proven adequate for the investigation of internal representations with the use of simple geometric patterns (Cheng, McFadzean & Copeland, 2001). Therefore, the experiments in this study will employ the GPA method as the type of analysis for all drawing outputs applied to more complex stimuli.

We have, thus far, discussed the methods for analysing drawings. The following section will review the literature on chunking in drawings.

## 2.3 Chunking in drawings

This section will discuss the effects and methods of processing chunks with regards to drawing. The review will first introduce the term *chunks* and discuss the properties of the basic chunks. Studies on chunking are also reviewed by analysing the theories and models of chunking. The effects of chunking will be further reviewed in greater detail with respect to the processes of drawing. A review of the mental representation of chunks in the format of hierarchical organizations will be performed. Finally, we will describe the effects of chunks from motor behaviour.

### 2.3.1 Basic properties of chunks

The limited capacity of the working memory affects the way we perform complex cognitive tasks such as remembering phone numbers, playing chess, memorising list of items from various categories and reading musical notes whilst playing an instrument (Chase & Simon, 1973; Buschke, 1976; Cowan, 2001; Williamon & Valentine, 2002; Gobet, 2005). Thus, a method to overcome the limitation of the working memory is essential. *Chunking* is an effective mechanism employed by the working memory to separate the large task into sets of smaller tasks such as the examples given. Earlier on, the term *chunk* that was first introduced by Miller (1956) was defined as a group of related information that shares related characteristics which normally appear in sets of small groups called units. Miller's key contribution proposed that chunks of information can be remembered between 7 ± 2 at a time in the working memory. Chase and Simon (1973), Simon (1974) and Cowan (2001) further define chunks as collections of elements that have stronger associations with its constituent members, but weaker associations with elements belonging to a different chunk. De Groot (1978) proposed the chunking mechanism from the problem solving perspective through the strategies chess players adopt to organize their thoughts upon deciding their next move.

Studies on chunks reveal several basic features (Miller, 1956; Tulving, 1962; Mandler, 1967; McLean & Gregg, 1967; Pollio, Richards & Lucas, 1969; Chase & Simon, 1973; Simon, 1974; Buschke, 1976; Reitman, 1976; Palmer, 1977; Egan & Schwartz, 1979; Reitman & Rueter, 1980; Servan-Schreiber & Anderson, 1990; Sakai et al., 2003, 2004; Gobet & Clarkson, 2004; Pammi et al., 2004). The most important of these basic properties are shown in Table 2.1.

Table 2.1: Summarized basic properties of chunks

| Basic properties of chunks | Investigators |
|---|---|
| 1. *Chunks consist of small units at the beginning of learning. The chunk size becomes larger as learning improves.* | Miller, 1956; Tulving, 1962; Buschke, 1976; Sakai et al., 2004 |
| 2. *Experts initially recall larger chunks followed by smaller chunks, while novices recall smaller chunks followed by further smaller chunks.* | Chase & Simon, 1973; Egan & Schwartz, 1979 |
| 3. *Basic chunks are stable and recurrent.* | Miller, 1956; Tulving, 1962; Chase & Simon, 1973; Buschke, 1976; Reitman, 1976; Sakai et al., 2004 |
| 4. *Chunks are well-defined and organized.* | Chase & Simon, 1973; Buschke, 1976; Reitman, 1976; Sakai et al., 2004 |
| 5. *All items in a chunk are recalled as a whole before items from other chunks are recalled.* | Reitman, 1976; Reitman & Rueter, 1980 |
| 6. *Items in a chunk are spontaneously clustered.* | Buschke, 1976; Sakai et al., 2003; Pammi et al., 2004 |
| 7. *Items within a chunk remain intact when basic chunks are grouped in a higher order organization.* | Buschke, 1976; Palmer, 1977 |
| 8. *Items in a chunk form a collection of within and between chunks.* | Pollio et al., 1969; Chase & Simon, 1973; Reitman, 1976; Egan & Schwartz, 1979; Reitman & Rueter, 1980; Sakai et al., 2003; Pammi et al., 2004 |
| 9. *The order of items in a chunk may change in different recalls.* | Buschke, 1976 |
| 10. *An item can be a member of different chunks.* | Buschke, 1976; Reitman, 1976 |
| 11. *Chunks are commonly formed based on spatial proximity or semantic relations.* | Pollio, Richards, & Lucas, 1969; Chase & Simon, 1973; Reitman, 1976; Palmer, 1977; Reitman & Rueter, 1980; Servan-Schreiber & Anderson, 1990 |

Three of the controversial chunk features are: (1) an item can be a member of different chunks; (2) all items of a chunk are recalled before those from other chunks; and (3) retrieval of chunk sizes differs in various tasks (i.e. larger chunks are recalled before smaller chunks as opposed to smaller chunks are recalled before larger chunks). In response to the first feature, Reitman (1976) argued that an item cannot be a member of more than one chunk because chunks which are organized in a hierarchical manner cannot possibly have an element as a member of the other chunk at a higher level. Nevertheless, Buschke (1976) proposed that repetitive items in different chunks are likely to occur due to indirect or direct relations with other members of the chunks. However, the nature of the task and the type of stimuli used in both of these studies are different. For example, Reitman employed the Go game stimulus, which is an example of a formal domain that relates to well-structured games where the pieces are grouped by certain well-defined rules. On the other hand, Buschke employed word lists as the stimulus in his experiment where the structure of the domain is simpler, as memorizing elements does not necessarily require the participant to strictly follow a set of predefined rules, thus serving as a less-structured task. At least until the time of writing, to the best of the author's knowledge, this issue has not been resolved yet. The differences pointed out by these two studies may be due to the nature of the task. Thus, it may well be that the formation of the chunks for a well-structured domain does not produce overlapping chunks as compared to the less-structured domain where chunks may overlap. Alternatively, these differences may occur due to the coincidence of the kinds of knowledge domain these studies considered.

With regard to the second feature, Cohen (1966), Reitman (1976) and Reitman and Rueter (1980) proposed that items in a chunk are recalled as a whole before those from other chunks. For example, Reitman (1976) performed an experiment by asking Masters and novice participants to recall meaningful and random clusters of stones of the Go game. It was found that the Masters participants tended to recall as many stones from a single cluster before stones from a different cluster were subsequently recalled. This theory which has also been applied by other investigators (Bousfield, Sedgewick & Cohen, 1954; Tulving & Pearlstone, 1966; Pollio, Kasschau & DeNise, 1968) in other types of tasks based on recall from memory for words, showed similar findings. Reitman (1976), however, further noted that it is impossible to recall all elements of a chunk before recalling elements from another chunk. This idea that was empirically supported by Reitman and Rueter (1980) was introduced to account for patterns of overlapping chunks.

The final controversial chunk feature is related to the size of chunks that changes from the initial learning stage towards mastering the material in question. Chase and Simon (1973) argued that Master chess players recall larger chunks during the initial learning stage in which the chunks are broken down into smaller pieces over time as learning progresses. This notion was supported by Egan and Schwartz (1979) in tasks related to recall of symbols for electronic circuit diagrams. Conversely, Buschke (1976) proposed that smaller chunk sizes are demonstrated in uncategorized word list recall. Similar findings were reported by Tulving (1962). These contradicting ideas in terms of the changes in the size of chunks as learning occurs may be due to the nature of the tasks employed in the experiments reported by these authors. For example, retrievals of chess and circuit symbols are structured because the functions of the constituent items have a role to determine the grouping of the chunks. Alternatively, broader domain-specific knowledge among experts than novices as that shown in recall of chess chunks (Chase and Simon, 1973) and electronic circuit symbols (Egan & Schwartz, 1979) may be a possible reason why larger chunks are first recalled as opposed to smaller chunks. This is because experts tend to have a global picture and more complete knowledge about the task of concern. As a consequence of being able to relate different chunks together, these experts are therefore able to execute a general solution which may correspond to the larger or higher level chunks followed by smaller chunks of the sub-solution during the process of problem solving allowing them to retrieve the related information systematically. It is on these grounds that chunks are considered to be organized hierarchically.

The following section discusses studies on chunking emphasizing the computational model of chunking that predicts how chunking is used during learning.

### 2.3.2 Models and theories of chunking

Since the discovery of chunks, chunking as an important mechanism for learning has been widely studied in cognitive science. Among the earliest studies related to chunking were those involving computational models. Two main computational models widely discussed among researchers related to the chunking process during perception are EPAM (Feigenbaum et al, 1962; 1963; 1984) and CHREST (De Groot & Gobet, 1996; Gobet & Simon, 2000; Gobet et al, 2001; Gobet, 1998; 2005; Gobet & Clarkson, 2004; Lane, Gobet, & Cheng, 2000). These models serve as a foundation for the theoretical framework of how chunking is used during the process of human learning which computationally predicts chunks. For example, EPAM simulates learning through the growth of a discrimination network represented by leaf nodes, and has been applied to the role of strategies in concept development (Gobet, Richman, Staszewski, & Simon, 1997) and to the acquisition of chess expertise (Simon & Barenfeld, 1969; Simon & Gilmartin, 1973). CHREST, an improved version from EPAM has more additional functions (e.g. every node has an image) that incorporate semantic associations between chunks that form schemas as shown in Figure 2.4. This has improved the semantic memory property for the learning simulator where learning using the association between chunks called lateral links can only happen based on the spatial relationship between the nodes. One of the functions of CHREST is the ability to create retrieval structures known as templates, which adopts a form of slotted schemas that is referenced in the short-term memory as an individual chunk. The template allows the details of the stimulus to be stored in the slots, hence ensuring rapid recall. The mechanism simulated in EPAM has led to the development of chunking theory while the presence of templates in CHREST has motivated research on schemas. Other computational models that also adopted the idea of chunking are MOSAIC-a variant of CHREST (Crocker, Pine, & Gobet, 2000), Soar (Newell, 1990) and ACT-R

(Anderson, 1983). The two latter models respectively represent chunks as procedural rules and declarative knowledge.

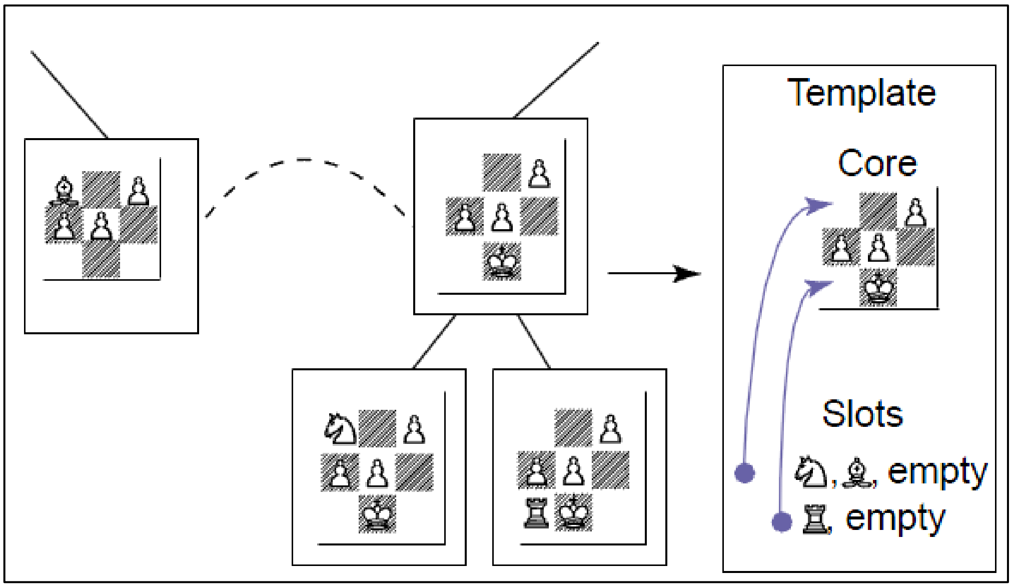


Figure 2.4: Example of template based on chess used in CHREST [source: Gobet et al., (2001)]

The chunking effect has been extensively studied in the chess domain. De Groot (1978) in his memory task experiment involving brief presentation of chess positions, demonstrated that the level of expertise could be determined by improved recall among experts (i.e. at and above Master level) compared to poorer level of recall among novice chess players. In a similar study, Chase and Simon (1973) further found no recall performance differences among players at different skill levels (i.e. a Master, a class A player and a novice) when the shown chess positions are in random order. However, a systematic review of experiments further conducted by Gobet and Simon (1996) demonstrated that Master players recall random positions better than novices from 13 studies, in 12 of which Masters outperformed the novices. Taken together, this evidence strongly supports the view that not only the internal knowledge has a major influence for expertise, but also the structure of chunks is more organized in experts' memory as they demonstrated superior performance even in random positions. Furthermore, expert players often have slight advantage over novices even in random patterns of chess because of their extensive knowledge of chess positions and moves. Therefore, it is likely that the Master players are able to match a few of the encountered random patterns with the positions previously seen in some of the games they played.

This offers further evidence for chunk-based theories as that proposed by Chase and Simon (1973). The Chunking Theory has two assumptions: (1) items are encoded into two symbols referred as stimulus and response symbols, (2) chunking consist of three processes (i.e. encoding, mapping and decoding). The first assumption means that each item of a chunk is mapped (using the second assumption) to a verbal code of the respective item. The advantages of this theory are that (1) the processes of encoding and decoding are equally fast to the hierarchical process, (2) the grouping of items based on chunks increases performance, therefore reducing the number of mappings and processes, (3) chunks are accessed in a bottom-up way. Although this theory may seem applicable to the chess patterns, Charness (1974) and Frey and Adesman (1976) did not agree with this notion because they debated that recall of chess positions is limited if memory for the verbal materials is interfered with during the task. Charness and Frey and Adesman performed a study by asking participants to name chess pieces or find the best moves from a different position. They found no evidence of visual patterns represented by verbal labels in the short-term memory. This introduces an open-ended question about the strength of association between symbols and the verbal labels in the memory.

In response to this drawback, Egan and Schwartz (1979) proposed the Conceptual Chunking Hypothesis that associates chunks with the systematic organization of concepts stored in the long-term memory. Egan and Schwartz described that rather than using verbal labels from the short-term memory to cue the actual chunks stored in the long-term memory during recall - a notion proposed by Chase and Simon (1973), chunks are cued by conceptual category from the long-term memory. The advantages of this theory is that (1) during retrieval, chunks from an appropriate conceptual category for the topic of concern will be cued although the drawer processes a single chunk which links to a known general category, (2) the appropriate schemas or knowledge about the conceptual category of concern enables the drawer to devise a systematic recall and search process because the information accessed from the schemas is conceptually related. Palmer (1977) and Pollio, Richards, and Lucas (1969) reported similar effects where figures have strong relationships with the underlying conceptual knowledge.

This section has reviewed the theories and models related to chunking. The following section discusses the effect of chunking in drawings.

### 2.3.3 Chunks in drawings and diagrams

The effects of chunking have been found in a number of drawing studies. Egan and Schwartz (1979) conducted research on skills of reading symbolic drawings between skilled and novice participants. Three experiments were performed (1) on a skilled electronic circuit diagram reader to indicate his mental organization of the drawings; (2) to find out if skilled participants have an advantage over unskilled participants during the recall of symbolic drawings; and (3) whether increased study time would improve recall. The type of drawing task was to draw circles to indicate meaningful groups of symbols apart from recall of symbols for the circuit drawings. The outcomes of the experiment were measured by the number of chunks, the size of each chunk and the number of correct chunks produced. The major finding was that skilled readers recalled larger chunks than unskilled readers, as the experts recall symbols based on the functional units of the chunks using the generate-and-test method rather than relying on spatial proximity alone, as that demonstrated by novice symbolic drawing readers. In this context, Egan and Schwartz refer to the generate-and-test method employed by the experts as the ability to generate more symbols within each chunk if the experts know that a display consists of certain defined functional units. Furthermore, it was found that skilled participants were superior to novice readers as the numbers of transitions between chunks reduced over increasing recall of chunk outputs. As discussed by Egan and Schwartz, skilled participants tended to demonstrate systematic recall even with random recall which indicates well-organized structure of the chunk units that correspond to established conceptual knowledge in the long-term memory. Egan and Schwartz based their findings on the Conceptual Chunking Hypothesis on the grounds that visual patterns are not represented by verbal labels, and thus chunking could be associated with the organization of concepts. Therefore, experts are possibly superior to novices because they possess greater depth of conceptual knowledge of the symbolic drawings domain. By this, Egan and Schwartz could have referred the conceptual knowledge to schemas although the term was not clearly specified. Furthermore, Egan and Schwartz showed that the recall of chunks from symbolic drawings has some relations with the organized structure of the conceptual knowledge of this specific domain.

Karmiloff-Smith (1990) explored representational change during child development. In her experiment, children in various age groups were asked to produce drawing of objects (e.g. house, man or animal) that exist and do not exist. The reason these tasks were chosen was to study the normal and unconventional drawing procedures demonstrated according to age, such as whether children at different ages were able to perform changes such as deletion, insertion and change of position or orientation in their drawings. Given these requirements, a substantial difference was found in the drawings between the younger and older age groups. Older children often make cross-category changes (e.g. drawing wings that belong to the animal domain to the side walls of the house domain – see Figure 2.5) from different domains in the middle of their drawing activity rather than at the end of the drawing procedure as commonly demonstrated by younger children. Thus, this shows that younger children often perform whole parts of their drawings before they continue drawing a different part. For example, they may complete the drawings of the heads before the hands and the legs are drawn, when asked to draw a human that doesn’t exist (e.g. many heads and legs) as shown in Figure 2.5. These parts could be taken as chunks, although Karmiloff-Smith did not specify parts or sub-procedures of the drawings in terms of chunks.

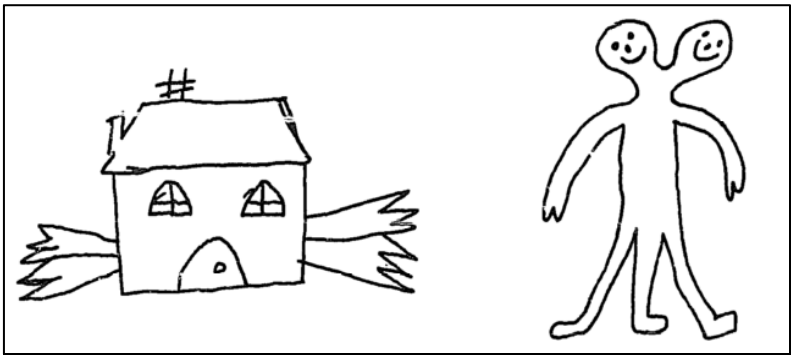


Figure 2.5: Examples of older (left) and younger (right) children's drawings [source: Karmiloff-Smith (1990) p68,70]

Vinter and Picard (1996) performed similar research to that reported by Karmiloff-Smith (1990). In their experiments, children in various age groups were asked to perform drawings of either a house or a television. The four drawings tasks were: (1) free drawing – cued based on verbal description; (2) copying – participants were shown the actual coloured objects as a reference figure during drawing; (3) innovation – participants were asked to draw based on imagination from the given instructions such as "objects on another planet" or "did not exist in our world"; (4) deletion – delete parts of the figure. Based on this experiment, the measured variables were the starting point of drawing, the direction of drawing and the sequence of the drawing movement. Vinter and Picard reported similar findings, which support the results obtained from Karmiloff-Smith (1990). Furthermore, based on their findings, the effects of chunks were apparent where 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 demonstrated changes performed to the drawings were: change of size, deletion, replication, changes of position or orientation of elements, modification of whole shape, assimilation to another object and *inter-representation change*. Younger children were more commonly observed to demonstrate *intra-representational element-based changes*, a condition where changes on the drawings occur within category and within chunk. In this perspective, drawings were mainly concerned with the modifications made to the elements. On the contrary, older children tended to show *inter-representational whole-based changes,* which enabled them to integrate and access components from different categories. Therefore, older children could manipulate the drawings by integrating different components from distinct categories rather than only elements within a specific component from a single category.

Other investigators proposed theoretical models of drawings such as how parts of geometrical figures are perceived for reproduction and representation of units of graphical elements in the knowledge organization. For example, Palmer (1977) proposed a framework for perceptual representation. In Palmer's experiment, among other tasks, such as verifying parts within figure and synthesizing figure from separate parts, participants were asked to draw and rate simple straight line figures in various configurations. Palmer termed chunks as "structural units" and regarded these units as elements of mental representation that are potentially processed as single entities. These grouped elements conform to the characteristics of the Gestalt principle. These units are reported to integrate in a hierarchical network in which Palmer proposed that the complete network of the structural units is called a *schema*. The schema has a role of integrating all related information such as the scene, objects, and parts of the geometrical figure perceived during the perceptual processing in a systematic framework. According to Palmer, the use of a schema is advantageous at the level of information selection for further processing including the analysis of the selected data and eye fixation on specific data of interest. Palmer found that (1) graphical elements (at least simple, straight lines figures) are represented in a hierarchical format consisting of at least three levels (i.e. whole figure, the multi-segment parts and individual line segments), (2) units of graphical elements are encoded selectively depending on the complexity and the context of the figure, (3) parts within a figure are processed as either good-parts (integration of segments of elements based on relationships that satisfy the Gestalt principles of grouping) or bad-parts, where the former is processed more efficiently, accurately and identified faster than the latter type (bad-parts). This is because good parts are recognized in parallel throughout the whole figure as opposed to serial and componential recognition of the bad parts, (4) more time was needed to mentally synthesize the bad parts in contrast to less time with more successful attempts for the good parts.  Although Palmer found that figures are represented in a hierarchical network which is formed based on chunks of graphical elements that satisfy the Gestalt principle, no information was given about the relationship between these figures with semantic knowledge such as whether parts from the figure are remembered as a consequence of the association in a meaningful context.

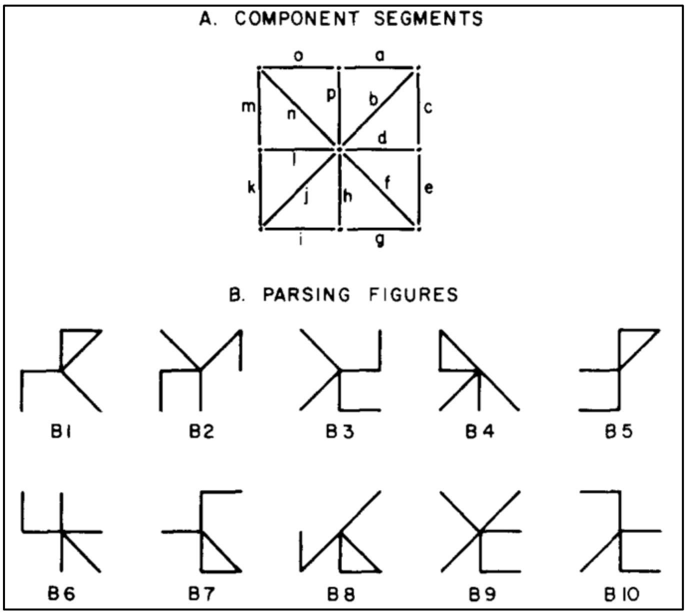



Figure 2.6: Stimuli used in Palmer's experiment. (A) defines the whole figure which consists of a total set of 16 segments, (B) shows 10 subsets of 6 segments decomposed from (A) [source: Palmer (1977)]

In another study, Koedinger and Anderson (1990) studied problem solving for geometric theorems and made a performance comparison between computer models and experts. Koedinger and Anderson proposed that chunks of geometry facts which are associated with the whole geometry image in the knowledge organization enable experts to skip minor steps and only focus on the key steps – which allows faster and easier geometric theorem problem solving compared to novices. Although, the study by Koedinger and Anderson accounts for the findings related to the underlying internal representation, the findings are specific to problem solving using diagrams and figures without any relation to the effects produced by the spatial and semantic conceptual knowledge. Therefore, the study reported in this thesis will step towards establishing a more detailed experimental evidence of the existence of chunks from ordinary drawing activities without specific focus on problem solving from conceptual domains such as physics or mathematics. Instead, the present research will investigate the use of semantic and spatial schemas during drawings.

More recently, Cheng, McFadzean, and Copeland (2001) studied the production of simple geometric figures as a means to investigate the chunking processes in drawing. Their experiment required participants to draw simple figures such as vertical and horizontal lines, and identified effects of chunks based on temporal patterns. The study suggested that the structure of graphical chunk organization is demarcated by the latency between the chunks. However, results from Cheng et. al (2001) did not consider the nature of the underlying internal graphical organization. Extending this work, the study in this thesis will make an attempt to probe the nature of the chunk structure in the mental schemas using more complex diagrams and figures.

The existence of chunks from graphical elements raises the question of how these chunks are mentally organized. Therefore, it is worth investigating the principles of the underlying internal organization of drawings in order to gain a deeper understanding of the process of drawing. This is discussed in the following section.

### 2.3.4 The organization of chunks in the mental representation

Studies on chunking and organization in memory have been investigated in detail since Bousfield (1953) suggested that items are potentially recalled in associated clusters that Miller (1956) later termed as chunks, which was shown to be necessary for enabling efficient information processing for the limited capacity of the memory. Examples of issues investigated in previous studies concerning the organization of chunks in memory included demonstrating that free recall is structured hierarchically, showing methods for analysing the degree of structure, identifying chunks of formation based on participant-specific selection or experimenter-defined specification, and analysing the intervention of items that obstruct the recall process. As discussed in this section, valid findings concerning the mental representation of various types of information were reported from studies in which experimental tasks focused on the use of textual materials such as word list recall (Bousfield, 1953; Mandler, 1967; Pollio, Richards, & Lucas, 1969; Bower, 1970; Tulving & Donaldson, 1972), artificial grammar learning (Servan-Schreiber & Anderson, 1990), and judgement of sentences (Collins & Quillian, 1969). However, it is still unclear whether these findings also apply to drawing tasks. Therefore, one of the aims of the present research is to investigate the organization of graphical materials as an effect of learning with drawing.

A number of techniques have been reported to demonstrate the details of the information organization in the underlying mental representation. More specifically, various methods have been used to recognize the chunk boundaries (i.e. within and between chunks). For example, pauses or IRTs have been used in many studies as an indicator for chunk boundaries from either the experimenter-defined or individually-defined chunks (McLean & Gregg, 1967; Pollio, Richards, & Lucas, 1969; Chase & Simon, 1973; Reitman, 1976; Egan & Schwartz, 1979; Reitman & Rueter, 1980; Card, 1982; Koch & Hoffmann, 2000; Williamon & Valentine, 2002; Sakai, Hikosaka, & Nakamura, 2003, 2004; Williamon & Egner, 2004; Pammi, Miyapuram, Bapi, & Doya, 2004). This method is used despite the fact that Reitman (1976) emphasized that IRT may not be an ideal tool to analyse the effects of within and between chunks. However, other methods such as *multidimensional scaling* (Kruskal, 1964; Sattath & Tversky, 1977), analysis of *distance matrices* (Johnson, 1967) and drawing circles around related items (Reitman, 1976; Egan & Schwartz, 1979) have been reported to serve the same purpose. Other measures of chunks in the mental organization (Tulving, 1962; Mandler, 1967; Reitman & Rueter, 1980) concern the consistency of chunk items recalled in sequence, which corresponds to the amount of structure rather than to the form of the organization. The *transition error probability* measure (Bower & Winzenz, 1969; Martin & Noreen, 1974) which determines the sub-chunk boundaries at a point where error rates are high was reported in serial order types of stimuli, such as word lists.

Findings from many studies in chunking and organization concur that chunks are hierarchically organized (McLean & Gregg, 1967; Bower et al., 1969; Buschke, 1976; Reitman, 1976; Palmer, 1977; Egan & Schwartz, 1979; Reitman & Rueter, 1980; McKeithen et al., 1981; Gobet, 2001; Sakai et al., 2003; Miyapuram et al., 2006; Cheng & Rojas-Anaya, 2008). Several investigators have depicted this representation in the form of graphic convention as shown on Figure 2.7 and Figure 2.8. For example, Palmer (1977) proposed that chunks on a hierarchical network are separated at many levels for which the perceptual representation of a complex figure, object or scene can be represented by a single whole chunk or a combination of primitive perceptual units (e.g. elements in a drawing that represents a house). The chunks are connected with relationships according to weighting values where the entire hierarchical network forms a schema, which becomes the conceptual knowledge about a specific topic of concern. These chunks have global and specific properties that consist of the parts and whole relationship. For example, considering the drawing of a house, a drawer may first draw the walls and roof. These outlines may indicate that a figure such as a house is likely to be drawn, which serves as the global property of the house object. Further drawings such as the pair of windows, chimney and door are all considered as the specific properties for the outline of the house. However, each of these properties is a global property for the more specific elements. For instance, the door may have other parts such as a doorknob or a bell, which are the specific properties for the door. Palmer noted that it was not possible to determine the likely type of search strategy whether depth-first or breadth-first search due to limitations in the experimental data. Thus, the study reported in this thesis will attempt to evaluate this issue in more detail.

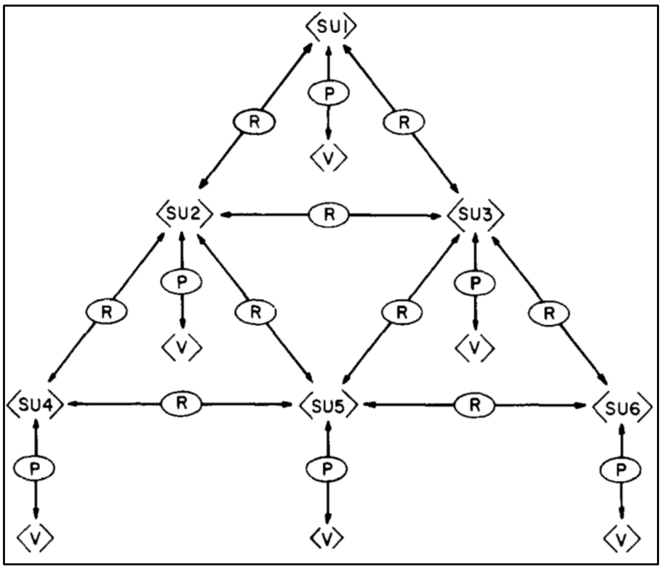



Figure 2.7: The general format of hierarchical chunk organization proposed by Palmer (1977). The chunks termed as structural units (<SUs>) on each level are defined by the values (<Vs>) and the structural relationships (<Rs>) with other structural units.

In another theoretical study, Reitman and Rueter (1980) proposed techniques to define and identify errors, and measure the amount of mental organization of information based on repetitive free recall. Therefore, their study is focused on the form of chunk representation rather than investigating the nature of chunk properties. Reitman and Rueter proposed that traversal of chunks in the hierarchical mental organization called an *ordered tree* can be classified according to constrained directionality such as (1) unidirectional where items or chunks are recalled in the same order (e.g. alphabet recitation), (2) bidirectional where items are recalled in one order and the inverse order (e.g. counting numbers in forward and reverse direction) and (3) non-directional where items are recalled in various orders (e.g. tasks that can be accessed in any order/items from a word list). Figure 2.8 demonstrates an example of the directionality of an ordered tree.

Although chunks can be accessed from various directionalities, Reitman and Rueter proposed that the search technique is depth-first search as this method minimizes the number of recall orders. In this technique the retrieval begins from the root node (or chunk) and traverses down the hierarchy until the solution is found at a terminal node before traversal is resumed to the immediately superior node with output of the terminal nodes that gives the solution. This method of traversal continues until the root node is reached. Considering Figure 2.8, examples of the retrieval strategies for a free recall are as follows: after recall of the root node, which determines the search for solution, a participant may begin the retrieval at item B, the next item for recall is C (to complete chunk 5), then recalls item A (to complete chunk 2), followed by items D – E – F (to complete chunk 3), and finally items G – H (to complete chunk 4). An alternative search if the participant begins the search at item G is to continue at item H (to complete chunk 4), then D – E – F (to complete chunk 3), then either A followed by B and C (complete chunk 2 before 5), or B or C followed by A.

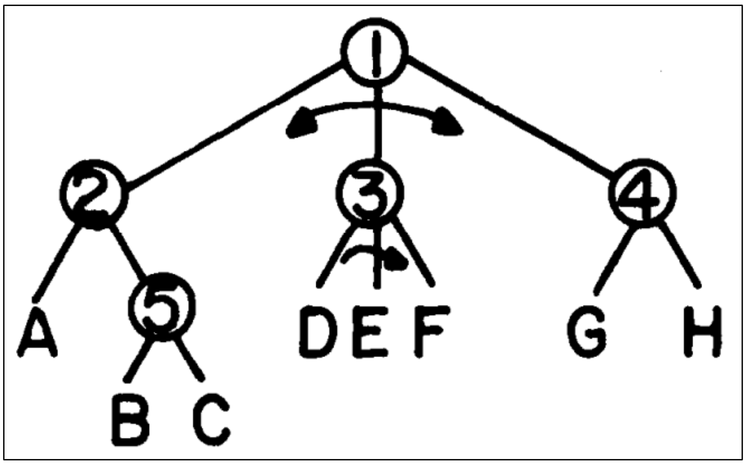



Figure 2.8: Example of constrained directionality shown on an ordered tree of items labelled A through H. Unidirectional chunks are marked by single-headed arrows as in node 3, bidirectional chunks are marked by double headed arrows and non-directional chunks by the absence of arrows as in node 2, 5 and 4
[source: Reitman & Rueter (1980)]

In order to better investigate the amount of information in order trees, Reitman and Rueter further suggest a method called *possible recall orders* (PRO) based on mathematical logarithmic functions. This algorithm calculates the number of different recall orders that can be achieved by traversing the chunks. In order to counter for errors, comparison of the PRO values across multi trial recalls are made to detect items that are not recalled within their own chunk. However, a shortcoming of this technique is that it is not possible to reveal the order of items recalled. Friendly (1977) and Monk (1976) proposed similar techniques. However, the study reported in this thesis will attempt to identify the chunk organization based on temporal pauses.

The technique developed by Reitman and Rueter (1980) was employed by McKeithen et al. (1981) to evaluate the form and amount of mental representation among computer programmers at different skill levels. After viewing a coherent and random version of computer programs, these programmers were required to recall by writing these programs over five consecutive sessions. The results showed that skill levels differentiate recall performance for normal over random version with experts showing superior recall to intermediates, who in turn outperformed beginners. This indicates that the mental organization of experts is more structured than that of novices as that shown in Figure 2.9. In a different part of the study, McKeithen et al. proposed the potential individual organization of the recall for the programming keywords. It was further found that novice programmers chunk keywords based on an either pure natural language, or a mixture of natural language and meaning of the programming keywords, while experts perform chunking based on useful programming relationships that have specific meaning to the programming language. Although experts may seem to reveal more chunks than novices, the depth of organization which refers to the structure of the higher and lower order chunks in the hierarchical organization did not indicate differences between the skill levels. Therefore, the general pattern of organization is unlikely to be an advantage in the recall performance, but the contents of the chunks may differ significantly. This suggests that the conceptual information is important to determine the structure of mental organization and its related recall performance.

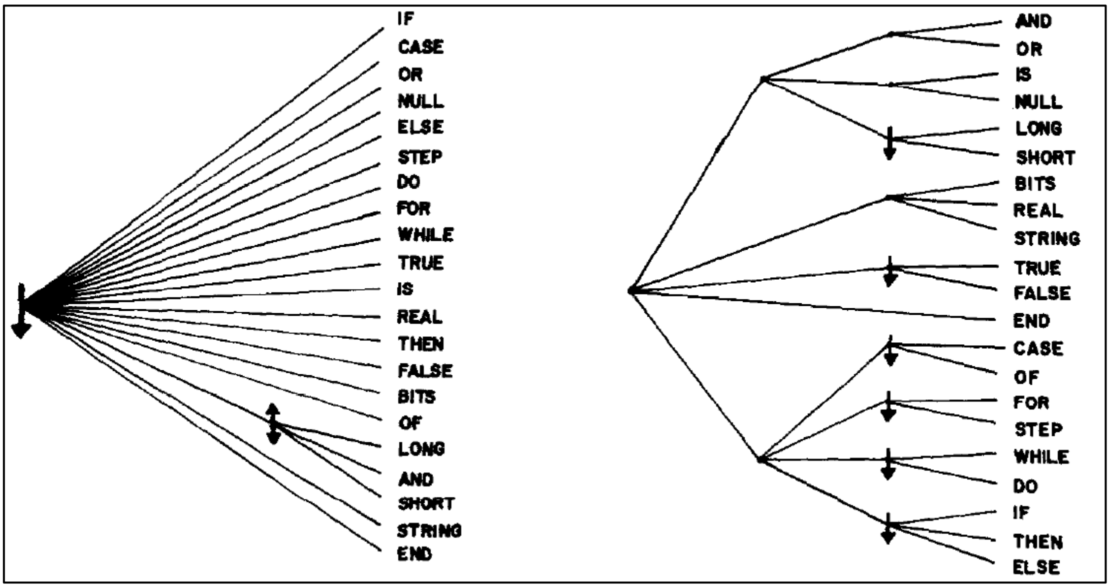



Figure 2.9: Chunk mental organization of programmers of novices (left) and experts (right)
[source: McKeithen et al. (1981)]

This section has reviewed a number of proposed methods for revealing the chunk organization and the potential form and amount of the mental structure. The following section discusses the effects of chunking from the motor behaviour perspective.

### 2.3.5 The effects of chunking in motor behaviour

Chunking has been observed during learning of visuomotor sequences and in motor movements. Sakai, Hikosaka and Nakamura (2004) discussed the association of the internally generated temporal pattern referred to as *rhythms* with the performance of skilled movement. For example, a repetitive action of signing a name on a paper produces a consistent rhythm for which timing is an important factor in order to achieve well-learned motor sequences (Sakai et al., 2004). In their study, participants were asked to learn sequence of button presses with fixed response-stimulus which recorded the inter-response time (IRT). Sakai et al. found that longer reaction times were found between pattern changes (e.g. 123-321). Thus, Sakai et al. proposed that chunk patterns depend on the sequence structure (e.g. 1234-567 vs 123-45-67). Individual-preferred rhythms, however, emerge when no specific pattern is given for a sequence of numbers from 1 to 10. Furthermore, as learning progresses, the patterns of chunks are reorganized into a hierarchical structure, which consists of several chunks. In addition, as learning improves, sequences are performed with fewer but larger chunks. These chunks become inseparable and are preserved once established. Hence, shuffling or separating the established chunks will produce more difficult learning. Furthermore, Sakai et al. suggests that performance of motor sequences within a chunk is performed more automatically than non-automatic performance between chunks. The automatic motor sequences reduce the cognitive demand that is required to control the performance of a task. On the other hand, more control is necessary in order to choose and execute the following chunks as for the motor performance for between chunks. Therefore, the temporal pattern of motor performance signifies an organized representation of the motor skill. This structure of motor chunks as proposed by Sakai et al. is hierarchical. As chunk patterns are dependent on the participant's learning history, each individual would thus acquire different organizations of chunk patterns.

In visuomotor sequence learning tasks such as keypad pressing, Sakai et al. (2004) suggested that chunking is acquired spontaneously whilst Koch and Hoffmann (2000) suggested that chunks are not formed spontaneously, instead, the members of a chunk are clustered based on physical practices such as repetition, inversion and transposition. Despite the fact that differences of how chunks are formed were discussed, both agreed that the hierarchical organisation of chunks benefits learning. This is because the chunks have been systematically organized in hierarchical order (Rosenbaum, Kenny, & Derr, 1983; Sakai, Kitaguchi, & Hikosaka, 2003; Miyapuram, Bapi, Pammi, & Doya, 2006; Pammi, Miyapuram, Bapi, & Doya, 2004; Schneider & Logan; 2006). Furthermore, smaller sizes of chunks are likely to allow greater reorganization of the chunk sequences (Pammi, Miyapuram, Bapi, & Doya, 2004; Sakai, Hikosaka, & Nakamura, 2004). The characteristics of chunks such as shorter temporal pattern for within chunk than longer temporal pattern for between chunks during sequence learning have been reported by Miyapuram, Bapi, Pammi and Doya (2006). These motor chunking findings are consistent with those found from perceptual chunking, as previously discussed in Section 2.3.1: Basic properties of chunks. Therefore, chunking does not only facilitate learning but also enables efficient performance during sequence learning. It is thus appropriate to assume that when a task is over-learned, the clusters of chunks are structured in a systematic and consistent manner, which reduces the time required to perform a task.

To summarize, studies on the chunking of motor sequences revealed that chunk patterns are potentially represented in a hierarchical organization as a result of the identified temporal pattern from the motor movement. At least with motor behaviour, the formation of chunk patterns is individual-specific, although all participants learn the same sequence of stimuli. In spite of this, chunking is regarded as important for enabling tasks to be performed efficiently, and that the temporal pattern or rhythm may facilitate motor skill learning by organizing rhythmic pattern for the chunks which governs an automatic control of the motor movement.

This section has reviewed previous work indicating that chunks found from motor learning produces similar effects to that found from the perceptual chunking and that the chunks for motor movement are ordered hierarchically. The following section will discuss prior knowledge or schema and its relations with drawings research.

## 2.4 Schema

> *A distance away, Tom heard a melodic tune from an ice-cream van. He waved and stopped the van. Then, he approached the van and ordered an ice-lolly. He looked for some money in his pockets and paid the exact amount as the vendor handed him the ice-cream.*

The short story above describes a scenario of a person who buys an ice-cream. Reading this story enables us to imagine and understand the contents as we could relate it to our previous experience of the situation. This previous experience reveals the internal representation of the conceptual knowledge for the specific topic of concern. For example, in this story, the knowledge of interest is related to buying an ice cream from an ice-cream van. This knowledge is called a *schema*. The term schema was first used by Piaget (1926), while the concept of schema was first introduced by Bartlett (1932). Since that time, the meaning of schema has been widely debated by many theorists leaving it with no fixed definition (Brewer & Treyens, 1981; Taylor & Crocker, 1981; Mandler, 1984; Brewer, 1999). However, a general definition of a schema may include the following: *Well-integrated chunk of knowledge a person possesses about the world, events, people and action or a particular domain*. As schemas are related to experience which each person perceives differently, the contents of a schema for a particular topic are different between individuals. Hence, what people remember is determined by the present schematic knowledge they posses.

Schemas are important and useful as they enable people to form expectations, hence making scenarios predictable. For example, in the story above, among many possible assumptions, a person can thus deduce that *Tom finally eats the ice-cream* or *gives it to someone else to be eaten or stores it in the freezer*. Although the story above may be incomplete (e.g. nothing was told about what happens after *Tom buys the ice-cream*), most people are still able to make inferences due to the rich content of schematic knowledge. Schemas also allow us to fill in the gaps of unspecified information between the story sequences. For example, without explicit information in the story, we are able to infer that *Tom counts the money correctly before he pays the vendor*.

Furthermore, the existence of schemas facilitates visual perception, as demonstrated by Palmer (1975). In his study, Palmer had subjects recognize the different pairing of objects and scenes to serve three contextual conditions (i.e. appropriate, inappropriate, no context). In the experiment, participants were first briefly shown a visual scene (e.g. a kitchen) or a blank scene (denotes no contextual scene). There was a 1.3sec pause before three different objects (e.g. a loaf of bread, a mailbox, a drum) that represents the contextual condition for the scene were shown between 20-120msec. This is followed by 20 sec duration of participants writing the name of the perceived object and rating their confidence level based on a five-point scale. Palmer found that identifying objects was best for objects appropriate to the scene (i.e. loaf of bread-kitchen, mailbox-yard) and worst when the context was inappropriate (i.e. drum-kitchen). This is because in the appropriate context, related schematic knowledge was activated which facilitates the visual perception. In an inappropriate context, however, it may be probable that unrelated schematic knowledge was activated in response to the visual stimulus initially seen by the participants. Therefore, the depth of knowledge a person acquires highly influences the degree of recognition of objects from a particular environment.

In this section, we have briefly discussed the definition of schema followed by an example from Palmer (1975), which demonstrates the use of schemas in object-scene recognition tasks. The following important question would be “how do schemas work?” and what is (are) the possible format(s) in which schemas are represented. These questions are addressed in the next section, which discusses proposed theories of schemas.

### 2.4.1 Schema theories and representation

As discussed in the previous section, the concept of schema was first proposed by Bartlett (1932). In his study that presents the foundation of Schema theory, Bartlett asked participants to recall complex material of folk tales from other cultures. Instead of assessing the accuracy of recall over successive learning, Bartlett studied the errors and distortions the participants produced which reflected to how they encode and store the material in the memory. Findings from the retrieval were that the story was shorter, more coherent and conforms to participant's own schematic knowledge. This is due to intrusion of the schematic knowledge that causes errors during retrieval, hence the inability to recall as accurately as the actual story. Bartlett's interest in studying the schema effects led to further investigation of the schema theories in later years.

The *Schema theory* developed by Anderson (1977) proposed methods related to how schemas function in the memory. More precisely, this theory explains the knowledge structure and the ability of people to recall information. The memory system requires three important capabilities: encode, store and retrieve. Although these three stages have different purposes, they interact with each other. For example, the method of storing the information affects what and how information is stored, which subsequently limits the process of searching and retrieving this information. Schema theory assumes that the encoding stage consists of four operations: (1) *selection*: chooses only relevant information from the stimuli for representation, (2) *abstraction*: stores the meaning of a message with no reference to the already stored syntax and context, (3) *interpretation*: generates prior schematic knowledge appropriate to the present context; and (4) *integration*: forms a holistic memory representation that links the three prior operations. The retrieval process has a central operation called *reconstruction*, where all related new and previous accessible knowledge is selected for representation at the time when an individual reproduces a memory episode. Therefore, schemas are important not only for registering new information to the existing knowledge, but also responsible for interpreting and decoding the specified information.

Over the years, the Schema theory has been detailed by other more systematic theories such as the *Frame theory* (Minsky, 1975) and *Script theory* (Schank & Abelson, 1977).

In the Frame theory, Minsky (1975) proposed that a frame is a type of schema which contains knowledge about the organization of familiar events such as the knowledge acquired by an individual about a descriptive story. The frame specifies the general information that sets the expected context of a situation. Referring again to the short story at the beginning of Section 2.4: Schema, a frame refers to the reader's knowledge about buying an ice-cream (e.g. the story relates terms from different domains, such as *an ice-cream, the van, pocket money, etc.*).

The Script theory (Schank & Abelson, 1977) specifies not only the general information about specific and familiar events, but also the sequence of the events involving actions. The script details more specific information about the contents of the event. Again, using the short story example above, the script details the *order of buying an ice-cream event* (e.g. *hears melodic tune, waves and stops van, order an ice cream, find money, vendor gave ice cream, pays the vendor*).

The majority of the past and present literature on memory research with respect to schema theories has not aimed at testing the degree of applicability of these theories. However, the focal interest has been on the investigation of issues whose results are supported by or interpreted with reference to these theories. The study in this thesis will also adopt the same interest in which we are not testing whether or not schemas are plausible to explain the result we will achieve, but rather to interpret our results based on these well articulated schema theories. In particular, our investigation will focus on the organization structure of schemas and its related processes during retrieval in relation to graphical information.

As previously discussed, schemas can be represented as frames or scripts, but it is worthwhile to further discuss the types of structure and representation schemas adopt. Previous investigators have proposed that schemas are formed of *slots* where the information that fills the slots is called *fillers* (Ohlsson, 1993; Yu & Nelson, 1993). Therefore, if a stimulus conforms to an existing frame but does not contain all of the information specified for a particular schema, the missing information will be replaced with "default values" as that proposed by Minsky (1975). A schema filled with the default values is called a *prototype*. Hence, a prototype can be considered as an instance of the schema as it consists of more specified information rather than a general organized abstract framework.

One of the recognized characteristics of the structure of a schema is that simpler schemas can be nested within more complex schemas (D'Andrade, 1995). Hence, schemas can be regarded to represent a hierarchical structure where the highest level of the hierarchy is the goal or the most general form of information. The principle of the hierarchical structure links a sub-schema (e.g. sub-ordinate) to another higher-level schema (e.g. super-ordinate). For example, the related schemas involved in a person going to the cinema to watch a movie could be as follows: "finding a seat" schema is part of the "finding the correct theatre room", which is part of "watching a movie" schema, which may be associated to a higher level of the "having fun" schema. Another type of hierarchical principle of schemas is the part and whole relations as demonstrated, for instance, by musicians who recognize part of music chords from a longer sequence of musical phrase (Williamon & Valentine, 2002; Williamon & Egner, 2004). A number of studies have demonstrated that schemas are represented in an organized hierarchical format (Bower, Clark, Lesgold, & Winzenz, 1969; Hudson & Fivush, 1983). However, Widmayer (2005) argues that schemas are not necessarily represented hierarchically as they are claimed to be meaning-driven. Thus, each schema would be most appropriately represented in the form of *proposition*. For example, a person is able to reiterate a story based on meaning rather than the actual sentence or correct order of what is told. In different research, Lane, Gobet and Cheng (2000) compared the different schema representations (e.g. neural network, production-rule and symbolic network) using computer models.

It is difficult to conclude whether schemas are strictly represented in the form of hierarchical or non-hierarchical networks. The specific representation of a schema may be a result of a number of methodological variations such as types of stimulus, methods of stimulus presentation and types of memory task. The studies reported in this thesis will attempt to evaluate the findings in response to the hierarchical representation. In this direction, the following section reviews studies on drawings and schemas.

### 2.4.2 Drawings and schema

Studies on memory which relate to schema theories have mainly used textual materials (e.g. stories, sentences, letters, words) in tasks such as story recall and word categories (Bartlett, 1932; Collins & Quillian, 1969; Buschke & Schaier, 1979; Hudson & Fivush, 1983). Other types of non-textual materials were pictures and scenes (Palmer, 1975; Steinberg & Anderson, 1975; Mandler & Ritchey, 1988). The use of drawings as materials for this type of study, however, is still limited. Therefore, it is presently unclear whether memory studies related to schemas for drawings produce similar outputs as that found from textual materials.

Apart from using stories as experimental material, Bartlett (1932) also studied drawings on the effects of schemas. The materials used were *picture-signs* because of their function as meaning conveyors. Participants were required to perform repeated drawings of the symbols based on verbal cues. Bartlett found that participants always attempt to classify the series of symbols into groups on presentation of the material during the learning phase and before the experiment begins. In addition, the participants also attempted to focus on the form and spatial relations of the parts of the symbol, in which each symbol is considered as a unit. These symbols are further clustered based on the similarities or differences of either semantic or spatial information, where sub-grouping forms larger groups having “common references” such as “belonging to house” or “belonging to man”. Although Bartlett did not analyse the data using an appropriate statistical approach, his findings and observations closely resemble that reported by other more structured memory studies on mental representation. These findings serve as the characteristics of the schema and suggest some hints that schemas are represented in a hierarchical structure composed of chunks of information based on perceptual similarities according to meaning or spatial location.

A number of drawing studies have been dedicated to the investigation of memory and schemas. In a study using drawings to probe the nature of schema in memory, Stacey and Ross (1975) asked children to draw and redraw six drawings (e.g. house, tree, cat, bed, the child's teacher, the child falling down) under different sets of instructions (e.g. memory, copy). Children were allowed to create and manipulate their own representational drawings rather than having to comply with those defined by the experimenter. This instruction was given in order to measure the most natural drawing output driven by the child's conceptual knowledge. The findings demonstrate that schemas are stable as the drawing outcomes of each type of figure were somewhat similar regardless of the type of the given instruction.

Carmichael, Hogan and Walter (1932) used ambiguous stimuli with different verbal labels (e.g. eyeglasses and dumb bell, beehive and hat) and found that when participants were asked to perform drawings from memory, their execution of the patterns of drawings were determined by the associating label for the particular figure. This is because different mental processes were executed with different labels for the figure. For example, the order of lines for drawing a pair of eyeglasses is different than the one reproduced if the same figure was named dumb bell.

Bower, Karlin and Dueck (1975) asked people to recall meaningless patterns called "droodles" and found that recall for these patterns was poor. However, recall improved when meaningful labels accompanied the patterns. For example, figures that made no sense to the participants but had an associating interpretation such as "rear end of a pig disappearing into a fog" and "his nose coming out from the side of the fog" seemed to show improved associative recall compared to the same figures recalled without these interpretations.

Karmiloff-Smith (1990) found that children were able to integrate and draw parts of a figure such as "house with wings" or "human body with animal legs" from different schemas (e.g. man, house and animal). These studies demonstrate that drawings have strong relations to the verbal labels in order to access the meaning of the items to be drawn. Therefore, meaning is important as proposed by Bower et al. (1975, p216) that "memory is aided whenever contextual cues arouse appropriate schemata." The importance of meaning to enable people to perform tasks effectively is discussed in the following section.

### 2.4.3 Semantic schemas

The semantic memory has a major role in the retrieval of information. This is because the existence of semantic information facilitates recall by enabling people to access the relationship of category membership from the long-term memory. The category membership variable is effective if strong associative strength exists between the items. This facilitates the recall process.

Studies on semantic recall typically employ word association or categorization of word lists to assess the effects of semantic structure on retrieval. The notable effects found in these studies provided evidence for the hierarchical organization of semantic knowledge. In this type of format, information such as “items to be remembered” is categorized based on shared similarities such as function or properties. The higher level of the hierarchy consists of a category name that corresponds to larger categories (e.g. animal), and the lower level(s) consisting of smaller category names (e.g. dog, bird) (Collins & Quillian, 1969; 1970). The relation of the meaningful knowledge such as this is referred to as *semantic schemas*.

A large number of studies on semantic schemas have been conducted to probe the characteristics of hierarchical knowledge organization (Bousfield, 1953; Tulving & Pearlstone, 1966; Pollio et al., 1969;  Kahana & Wingfield, 2000). Among a few examples of the knowledge organization analyses are *category clustering*, *response bursting* and *temporal effects*. Although these analyses use different terminology, they serve the same purpose of measuring the recalled items, such as word lists, within the experimenter-defined semantic categories. The number of categories with at least one item from the category determines the structure of knowledge organization. The recall order of the items is clustered by meaningful categories with longer inter-response time (IRT) corresponding to items between different categories and shorter IRTs corresponding to items within the same category. These units of items are recalled based on category membership (Hoermann & Osterkamp, 1965), perceptual similarities or shared semantic relations between items that belong to the same category (Pollio et al., 1968).

In a study concerning the characterization of ideas from a story, Buschke (1979) proposed that a story is remembered in clusters for which each cluster is composed of a few memory units that contain a single idea (whereas Collins and Quillian (1969) referred the clusters as nodes). Thus, this corresponds to chunks of story information at many levels for which the retrieval of semantic knowledge involves the recall of different, recurrent and consistent chunks of memory units. Furthermore, Buschke posited that over repeated recall, the size of clusters and memory units remain similar, which implies stable mental representation potentially due to the highly structured information organization.

In a retrieval task, items are normally recalled together on the basis of the same natural category regardless of whether the presented stimuli are categorised or not. Researchers have come to a consensus that recall performance is faster when the recalled items are related and belong to the same category as opposed to slower recall performance for unrelated items from different categories. This phenomenon which is called *response bursting* (Pollio et al., 1969; Patterson, Meltzer, & Mandler, 1971; Howard & Kahana, 2002) was demonstrated in a variety of experimental contexts including the recall of pictures and word lists (Bower et al., 1969; Mccauley, Weil, & Sperber, 1976). The association between items hence set the influence on the temporal effects of item recall.

Considering the temporal effects, Landauer and Freedman (1968) assumed that latencies correspond to the category size. This is indicated by longer times used to categorize object names in a larger category and shorter times to categorize objects in smaller categories. Extending this research, Collins and Quillian (1969, 1970) added that frequently contrasted information (e.g. leopard-snail) is easier to recall than frequently confused items (e.g. lion-tiger). This is because in the former test, details of the items have a substantial and obvious difference whereas the latter have more common characteristics. Collins and Quillian (1970) have also emphasized that semantic relatedness between items is a critical factor to determine a systematic recall.

This section has reviewed the importance of semantic schema in recall. However, meaning alone may not be sufficient to facilitate recall. Another possible factor that mediates recall may be related to spatial information. The following section will discuss this topic in greater depth.

### 2.4.4 Spatial schemas

*Estimate the distance between your house and the university.*

*Point to the nearest bus station from where you are standing.*

In order to solve the problems above, we often visualize the relevant scenes. The mental images usually consist of spatial properties such as directions, locations, region of space and relative distance between the objects. The capability to solve the problems above suggests the importance of spatial knowledge. One of the fundamental questions often asked in studies on spatial cognition is how is the knowledge about space encoded in the memory? In general, researchers have debated that spatial memory can either take the form of hierarchical or non-hierarchical networks.

Stevens and Coupe (1978) were the first to propose that the spatial memories are hierarchically represented in the form of conceptual networks. This theory is based on their studies where people are prone to make errors when judging the direction and distance between locations. Errors during the misjudgement occur because of strong influence by the perceptual, conceptual and physical boundaries such as those obtained from geographical location. However, McNamara, Hardy and Hirtle (1989) argued that the spatial memories are still represented in a hierarchical structure even in the absence of physical and perceptual boundaries. Similar to findings from semantic recall, McNamara et al. also reported the *response bursting* effect in the recall of spatial information, where adjacent objects are recalled faster than distant objects. In one of the tasks from McNamara's study on subjective organization of spatial memory, participants were required to circle items presented in a random order. The outcome of the experiment showed that participants form clusters that amalgamate into larger clusters, which correspond to a tree-like structure obtained from recall protocols. This result is consistent with their theory that the chunks reveal hierarchical mental representation of a participant's memory. Similar findings were demonstrated by Hirtle and Jonides (1985) who had participants successively recall a landmark and submit the recall protocols to an ordered tree algorithm. Holding (1992) who replicated the study using university buildings supported the findings. Collectively, these results provided a strong indication that the spatial relations are encoded hierarchically on the basis of object location and region of space. However, although the reported findings successfully showed the existence of chunks in a hierarchical format, the studies more commonly demonstrated the relation between the chunks at a limited level (i.e. one level).

Conversely, McNamara (1986) also proposed that the spatial relations among objects may be represented in a non-hierarchical representation such as networks, propositional or picture-like called the analog format (Kosslyn, 1975; Shepard, 1975; Anderson, 1978). These types of representation are referred to as analog due to the continuous varying properties of the information. Thus, in contrast to hierarchical representations, analog representations are assumed to represent information at the same level. Byrne (1979) argues that spatial memory for a town environment can be viewed as a topological network where location corresponds to nodes while paths between the locations are represented by links between the nodes of the network. Participants were asked to estimate the distance between locations and the angle between roads with an assumption that with increasing familiarity of the distance, the number of turns between locations increases. It was found that participants provided longer distance estimation for routes with many turns than for equally long routes with fewer turns. In addition, Byrne reported a bias in remembering the angle of turns. However, the outcomes of the experiment may be distorted by the heuristics applied by the participants to perform these tasks (e.g. the longer the route, the more locations are remembered along the route). Therefore, this method may not reliably represent the spatial mental representation.

The spatial representation and the related processes have been studied in various tasks such as distance estimation, orientation judgement, map drawing and navigation (Kozlowski & Bryant, 1977; Anooshian & Young, 1981; Tversky, 1981; McNamara, Ratcliff & McKoon, 1984). Some of the common materials used are scene representation, maps and actual environment perception. However, drawings have not been fully utilized for the same purpose of study. Drawing actions would be a suitable type of material because reproducing figures requires spatial cognition abilities. As emphasized by McNamara (1986), the study of spatial knowledge in various domains is vital to find out how knowledge in diverse contextual domains is organized and integrated in memory. Therefore, drawing is a suitable domain for the evaluation of the underlying knowledge organization.

## 2.5 Motivation of research

Three main areas of interest have been reviewed: the role of drawings in learning, the effects of chunking in drawing, and the role of schemas in drawing). Based on the review, we have recognized that within these areas, there has not yet been much research investigating drawing in relation to the contrast between the use of spatial and semantic information, such as how and to what extent, spatial and semantic coding influences learning with drawing.

The general aim of the study reported in this thesis is to investigate the role of chunking and schemas with learning graphical material by manipulating the use of spatial and semantic information. We are further interested in investigating these effects in relation to the form of the underlying mental representation of graphical material.

The review in this chapter directs our interest to the investigation of the effect of chunking in drawings and the chunks organization, which can potentially fit into a hierarchical representation. Moreover, this summary has emphasized the importance of spatial and semantic information in evaluating learning from drawings. In order to test these aims, we devise three experiments for which learning materials will be manipulated based on the following conditions: (1) spatial information, (2) semantic information and (3) divisions structure.

Experiment 1: Investigate the effects (relation and role) of chunks in various modes of drawings

The first experiment will investigate the presence of chunks in a complex abstract diagram using the Rey Figure. This includes the investigation of the properties of chunks produced from drawing. We will test this across four modes of drawing tasks namely Tracing, Copying, Delayed Recall and Immediate Recall from memory. Based on these findings, we will attempt to delineate the potential chunk organization and describe the learning performance along with the drawing strategies the participants commonly employ to facilitate the production.

Experiment 2: Investigate the effects of spatial and semantic schemas in learning

The second experiment will investigate the effects of material presentation on the underlying mental schema. This experiment involves four stimuli, varying from no structure to highly-structured, according to the manipulation of the spatial and semantic information. The contents of the materials are objects adopted from familiar scenes such as house, garden, sea and shop. Similarly to the first experiment, we will identify the presence of chunks and their potential hierarchical organization. In addition, we will evaluate the learning performance for these types of presentation.

Experiment 3: Investigate the effects of learning with different strengths of spatial and semantic schemas

The third experiment will be an extended study of the second experiment. More focused investigation will be performed on evaluating the effects of learning with different degrees of (i.e. weak and strong) semantic and spatial information. This final study will verify the findings of the second experiment with more detailed investigation of the types of general strategies applied during learning with drawings.

# Chapter 3 Experiment 1: Role of chunking and schemas in drawing a complex abstract diagram

*Add legs to the snake after you have finished drawing it*
*(Chinese proverb)*

## 3.1 Introduction

A lot of research has been conducted on the use of drawings as a tool to investigate the nature of cognitive processes. Examples of the most interesting research approaches include: probing the effects of diagrams as an aid for learning, reasoning and problem solving, measuring the state of cognitive skills and determining the difference between experts and novices (Larkin et al., 1980; Koedinger, 1992; Rogers, 1999). The study of cognitive processes through the use of drawings can reveal the underlying mental processes in how graphical information is perceived, selected, encoded, stored and retrieved from memory. The work of van Sommers (1984) pioneered the study of the processes associated with drawing and proposed a drawing model that specifies those general processes involved during a drawing activity. Gesell and Ames (1946), Goodnow and Levine (1973) and Hanfmann (1933) also studied the general preferences of drawing processes, such as the progress of drawing that starts from left to right, top to bottom and drawing that is vertical rather than horizontal. Although much work has been done in studying the cognitive processes involved during drawing activities, less is known about the internal processes that underlie them, such as the configuration of mental representations for graphical elements.

It is a well-known fact that an individual can only process a limited amount of information at a time. Chunking is, therefore, an essential mechanism that ensures activities, including drawing processes, are carried out effectively. The effects of chunking have been extensively demonstrated by various types of drawing tasks, such as drawing electronic circuit diagrams (Egan & Schwartz, 1979), drawing normal and "non-existent" objects (Karmiloff-Smith, 1990) and drawings produced by disabled patients in an effort to evaluate the amount of their visuo-spatial ability (Smith, 2002). Investigators in areas other than the cognitive study of drawings have also demonstrated that the underlying mental representations are organized according to information, which is structured in chunks (Bousfield, 1953; Buschke, 1976; Mandler, 1967; Reitman & Rueter, 1980). To date, however, and to the author's knowledge, little research has been conducted on the representation of internal graphical information, including the organization and processes involved during the activity of drawing. Furthermore, less is presently known about the potential use of chunks to organize the graphical elements in mental representations. At a more general level, understanding how drawing elements are acquired, stored, organized and retrieved from memory is still limited.

The existing evidence (Palmer, 1977; Reitman & Rueter, 1980; McNamara, 1986; Cheng & Rojas-Anaya, 2008) suggests that knowledge is mentally represented in an organised tree-like hierarchical manner. In the case of drawings, however, this has not been empirically studied in detail. It is assumed in this thesis that the reliability of these theories will be enhanced if similar patterns are observed in the processes associated with drawing. Understanding how graphical elements are stored in the memory would enable us to propose appropriate ways of presenting materials when learning through the use of drawings is deemed beneficial. As a result, effective learning can be promoted.

Therefore, the aim of the present experiment is to investigate the role of chunking in the organization of internal mental representations, with regard to the act of drawing. The selected figure in this experiment is an abstract diagram formed by various geometrical shapes. The reason why it was chosen as the stimulus is its level of technicality, which makes it more structured than freeform artistic figurative drawings. As such, it may evoke an organized mental schema of graphical elements. Further, testing structured drawings may provide more consistent results, as the interpretation of the shapes presented therein are less ambiguous than in figurative drawings.

In more general terms, our interest lies in whether chunking takes place in abstract drawings. The aim of the experiment is further divided into three parts. First, we seek to investigate the effects of chunking in abstract drawings and the process of learning over repeated drawing sessions. In this, we question the possibility whether groups of elements are coded together and recalled in patterns that share common characteristics. If this were the case, would these chunks exhibit the typical features of chunking (e.g. small numbers of elements in each chunk, hierarchical organization implying that larger units are recalled before smaller ones, redundant recall of items)? How does this change over several sessions? Finally, are the chunks recalled in a consistent order, echoing that observed during other tasks (Chase & Simon, 1973; Egan & Schwartz, 1979)?

If chunks are indeed used in the production of abstract drawings, this experiment will further investigate whether the higher-level structures have a role to play in the organization of graphical elements. Buschke (1976) and McKeithen et al. (1981) argued that items chunked for tasks involving the recollection of lists of words or programming keywords showed evidence that these chunks were internally represented in an organized hierarchical structure. It will be interesting to examine whether the mental representation of units of graphical elements is also hierarchically organized. On the contrary, will graphical elements still be recalled in chunks if there is no involvement of the higher-level organization structures?

People learn by associating their previous experience with current discourses. For example, understanding the relationship between shapes or patterns with the corresponding name of the specific shape that may have been learned since early childhood would enable an individual to recall and recognize certain perceived graphical patterns at a later time. Understanding a concept so that it can be referred to at a later time involves the use of a *schema*. In a drawing experiment with children, where they were asked to produce "non-existence" drawings, Karmiloff-Smith (1992) investigated whether parts of the drawing's elements could be interfered with during a drawing activity. It was found that older children with more defined schemas were able to engage with a drawing activity by producing parts of the drawing from different schemas. For example, they would rely on their schemas of a house and an animal in order to draw the requested house with wings. The ability of older children to integrate different schemas in their drawings provides evidence that these have a substantial role in drawing. In this experiment, we will examine the nature of mental schemas in the drawing of abstract geometrical shapes by adults. In this respect, we will explore the extent of the use of mental schemas and how prior knowledge is used during drawing, especially in the reproduction of well-structured complex diagrams. Following from that, our second aim will be to investigate the extent of the use and development of mental schemas with regard to this type of drawing.

Our final aim is to investigate the process and effects of learning over an extended period of time using various modes of drawing. In this experiment, we will examine four types of drawing tasks, namely: (1) Tracing, (2) Copying, (3) Immediate Recall from memory and (4) Delayed Recall from memory. These tasks are employed in order to determine whether chunking is used differently in each mode of drawing. The rationale behind the selection of these four types of tasks is explained below:

1) *Tracing*: For the purpose of determining the effects and extent of chunking employed in drawings when little effort is necessary during retrieval. A possible approach taken in the Tracing task is to draw consecutive elements based on the nearest neighbour strategy (this being an economical drawing method).
2) *Copying*: For the purpose of studying whether parts of a figure are drawn in groups of related elements based on Gestalt principles. Does the copying of parts of a figure change over time or does retrieval of the elements exhibits a recurring and consistent pattern?
3) *Immediate Recall*: For the purpose of studying the effects and accuracy of retrieval from memory after recent exposure to the stimulus during previous tasks.
4) *Delayed Recall*: For the purpose of studying how coherently and precisely a figure can be reproduced following a long delay (e.g. a gap of multiple days).

Figure 3.1 shows the chosen abstract diagram, which has been named the Rey-Osterrieth Modified Complex Figure, as it is adopted from the original Rey-Osterrieth Complex Figure (Rey, 1941; Osterrieth, 1944). It has been used widely in tests relating to the investigation and assessment of perceptual organization and visual memory (Binder, 1982; Meyers & Meyers, 1995; Shin et al., 2006). The Rey Figure (for short) is a relatively complex stimulus composed of many elements that may be mentally structured according to various regular patterns. This organization may facilitate retrieval during reproduction. The elements or patterns can be categorized using the *Gestalt Principle of Perception*, which is based on attributes such as closure, similarity, symmetry and proximity. Such a figure is, thus, suitable for testing the effects of chunking during learning through drawings in this experiment.

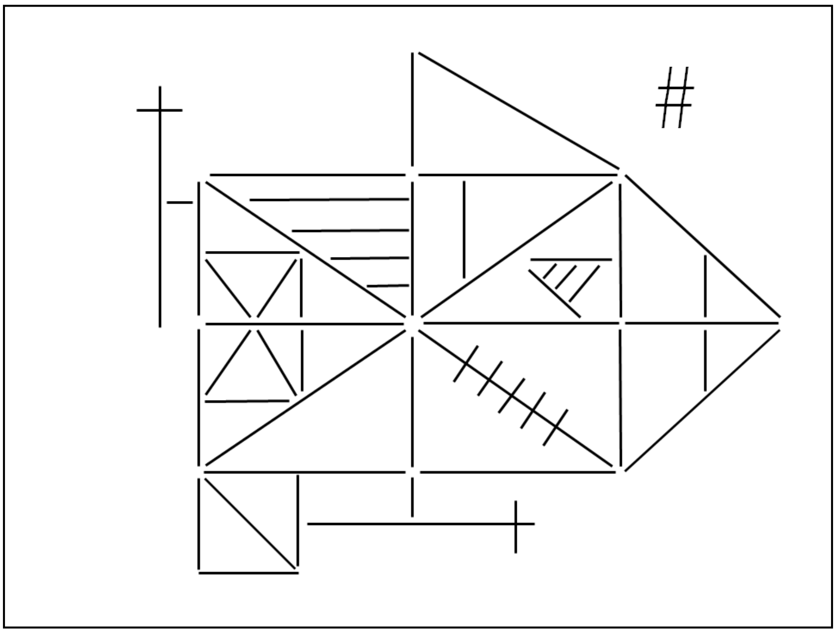


Figure 3.1: The modified Rey-Osterrieth Complex Figure, which serves as the stimulus for this experiment

In order to facilitate and standardize the process of scoring the participants' drawings, the Rey Figure has been deconstructed according to specific grouping criteria. These criteria, otherwise known as coding schemes, were developed to test the consistency of the sequence of the elements drawn and to provide rules that would resolve ambiguities in unclear drawings. In the Rey Figure, lines that look similar or parts of the figure that potentially belong together are grouped into 13 patterns as shown in Figure 3.2. The pattern groupings defined by the experimenter are largely similar to the element categorization criteria defined by Osterrieth (1944), Lezak (1983) and Corwin and Bylsma (1993). Any differences are mainly due to the use of smaller groupings by these researchers, which adds to the number of categories in their definition. As shown in Figure 3.2 we gave each of these pattern groupings a name borrowed from the terms used to describe the anatomy of a fish, such as gill, tail, fin, eye and spike.

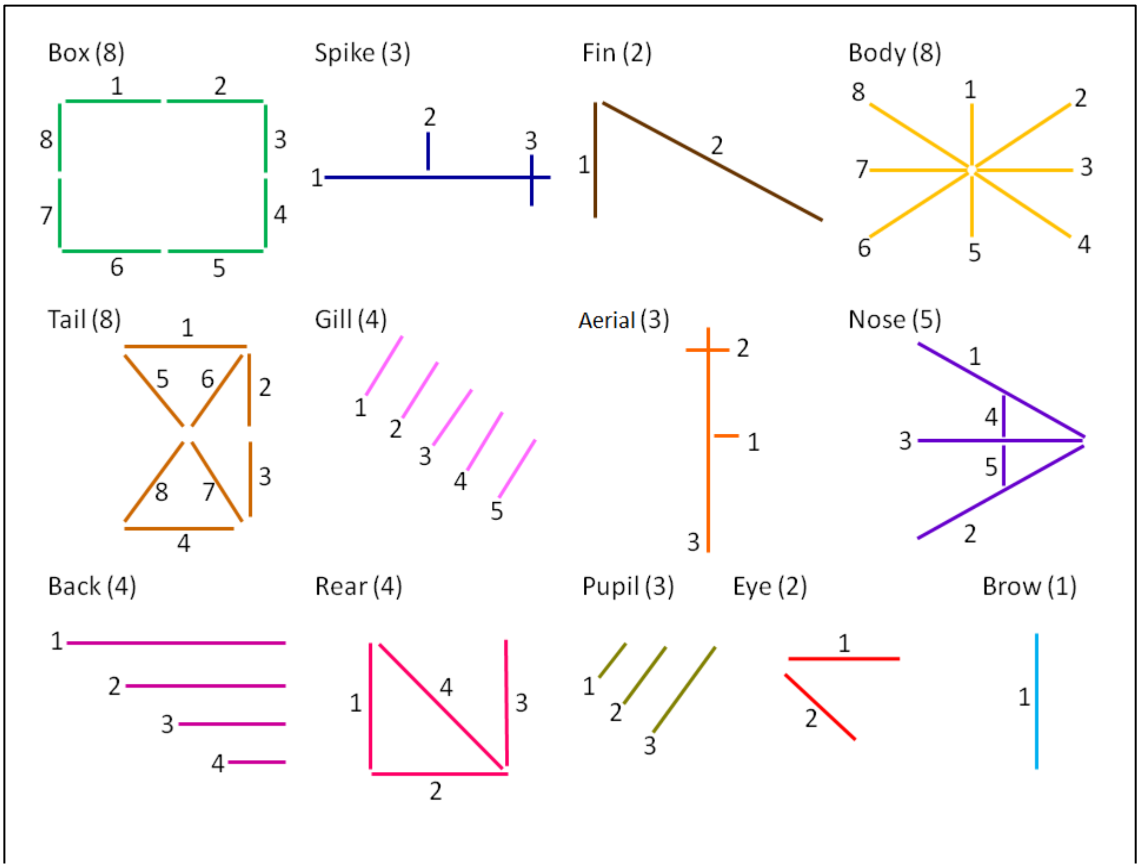



Figure 3.2: Default patterns of the Rey Figure

Pauses occur between drawing strokes. We use pauses as an indication of whether the participants treat a collection of elements in the Rey Figure as *chunks*. A *pause* is defined as the time difference between two points, the first being when the pen is lifted from the paper once a line is complete and the second when the pen touches the paper again at the beginning of the subsequent line. The pauses, also known as temporal chunk signals, are coded as *L1-elements within a pattern* (or L1 pauses) and *L2-elements between patterns* (or L2 pauses). As shown in Figure 3.3, the L1 pauses are defined as elements from the same pattern drawn one after another, such as the lines from the *rear* chunk. An example of an L2 pause is also apparent in Figure 3.3 and can be defined as the pause between the last line of the *rear* element and the first line of the *spike* element.

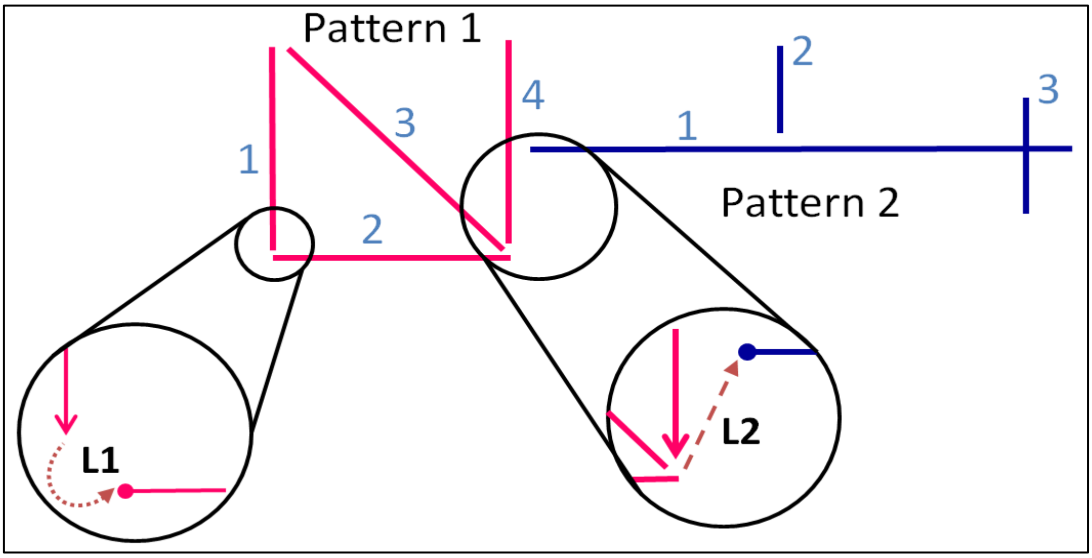



Figure 3.3: Example of L1-within and L2-between pattern(s) pauses (Pattern 1: rear, Pattern 2: spike. The numbers on each pattern denote the order of drawing)

## 3.2 Questions

This experiment serves as an exploratory study on chunking during abstract diagram drawing. Furthermore, it serves as a means to confirm empirically the theoretical assumptions proposed by Palmer (1977), van Sommers (1984) and Cheng and Rojas-Anaya (2008) regarding the notion of hierarchical knowledge organization and its relation to the learning of diagrammatic material. Our overall aim is to investigate the effects of chunking during the process of drawing. Additionally, we will examine the effects of learning through repeated trials, while using different modes of drawings.

The aims of this experiment can be also expressed in the following three sets of questions:

**1) Do people use chunking during the drawing of abstract diagrams? If so, do they chunk in patterns similar to those defined by previous investigators?**

Given the complexity of the Rey Figure, there is a possibility that people will segment the components of the abstract diagram and subsequently use them as chunks during the process of retrieving graphical elements from memory. It would be surprising if this were not the case, as the Rey Figure consists of 56 lines. Indeed, it would be remarkable if the elements of the figure could be recalled in an arbitrary order without any patterns of association.

If chunks exist as a mental structure during retrieval, it would be interesting to examine whether the patterns of chunking are similar to the patterns, or scoring criteria proposed by previous investigators (Rey, 1941; Osterrieth, 1944; Lezak, 1983; Corwin & Bylsma, 1993), including the default patterns shown in Figure 3.2. This assumption would be consistent with the *Gestalt Principle of Perception*, where elements are chunked based on certain characteristics such as similarity, proximity, closure, symmetry, continuity and simplicity. The effects of chunking can be discerned in the pauses one makes during drawing. It is predicted that the L2-between patterns pauses are longer than the L1-within pattern pauses. This paradigm makes it possible to investigate whether the participants retrieve elements from the Rey Figure in chunks. If this is true, it is further predicted that these chunks will be coherently reproduced during retrievals across the sessions.

### 2) How are the chunks of graphical elements organized in mental representations? What is the likelihood that these chunks will be structured in a hierarchical manner?

If graphical elements are recalled in chunks, then there is the possibility that these chunk patterns will be mentally organized in a hierarchical format. This is consistent with the notion proposed by Palmer (1977), van Sommers (1984) and Cheng & Rojas-Anaya (2008), who claimed that chunks of information are organized on many levels. The structuring of these chunks may bear some relation to the strategies used during drawing. For example, a participant may execute their drawing of patterns of elements based on mentally stored sequence patterns. A possible measure to determine whether chunks of graphical elements have a high-level structure is by inspecting the patterns of drawings across the sessions for all types of drawing tasks. Therefore, it is predicted that recall in memory tasks (i.e. delayed and immediate) will have a consistent hierarchical organization, because information based on recall is more structured in comparison to that received during the Tracing task. The Copying task may also present a more consistent hierarchical structure, as participants have to focus on identifying and selecting patterns from the figure.

The drawing strategies can be assessed with the use of methods, such as the nearest neighbour technique (i.e. drawing subsequent elements by choosing the closest line to the last one drawn) that examines whether drawings are produced in a rigid sequence. This type of analysis will also provide useful information about the possible underlying structure of the mental representation of graphical elements.

### 3) What are the effects of practice for different types of drawing tasks? How fast does learning occur?

Learning is a consequence of repetitive drawing across the sessions. Given that the participants are required to execute various drawing tasks (i.e. Tracing, Copying, Immediate Recall and Delayed Recall from Memory), one would gradually expect to discern the effects of learning, namely how quickly the participants learn to perform the tasks more effectively due to practice.

It is unclear, however, how well the diagram is learned after each given session. In addition, the manner in which the different modes of production affect the drawing of the Rey Figure is unclear.

The experiment is designed to include 10 sessions on the assumption that gradual learning occurs over time. It is expected that the participants will require many sessions in order to learn due to the complexity of the figure. The drawing outcomes from the different modes of production are measured by assessing pause durations, the existence and use of chunks, the order of drawings, and the types and rates of errors produced across the sessions. For example, fewer errors may indicate that drawing for a particular type of task may be reasonably easy.

It is predicted that as learning improves over time, the drawings will become more accurate as a result of better-structured and better-defined strategies for the retrieval of graphical information. The accuracy of the reproduction will indicate that the figure has been fully absorbed.

## 3.3 Method

### 3.3.1 Participants

Normal adults were recruited for this experiment. Five adults (one female, four males), who were postgraduate and undergraduate students at the University of Sussex, participated in the study. Their age was between 21 and 30 years old (Median: 25 years, 4 months). Two of them were paid £50 each for their participation, while the rest volunteered for the experiment. All participants had experience with technical figures as they came from a science education background. All participants were right-handed with the exception of one, who was left-handed.

### 3.3.2 Design

The experiment employed a fully within-subject repeated measures design. We used:

1) Two independent variables:
    a. Four *task types* (i.e. Tracing, Copying, Immediate Recall and Delayed Recall from Memory)
    b. 10 *sessions* (i.e. 1-10)
2) Four dependent variables:
    a. Pause duration (i.e. L1 and L2 levels)
    b. Frequency of errors
    c. Transition counts between patterns of elements
    d. Order of drawing elements

As previously mentioned, the four tasks each involve drawing a single Rey Figure in landscape orientation by: (1) *tracing* the stimulus printed in light grey on a piece of A4 white paper, (2) *copying* the stimulus on a blank sheet of paper while referring to the target stimulus printed in black ink, (3) drawing with *immediate recall* right after the participants have performed both the Tracing and Copying tasks, (4) drawing with *delayed recall* at the beginning of each session from the second onwards until the final (tenth) session. The experiment is designed to include 10 sessions in order to give the opportunity to the participants to complete their learning process, so as to be able to perform chunking effectively. What follows is a description of the order of the drawing tasks.

**Session 1**: Participants began the experiment with a practice task followed by the Tracing, Copying and Immediate Recall from Memory tasks. No Delayed Recall from Memory task took place.

**Sessions 2-10**: Participants began with the Delayed Recall from Memory task before they were asked to perform either tracing or copying.  Across the 10 sessions, therefore, there was a total of only 9 Delayed Recall from Memory tasks. The Copying and Tracing tasks were alternated between sessions to reduce the possibility of order effects.  This was decided upon to avoid the participants' inclination to draw based on routine, which might become the case if the same ordering of tasks was presented at each drawing session. Each session ended with the Immediate Recall from Memory task. There were a total of four drawings involved.

Table 3.1 shows the order of the drawing tasks. All participants followed the same ordering.

Table 3.1: Order of tasks across sessions

| **Session 1** | **Session 2** | **Session 3** | **Session 4** | **Session 5** | **Session 6** | **Session 7** | **Session 8** | **Session 9** | **Session 10** |
|---|---|---|---|---|---|---|---|---|---|
| Practice task | Delayed Recall | Delayed Recall | Delayed Recall | Delayed Recall | Delayed Recall | Delayed Recall | Delayed Recall | Delayed Recall | Delayed Recall |
| Trace | Copy | Trace | Copy | Trace | Copy | Trace | Copy | Trace | Copy |
| Copy | Trace | Copy | Trace | Copy | Trace | Copy | Trace | Copy | Trace |
| Immediate Recall | Immediate Recall | Immediate Recall | Immediate Recall | Immediate Recall | Immediate Recall | Immediate Recall | Immediate Recall | Immediate Recall | Immediate Recall |

### 3.3.3 Materials

A single stimulus was used in all drawing tasks in this experiment adopted from the actual Rey Figure as shown in Figure 3.4. The following modifications were made to the original Rey-Osterrieth Complex Figure to suit the use of the Graphical Protocol Analysis (GPA) technique as shown in Figure 3.4: (1) the circle and three dots were replaced with lines, (2) the vertical line was drawn closer to the tip of the two diagonal lines that form the sides of a triangle, (3) two elements, namely the horizontal line on the top left rectangular box and a diamond-shaped figure at the tip of the triangular vertex, were both eliminated. These modifications, in addition to spaces between the ends of each line, were deliberately introduced to ensure that all drawing data and pause durations between lines could be recorded within the capabilities of the TRACE software. The diagram consists of 56 lines excluding the hash (#). Figure 3.5 shows an example of the experiment settings for the Copying task.

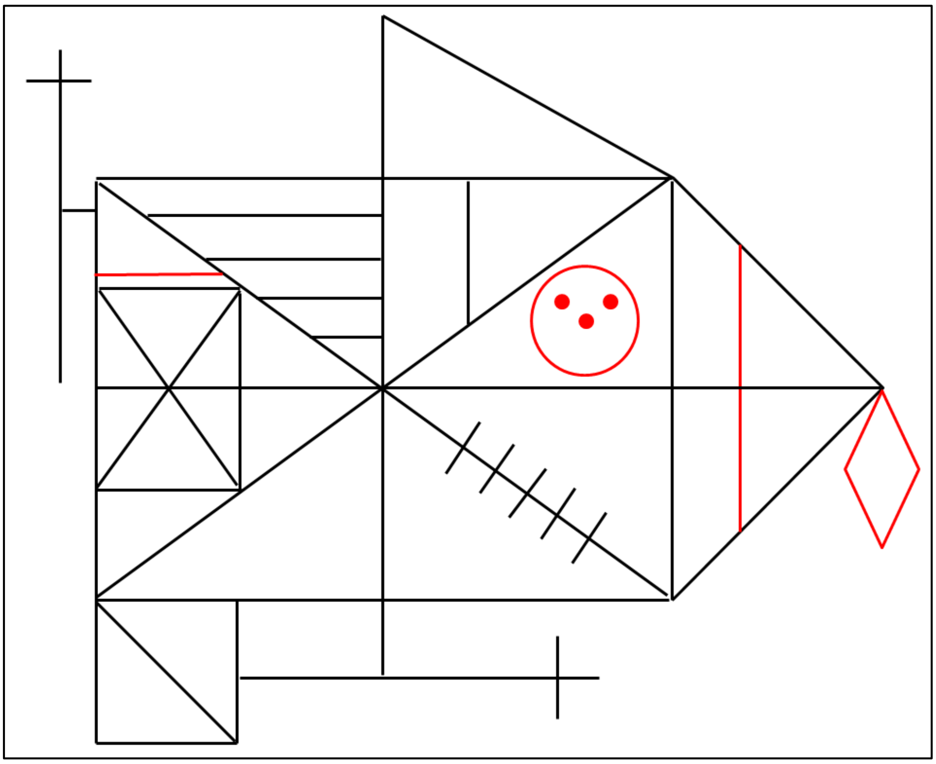


Figure 3.4: The original Rey-Osterrieth Complex Figure. The red lines show the modifications introduced in the present experiment

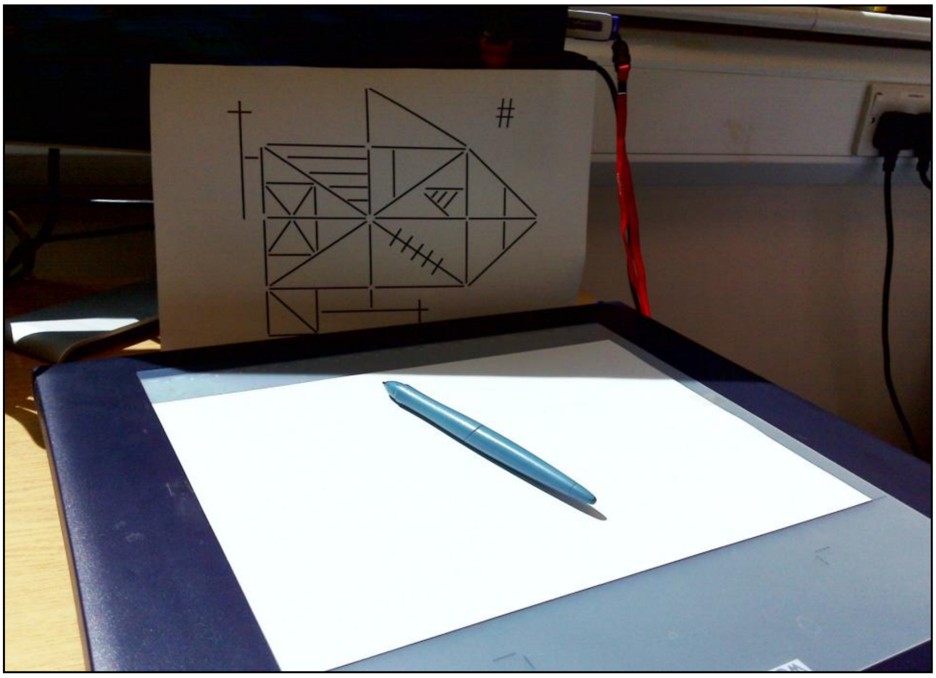


Figure 3.5: Example of the materials used for the Copying task

### 3.3.4 Procedure

Experiments were conducted in independent sessions with each participant. At the beginning of the experiment, the participants were given brief instructions about the tasks they were required to perform. Further explanations were given until they consented that they have fully understood the tasks requirements. In all tasks the participants began their drawings by writing a hash (#) so that the pause for the first line of the stimulus could be considered valid.

In order to familiarise the participants with drawing on the graphics tablet, the experiment was initiated with a practice task. A total of 44 drawings were requested from each participant. Each of the participants completed all 10 sessions in alternate days within 2 weeks.

All drawings tasks were performed on a piece of A4 paper placed on a Wacom Intuous®2 Graphical Tablet using a special ink pen. A specialized software program, TRACE (Cheng & Rojas-Anaya, 2004), was used to capture all drawing activities. TRACE was also used to extract pen positions and compute pause durations between the drawn elements. An example of the drawing outcome from the Tracing task performed by one of the participants is shown in Figure 3.6.

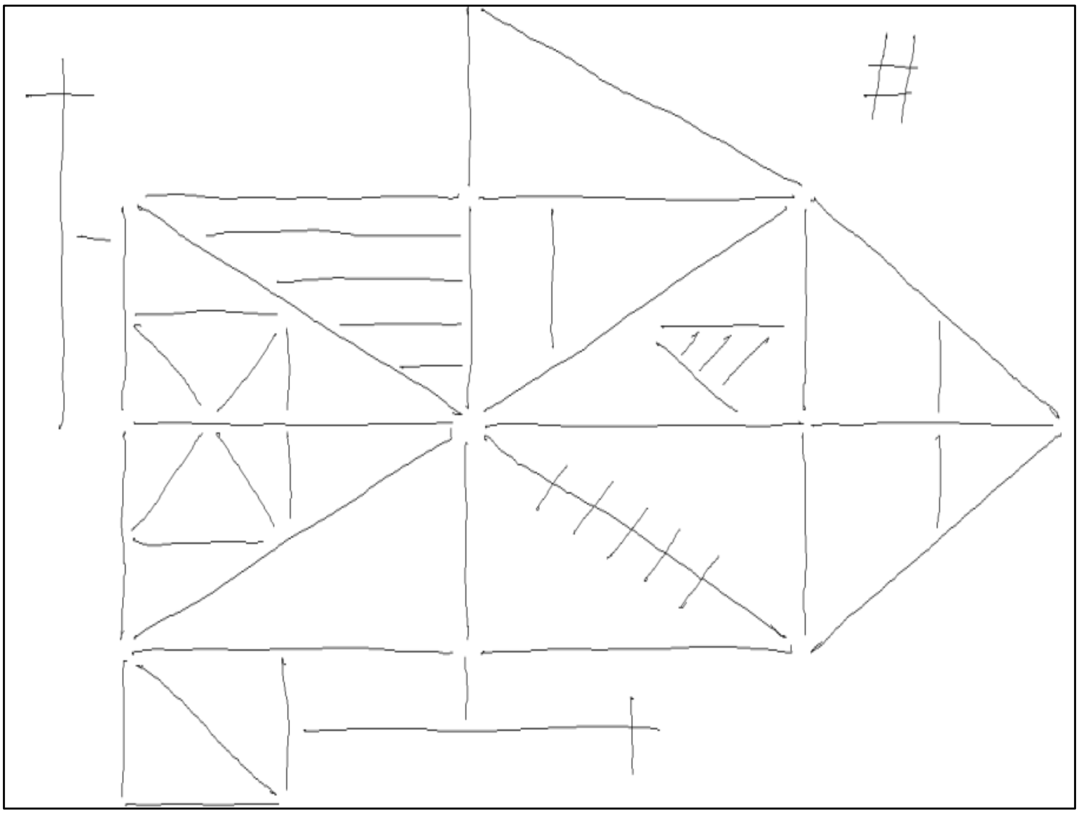


Figure 3.6: Example of a participant's drawing of the Rey Figure (ATr9)

### 3.3.5 Analysis

All drawing data captured by TRACE were pre-analysed to extract pen positions and to calculate the pauses between these positions. A specially written program (written in CLIPS by Peter Cheng) was employed to categorise each drawn line into its corresponding group according to the pre-defined patterns as shown in Figure 3.2. Figure 3.7 shows an example of the regenerated drawing according to the drawing data of one of the participants. The elements of the drawn figure were matched with the ideal stimulus, called the target diagram, illustrated in Figure 3.1. These elements were further matched with the 13 categories that were pre-defined by the experimenter as described in Section 3.1: Introduction. Excel spreadsheets were used for further analysis including graph generation and the calculation of median, mean and standard deviations.

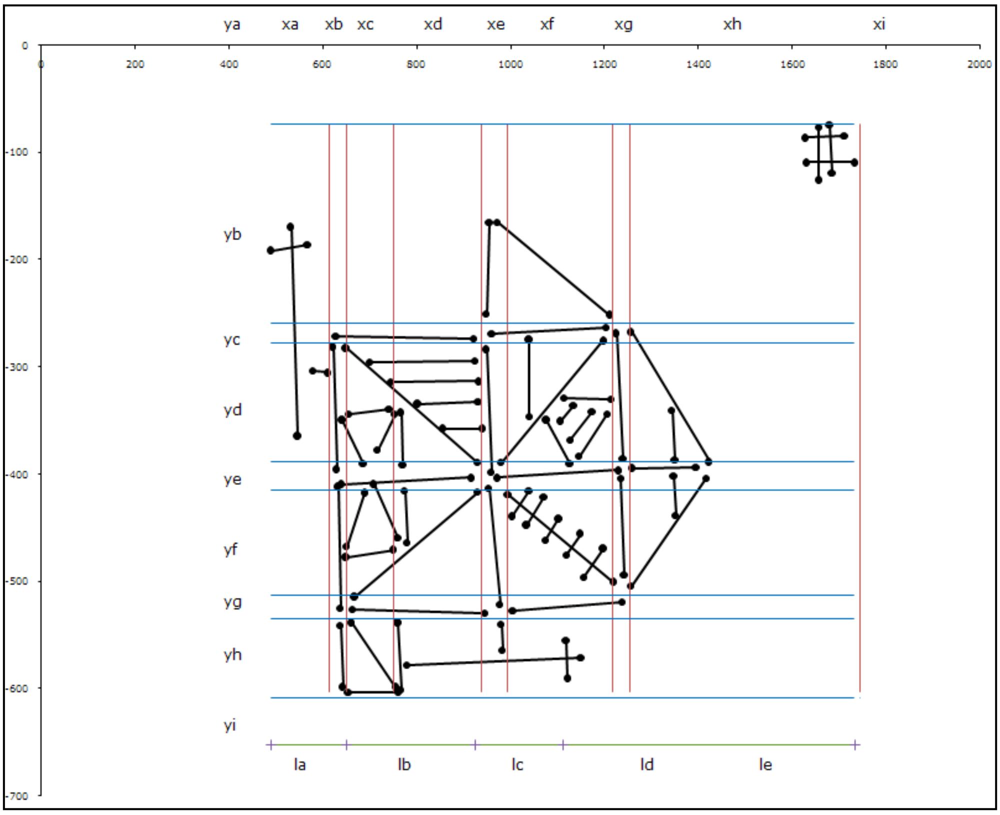



Figure 3.7: Regenerated drawing of the Copying task (G2Cp1)

## 3.4 Results

Our findings will be explained in response to the questions and predictions discussed in Section 3.2: Questions. The results are reported based on the collective evidence assembled from the various measures.

### 3.4.1 Pause duration (L1-within pattern and L2-between patterns)

The two levels of pauses examined in this experiment were coded as L1-element within pattern and L2-element between patterns pauses. Figure 3.8 shows an example of pause durations that occur between the elements during the drawing (in this example, the Copying task) of a complete Rey Figure. In Figure 3.8 it is generally noticeable that the pauses for the first element of a pattern (L2-between patterns) are longer than the pauses between elements of the same type (L1-within pattern). In other words, pauses are longer for the elements between two different patterns (e.g. box-body) and shorter between the elements belonging to the same pattern (e.g. box-box). The patterns (e.g. box, body, nose, eye, etc.) shown on the x-axis of the graph in Figure 3.8 signify the order of drawn elements. Longer pause duration at the first element of a pattern, as against the shorter pauses for the following elements of the same type, indicates the potential existence of chunks that match these patterns.

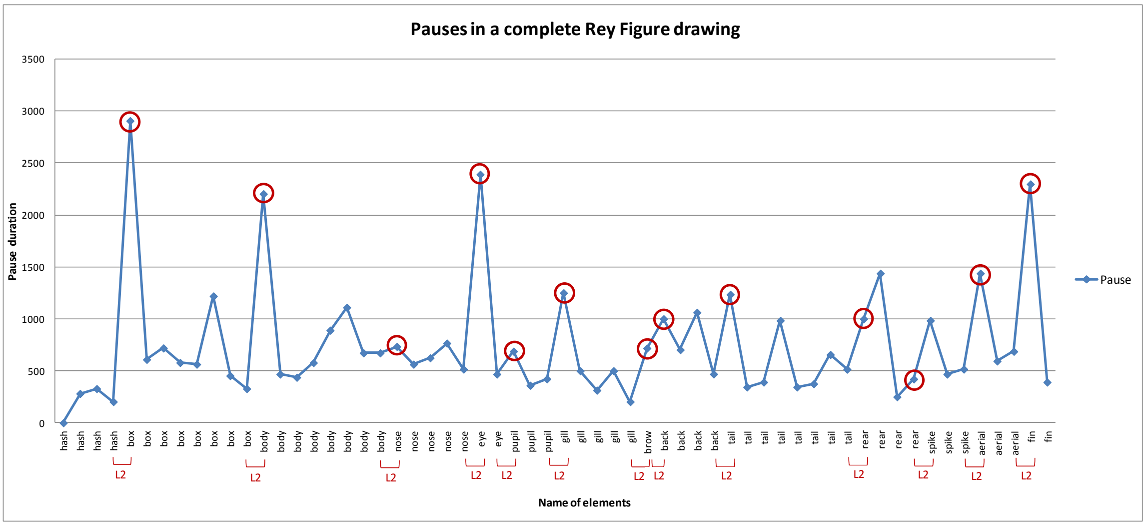


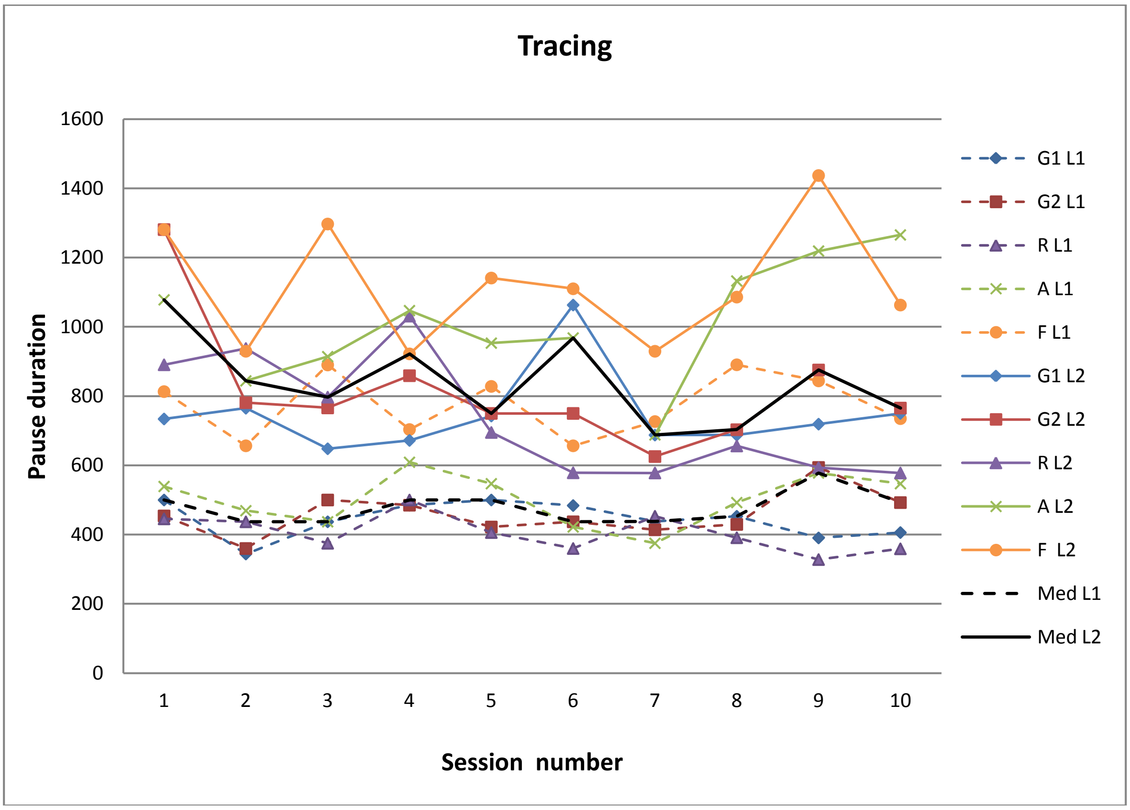

Figure 3.8: Example of a temporal signature graph (G1Cp2)

Figure 3.9 shows the median of the L1 and L2 pauses for each mode of production for all participants. Note that there is a datum missing from one participant for session 3 of the Delayed Recall from Memory task due to an experimenter's error. The missing datum, however, does not adversely affect the overall results. The median measure was selected because pause data is often skewed.

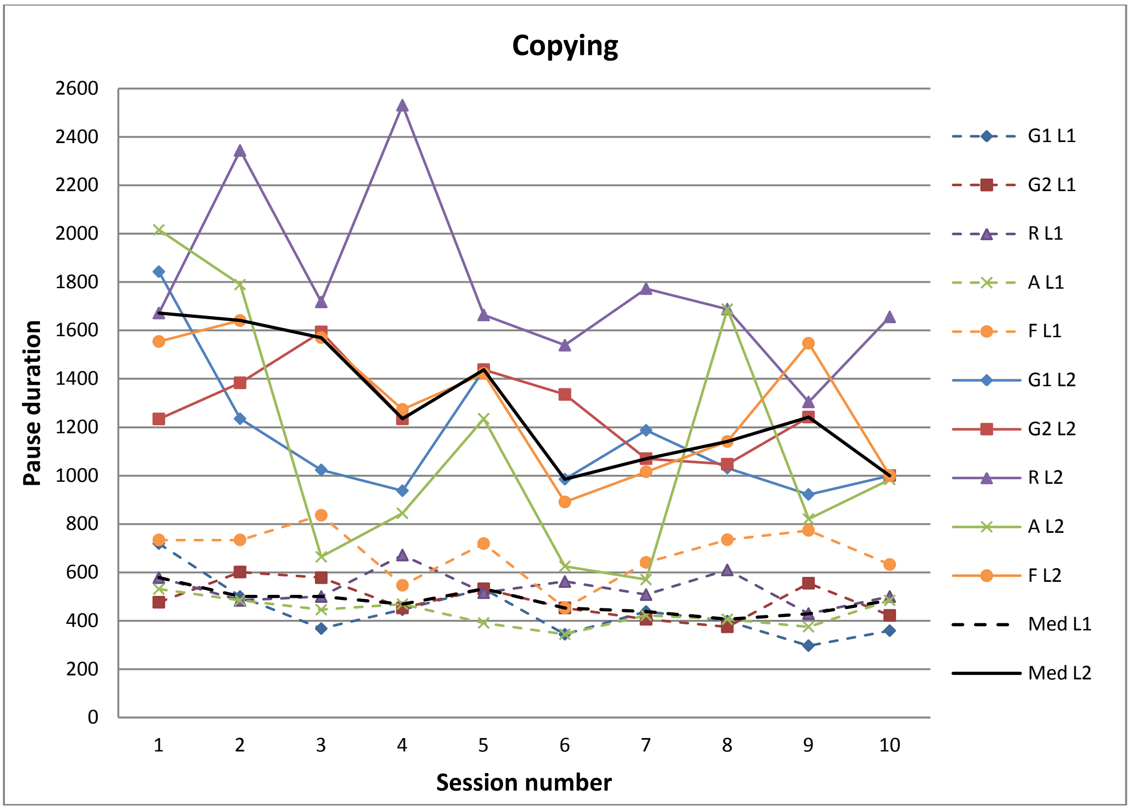
Across all modes of drawing for all participants and sessions, the L1-within pattern pauses are shorter than the L2-between patterns pauses. The L2 pauses are more variable. The L1-within pattern pauses fall within the range of 375-578ms for all modes of drawing, while the L2-between patterns pauses fall within the higher range of 688-2437ms. The means of the pauses for each drawing mode is tabulated in Table 3.2. This finding, which is consistent with the hypothesis, indicates that the patterns of elements are potentially grouped and retrieved as chunks.

Table 3.2: L1 and L2 pause range for each type of drawing task

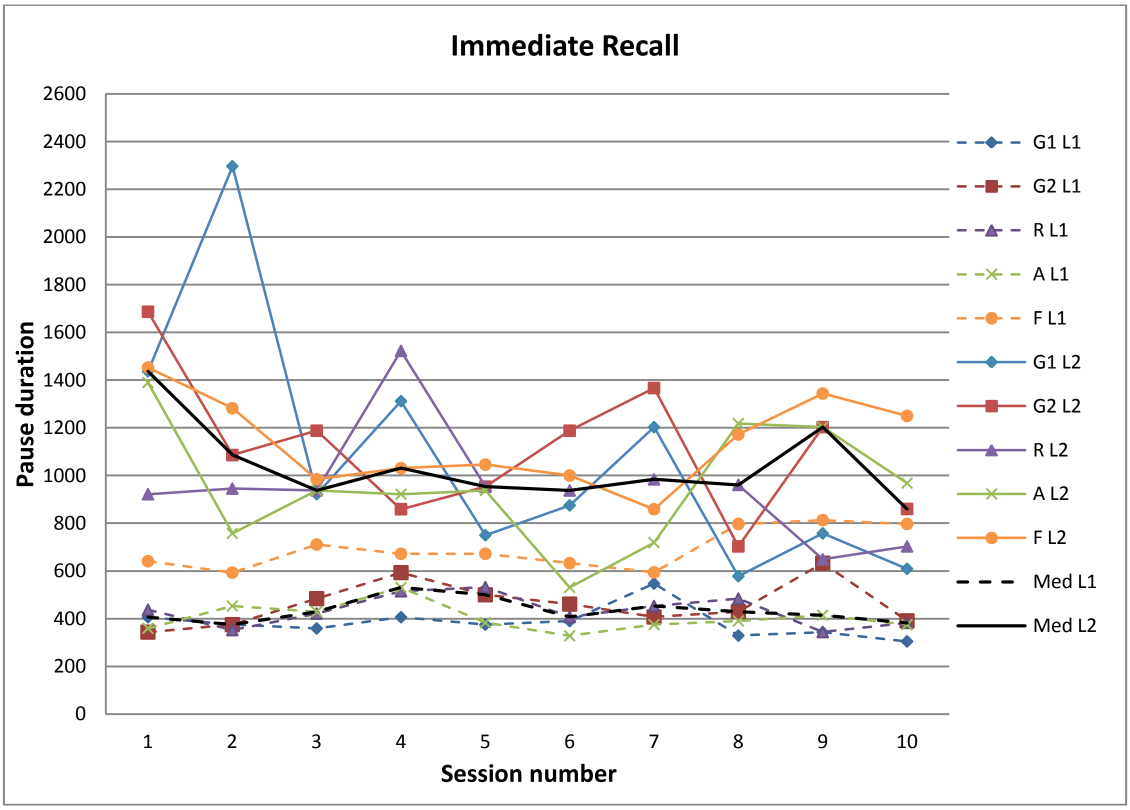
| Task type \ Pause type | Mean | | Median | | Standard deviation | |
|---|---|---|---|---|---|---|
| | *L1* | *L2* | *L1* | *L2* | *L1* | *L2* |
| *Tracing* | 477 | 839 | 473 | 821 | 46 | 124 |
| *Copying* | 479 | 1299 | 477 | 1238 | 51 | 263 |
| *Immediate* | 433 | 1039 | 422 | 973 | 50 | 169 |
| *Delayed* | 459 | 1295 | 453 | 1187 | 28 | 458 |



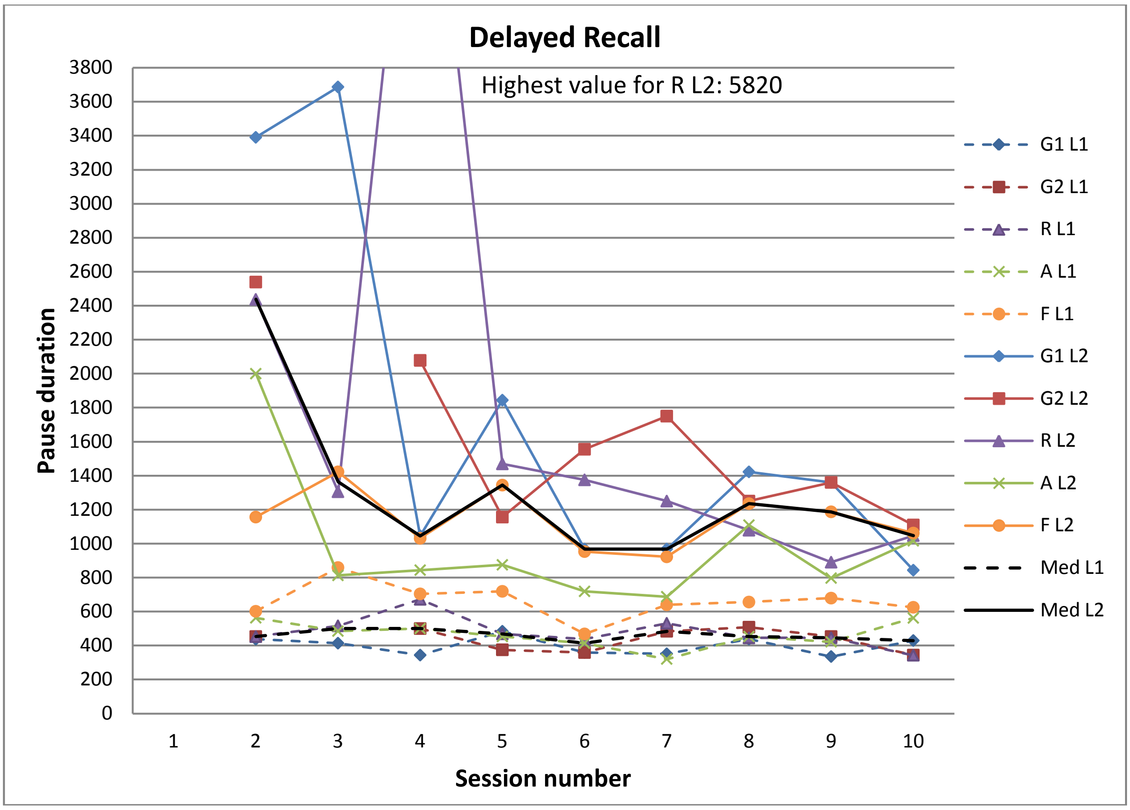

(a)


Copying
Pause duration
Session number
G1 L1
G2 L1
R L1
A L1
F L1
G1 L2
G2 L2
R L2
A L2
F L2
Med L1
Med L2

(b)


Immediate Recall
Pause duration
Session number
G1 L1
G2 L1
R L1
A L1
F L1
G1 L2
G2 L2
R L2
A L2
F L2
Med L1
Med L2

(c)




(d)

Figure 3.9: Median of L1-within and L2-between pattern(s) pauses for all participants across 4 modes of drawing

A repeated measures ANOVA was used to examine whether differences exist between the L1 and L2 pauses for all drawing tasks. The Delayed Recall from Memory task does not have data for the first session. Therefore, in order to conduct the analysis, data from the first session of the Tracing, Copying and Immediate Recall from Memory tasks were eliminated. Hence, the comparison between the tasks was based on data collected from sessions 2 to 10. The ANOVA test investigated three main effects (i.e. task type, pause level, session) and four interaction effects (i.e. task type x pause level, task type x session, pause level x session, task type x pause level x session).

Across the tasks, the ANOVA showed a significant main effect for the task type, $F(3,12)=4.07$, $p<.05$ and pause level, $F(1,4)=79.27$, $p=.001$ indicating that pauses differ between Tracing, Copying, Delayed Recall and Immediate Recall tasks. The difference between L1 and L2 pauses is consistent with the graph shown in Figure 3.9. The non-significant effect of the session factor indicates that no apparent differences occur in a comparison between the successive sessions. To illustrate, the pauses in later sessions did not become shorter than those at earlier sessions. A significant interaction effect was also found for the task type x pause level, $F(1.54, 6.15)=6.41$, $p<.05$. Further inspection revealed a significant effect for the comparison between Tracing and Copying at L1 and L2 pauses, $F(1,4)=8.85$, $p<.05$ and a marginally significant difference between Delayed Recall and Immediate Recall at L1 and L2 pauses, $F(1,4)=7.03$, $p=.057$.

A different ANOVA on L1 pauses for all tasks did not produce significant effects for either the main or the interaction factors. This is consistent with the graph in Figure 3.9, which demonstrates that the L1 pauses for all tasks were within an approximately similar pause range. The ANOVA test on the L2 pauses, however, only showed a significant main effect for the task type, $F(3,12)=5.13$, $p=.016$. The order of increasing L2 pauses for the task types are: Tracing < Copying < Immediate Recall < Delayed Recall. More specifically, in a pairwise test of the drawing tasks, a marginal significant effect was found between the Delayed Recall and Immediate Recall tasks, $F(1,4)=7.01$, $p=.057$.

Four other ANOVAs examined two main effects (i.e. pause level, session) and an interaction effect (i.e. pause level x session) for each type of task. The results revealed a significant main effect for the pause level (between L1 and L2 pauses) for all types of tasks: Tracing, $F(1,4)=102.75$, $p=.001$; Copying, $F(1,4)=52.76$, $p=.002$; Delayed Recall, $F(1,4)=24.80$, $p<.05$; Immediate Recall, $F(1,4)=173.04$, $p=.001$. No significant main effect, however, was found for the session and no interaction effect between pause level x session.

Further, a one-tail paired t-test was used to verify whether the differences between the L1 and L2 pauses were likely to have occurred due to chance. On account of the number of repeated t-tests, the Bonferroni adjustments were used in order to consider significance at .05 level. Therefore, the outcome of the t-test for the comparison between L1 and L2 pauses over the 20 sequences of drawings for the 5 participants in 4 modes of drawing shows significant effects ($p<.05$ once; $p<.01$ once; $p<.001$ eighteen times), which are summarised in Table 3.3.

Table 3.3: One-tail t-test for all five participants' L1-within and L2-between pattern(s) pauses across 4 modes of drawing

| Task / Partcpnt | *Tracing* | *Copying* | *Immediate Recall* | *Delayed Recall* |
|---|---|---|---|---|
| *G1* | 0.0000*** | 0.0000*** | 0.0027** | 0.0009*** |
| *G2* | 0.0001*** | 0.0000*** | 0.0001*** | 0.0001*** |
| *R* | 0.0000*** | 0.0000*** | 0.0120* | 0.0000*** |
| *A* | 0.0000*** | 0.0009*** | 0.0012*** | 0.0000*** |
| *F* | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** |

*Note.* *p < .05 once. **p < .01 once. ***p < .001 eighteen times.

Further t-test (one-tail, paired) comparisons of the two pause levels for all 5 participants for the 39 sessions (10 sessions times 4 modes minus 1 task as there was no Delayed Recall from Memory task data from session 1) were significant in all but two cases ($p>.05$ twice; $p<.05$ three times; $p<.01$ thirty four times), as shown in Table 3.4.

Table 3.4: One-tail t-test for all modes of drawing across 10 sessions

| Session \ Task | *Tracing* | *Copying* | *Immediate recall* | *Delayed recall* |
|---|---|---|---|---|
| *1* | 0.003** | 0.001** | 0.001** | |
| *2* | 0.000** | 0.003** | 0.019* | 0.005** |
| *3* | 0.001** | 0.005** | 0.001** | 0.084 |
| *4* | 0.003** | 0.016* | 0.009** | 0.075 |
| *5* | 0.000** | 0.000** | 0.000** | 0.003** |
| *6* | 0.002** | 0.004** | 0.003** | 0.006** |
| *7* | 0.001** | 0.014** | 0.006** | 0.010* |
| *8* | 0.008** | 0.003** | 0.007** | 0.000** |
| *9* | 0.003** | 0.000** | 0.002** | 0.004** |
| *10* | 0.007** | 0.004** | 0.001** | 0.001** |

*Note*. *p < .05 three times. **p < .01 thirty four times.

As shown in Figure 3.10, a mean computed for the median of the L2 pauses for all tasks recorded a decreasing pause from the longest to the shortest in the order of Delayed Recall (1462ms), Copying (1327ms), Immediate Recall (1010ms) and Tracing (885ms). In order to examine whether there was a significant effect between the tasks, the t-tests (one-tail, paired) of the L2-between patterns pauses for all pairs of drawing modes across all sessions were computed. The outcome was as follows:

1) Tracing < Copying: $p<.001$
2) Tracing < Immediate Recall: $p<.001$
3) Tracing < Delayed Recall: $p<.05$
4) Copying < Immediate Recall: $p<.05$
5) Copying – Delayed Recall: n.s.
6) Immediate Recall < Delayed Recall: $p<.05$

The L1-within chunk pauses are relatively constant, falling within the range of 375-578ms across the sessions for all tasks. An apparent decline, however, was observed in the L2-between chunks pauses as shown in Figure 3.10. The t-tests (one-tail, paired) performed between the participants' first and last session for the L2 pauses confirmed that pauses between patterns became shorter for the Copying, Immediate Recall and Delayed Recall drawing, all recorded significant at $p<.05$. The Tracing drawing mode did not show a significant effect between the first and the last session.

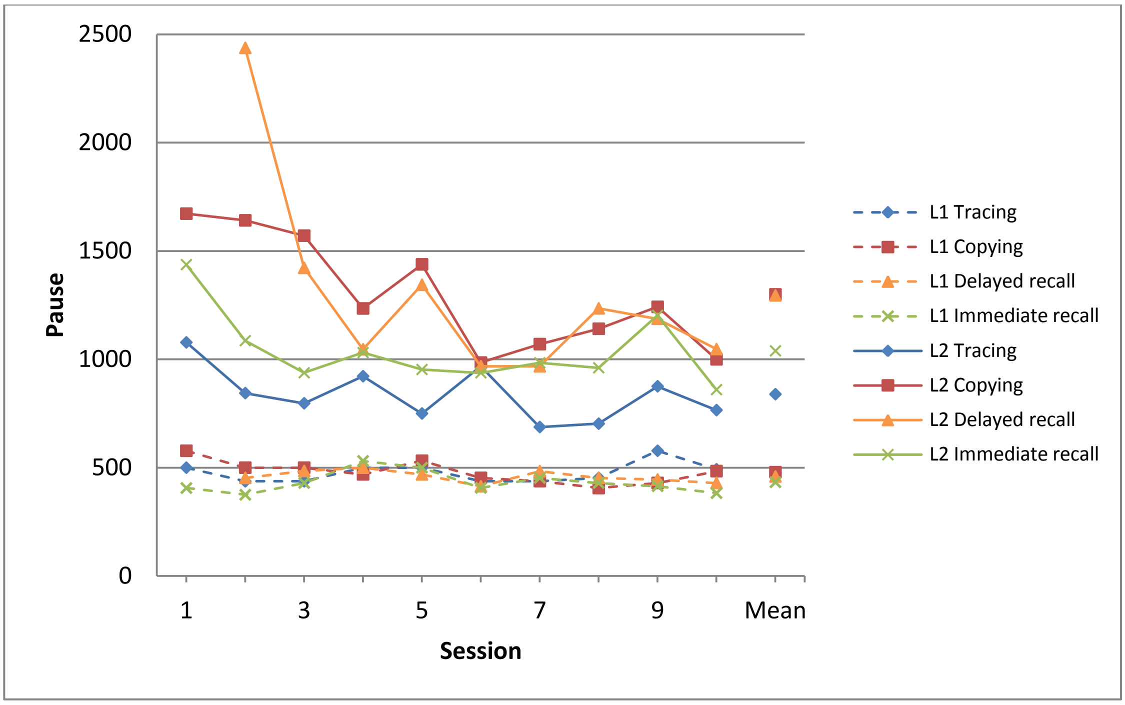



Figure 3.10: The within and between pattern(s) pauses for all modes of drawing

### 3.4.2 Number of lines

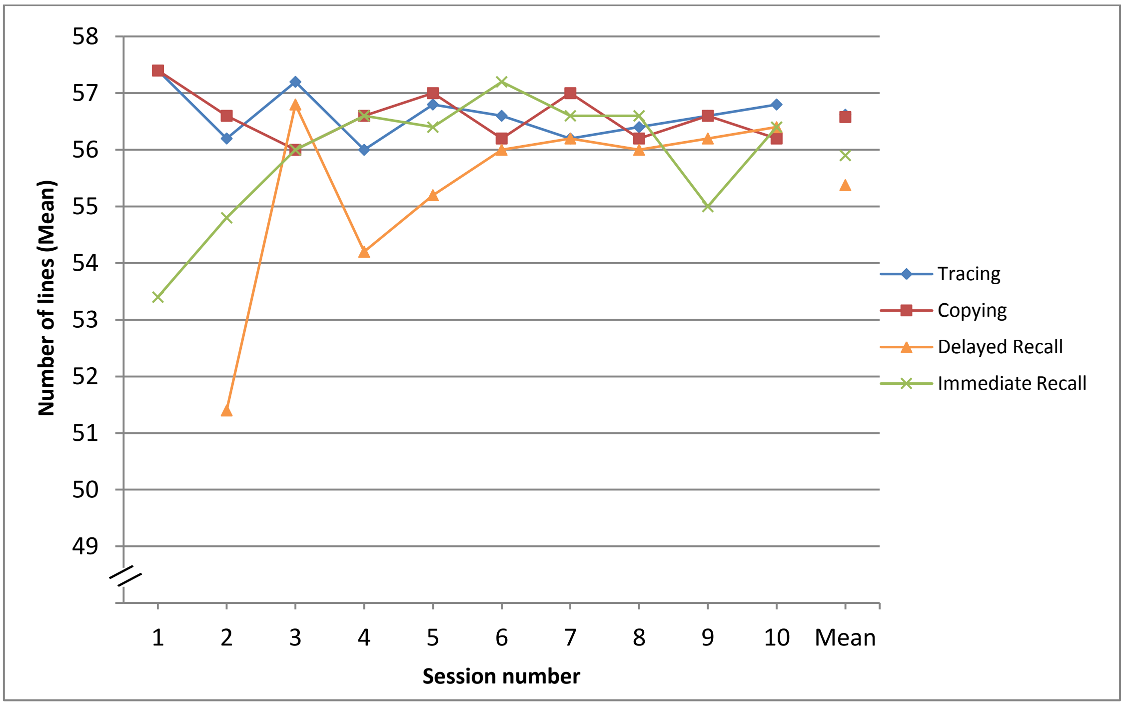



Figure 3.11: Number of lines produced for all tasks across all sessions

Figure 3.11 shows the aggregated number of lines produced by the participants across all sessions. The participants would have drawn a complete figure by using 56 lines. The number of drawn elements above this value indicates that they committed drawing errors. Consistent with the experimenter's expectations, the participants drew almost perfect figures across all sessions for both the Tracing and the Copying tasks. Generally, however, the number of lines produced for the Delayed Recall task was the lowest compared to the other tasks. This is also consistent with the experimenter's expectations and can be explained by the element of forgetting, which also suggests that this type of task is more difficult than the others. This effect was most obvious in the first retrieval of the Delayed Recall task, with participants using the least number of lines compared to all tasks and all sessions. On the contrary, more lines were produced in the Immediate Recall from Memory task, except in sessions 3 and 9. This is potentially due to the greater activation of the figure in memory as the participants had recently executed the Tracing and Copying tasks. In the final session, however, the participants produced a perfect figure for all tasks, which suggests that the Rey Figure was by then well-learned.

### 3.4.3 Pattern transition counts

An analysis investigating the frequency of transitions between the patterns was performed in order to test more rigorously whether the pattern of pauses is genuinely indicative of the chunk patterns imposed. If participants were in fact using chunks during recall in order to draw parts of the Rey Figure, it is predicted that there would be fewer transitions between elements for the different patterns.

To investigate this, a transition matrix was used as shown in Table 3.5. In this matrix, the number of transitions between elements of the same type and elements of different types are computed based on the drawing sequences of the figure in each session. The number of elements that lie on the diagonal line (yellow coloured cells) across the matrix, as shown in Table 3.5, defines the count of transitions within the same pattern, such as 7 transitions between the *box* (vertical) and the *box* (horizontal) elements and 1 transition between the *fin* (vertical) and the *fin* (horizontal) elements. On the other hand, the number of elements presented on either side of the diagonal line of the matrix (white cells) shows transitions occurring between elements of different patterns, such as the transition between the *hash* (vertical) and the *box* (horizontal) elements. The order of patterns drawn by a participant for the example presented in Table 3.5 shown partly using the arrows is as follows: hash – box – body – nose – fin – brow – eye – pupil – gill – back – tail – rear – spike – aerial.

Table 3.5: Transition matrix for the Rey Figure drawing for one session (G1Cp8)

| **To \ From** | *hash* | *box* | *body* | *fin* | *nose* | *brow* | *eye* | *pupil* | *back* | *gill* | *tail* | *rear* | *spike* | *aerial* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *hash* | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *box* | 0 | 7 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *body* | 0 | 0 | 7 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *fin* | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *nose* | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *brow* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *eye* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *pupil* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 |
| *back* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 0 |
| *gill* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 0 | 0 |
| *tail* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 1 | 0 | 0 |
| *rear* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 |
| *spike* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 |
| *aerial* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |

The differences in the transitions between elements of each pattern and the ideal transitions for the particular pattern were calculated. The ideal transition refers to the maximum number of transitions occurring between elements in the pattern without any jumps to other elements from a different pattern, such as 4 transition counts between any 5 lines of the *gill* pattern and 7 transition counts between any 8 lines of the *box* pattern as shown in Figure 3.12.

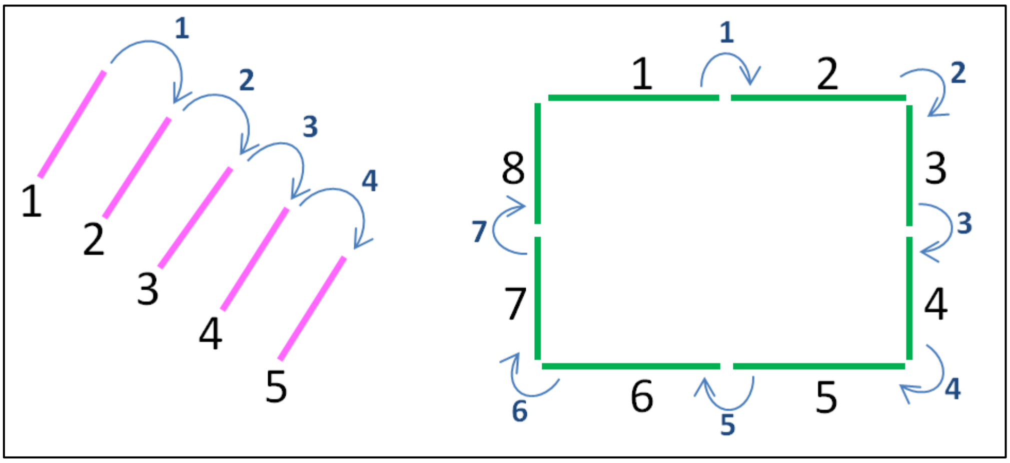
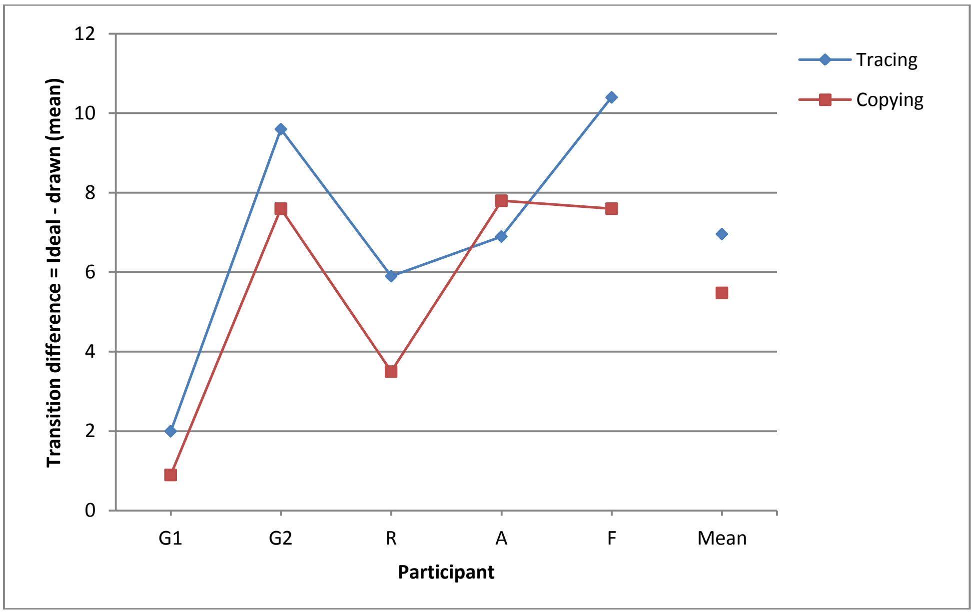


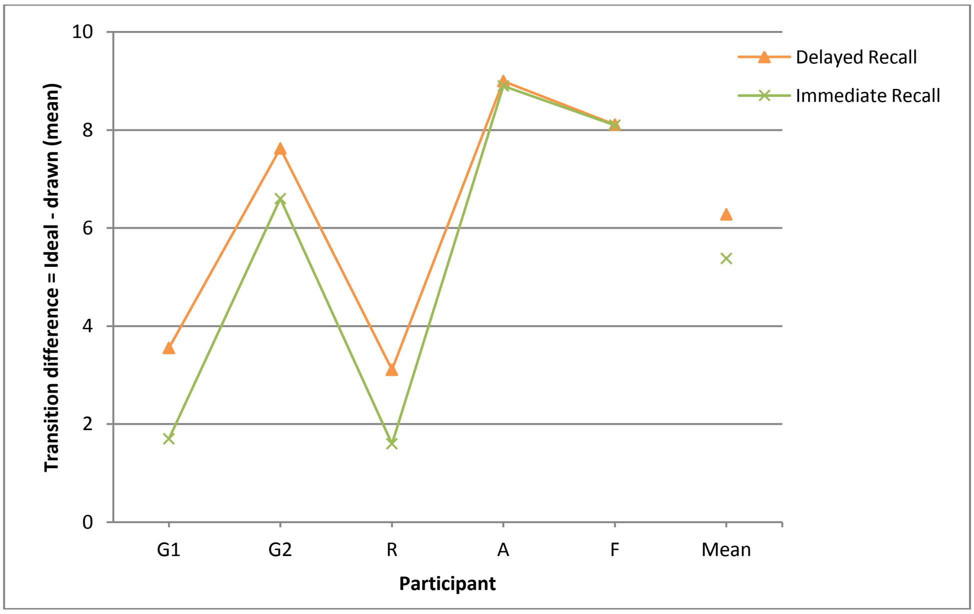
Figure 3.12: Examples of transitions between elements for two patterns (Left: gill, Right: box)

An interpretation of the transition matrix in Table 3.5 is as follows. The *box* pattern consists of 8 elements with a total of 7 transitions between each *box* element, as seen in the second row and second column of the transition matrix table (yellow coloured cell). The following cell at the second row and third column indicates that there is one transition between the *box* element and the *body* element. This shows that the participant firstly completes the drawing of elements from the *box* pattern before proceeding to drawing the next pattern. A largely similar number of transitions to the ideal number of transitions for the patterns along the diagonal line indicates that the participants generally draw the elements in chunks.

It is hypothesized that if no differences occur between the numbers along the diagonal cells and the numbers of ideal transitions, then the participants are likely to have drawn using a chunking scheme similar to that defined in the default patterns shown in Figure 3.2. Conversely, if differences exist, the participants would have probably drawn the figure using different chunks. Hence, this analysis would delineate the participants' basic chunk structure or categorization of elements drawn across sessions for each task.




(a): Tracing vs Copying




(b): Delayed Recall vs Immediate Recall

Figure 3.13: Differences between ideal and drawn chunks for all modes of drawing

Figure 3.13 shows the mean transition count that is calculated based on the differences between the ideal number of transitions for a pattern and the number of transitions produced by the participants. This serves as an additional evaluation of whether the patterns were drawn in chunks. The results present the mean of the transition differences for all patterns, for each participant. An example of this calculation follows:

> If a participant drew 4 elements from the *box* pattern of 8 elements, the number of transitions would be 4, which are calculated from the difference between the 7 ideal transitions from the *box* pattern and 3 transitions from the drawn pattern.
>
> If participants drew all elements of a pattern in sequence, then the transition count would be the same as the number of ideal transitions for a pattern; e.g. drawing 8 elements for the *box* pattern of 8 elements, the difference between the drawn and the ideal pattern would be 0.

The results are presented in two graphs for the sake of visual simplicity. Figure 3.13(a) presents a comparison between Tracing and Copying and Figure 3.13(b) between Delayed Recall and Immediate Recall. As shown in Figure 3.13(a) for all participants, the mean number of transition differences between the elements of the Tracing task is greater than that of the Copying task for 4 participants. Likewise, the Delayed Recall task produced greater transition differences than the Immediate Recall task across all participants (including participants A and F, 9.00 and 8.11 respectively for Delayed Recall, and 8.90 and 8.10 for Immediate Recall). The t-test (one-tail, paired) comparisons between the tasks, however, revealed significant differences only between the Tracing and Copying tasks, $p<.05$. Comparisons between other tasks (i.e. Tracing-Delayed Recall, Tracing-Immediate Recall, Copying-Delayed Recall, Copying-Immediate Recall, Delayed Recall-Immediate Recall) produced non-significant results.

Figure 3.14 shows the pattern transition count aggregated for all participants across all sessions for each type of task. For all of the tasks, the transition between patterns decreases across sessions. This indicates the possibility of the chunking structure becoming stable and coherent over time.

The findings from the transition count differences between the ideal and the participants' drawn patterns revealed that the mean for the Copying task aggregated across all sessions is lower than that of the Tracing task. This suggests that a more structured drawing procedure may have been applied during the Copying task. A similar result is found when comparing the aggregated means (across sessions) for the Immediate Recall task and the Delayed Recall task, where the Immediate Recall task could have influenced the participants to recall elements of the diagram more completely and accurately than the Delayed Recall task. Findings from the transition matrix analysis suggest that participants are inclined to draw similar looking elements in small groups that are then combined into larger units to construct a complete Rey Figure drawing.

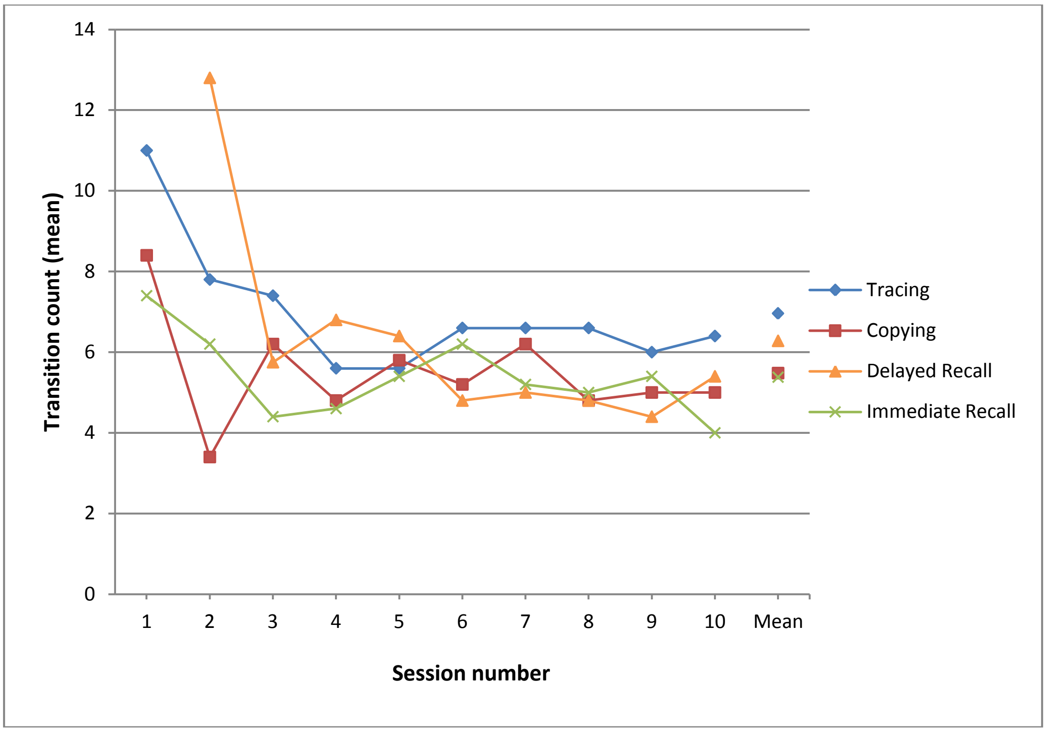



Figure 3.14: Transition count for each pattern

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 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 that is closest to the pen. The strategy was applied to the diagram using five different obvious starting points, as shown in Figure 3.15 (i.e. top left, top right, right, bottom left and centre). Each of the starting points gives a transition count: top left=22; top right=27; right=21; bottom left=22; and centre=27, yielding a mean transition count of 23.8. Therefore, values less than this suggest the use of chunks. This effect is noticeable in Figure 3.14, as the transition count dropped to approximately ¼ of the value of the nearest neighbour strategy (23.8) by the third session in all modes. A t-test (one tail, paired) comparison between the first and the last session of the transition counts, shown in Figure 3.14, showed a significant effect ($p<.05$) for the Copying, Delayed Recall and Immediate Recall modes of drawing. No significant effect was found for the Tracing task.

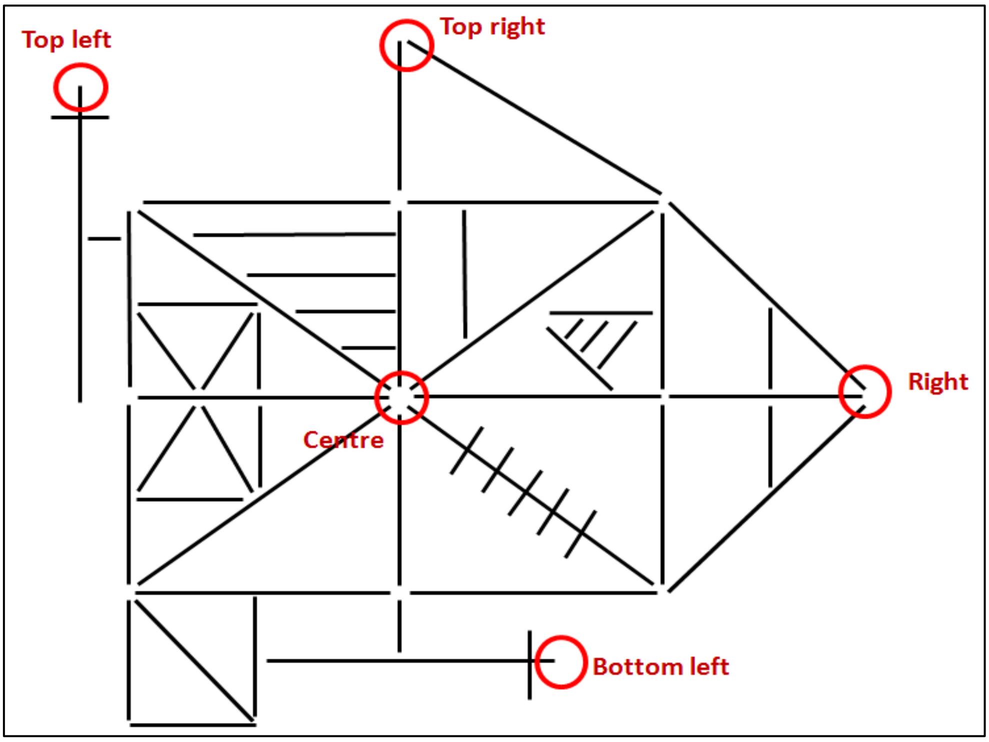
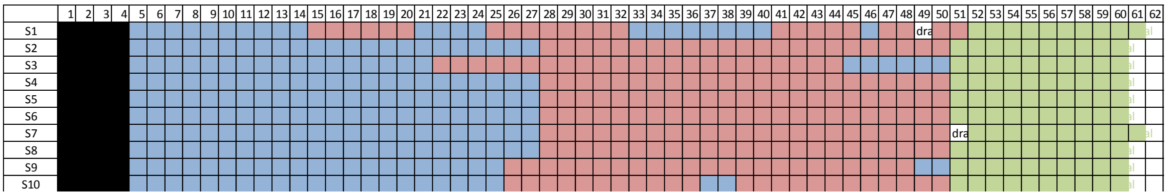


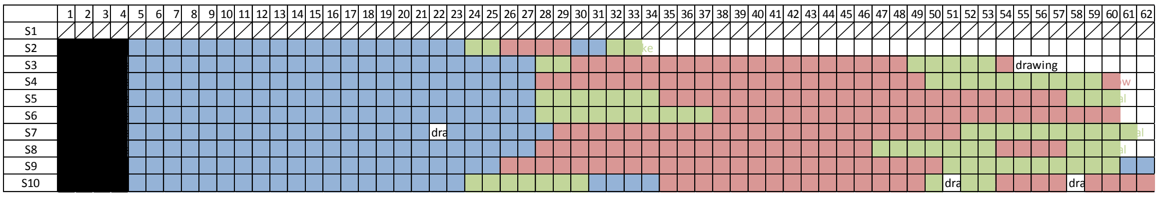

Figure 3.15: Nearest neighbour drawing strategy

### 3.4.4 Drawing patterns

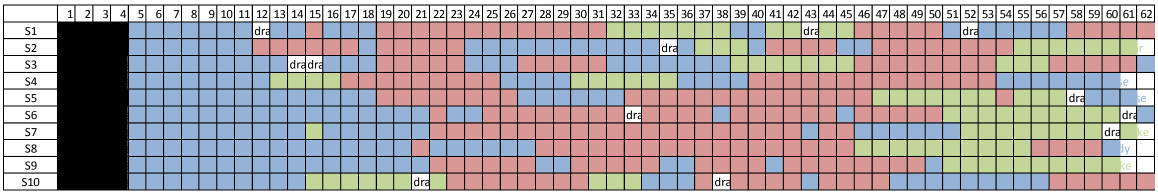
It was observed that some patterns of the Rey Figure are often drawn together. The majority of the participants tend to draw patterns in the sequence shown in Figure 3.16, where each column denotes a drawn element and each row denotes a single session. The first four columns (cells coloured in black) represent the 'hash' elements, as these are drawn first at the start of every session. As we will see, the blue, red and green cells represent patterns drawn together as one group. Figure 3.16 (a-c) shows three examples of drawing patterns ranging from the most to the least coherent. Figure 3.16 (a) is the most typical pattern (see Appendix A for the complete set of the drawing patterns for all participants). This drawing pattern is also mapped on the Rey Figure, as presented in Figure 3.17. We defined these groups of patterns as the *frame* group (blue), the *inner* group (red) and the *outer* group (green). The sequence of drawing in groups was commonly found to be following the order of *frame* group, *inner* group and *outer* group.



(a): Best example of drawing pattern (FCp)



(b): Intermediate example of drawing pattern (G1DelMem)



(c): Worst example of drawing pattern (RTr)

Figure 3.16: Examples of sequences of drawing groups of patterns for a complete rendering of the Rey Figure. (a,b,c) show the best, intermediate and worst examples of the drawing patterns. The white cells marked ‘dra’ indicate drawing errors

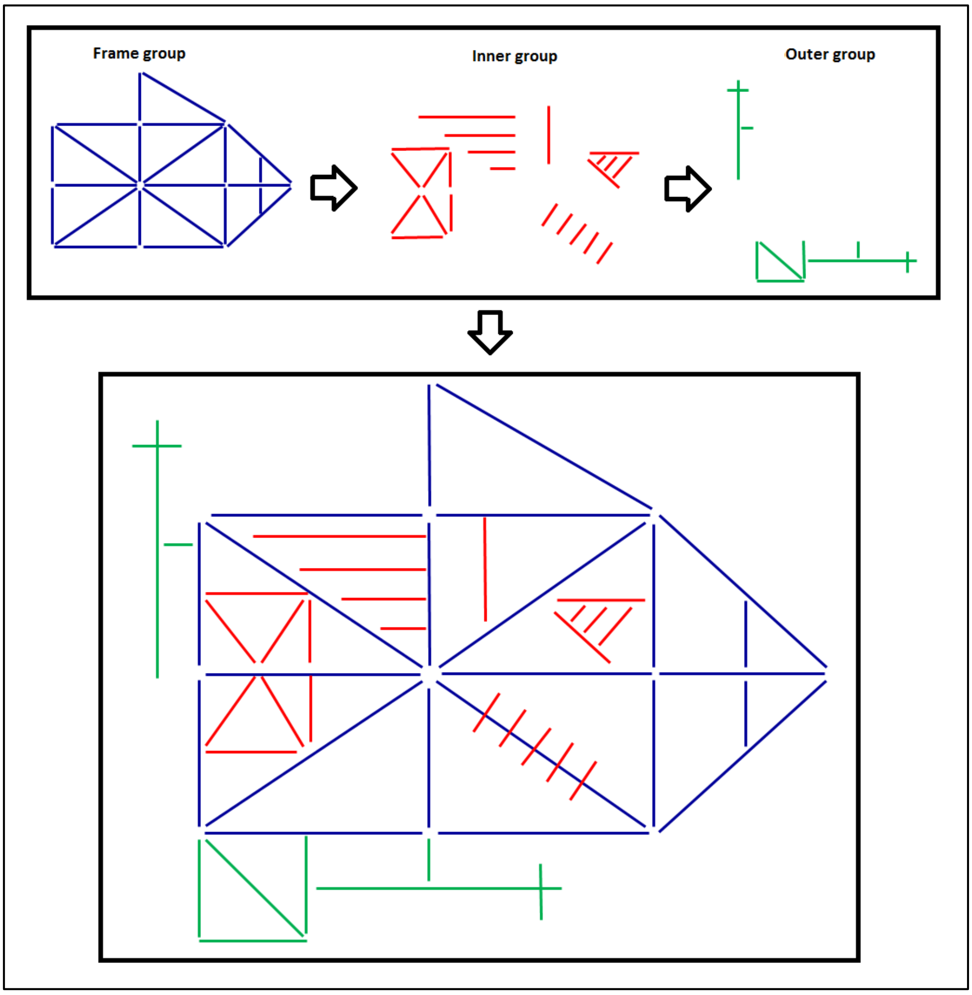



Figure 3.17: Most common pattern of drawing produced by the participants

To test whether these groups really have a substantive role in drawing, pattern group transition counts were obtained for every drawing, in a fashion similar to the pattern transition counts (see Section 3.4.3: Pattern transition counts), but at the aggregated group level. Applying the nearest neighbour drawing strategy with different starting points for the pattern groups produces transition counts in the range of 6 to 16 giving an approximate mean of 13. Figure 3.18 shows the mean group transition count for each mode of drawing. The pattern group transition count is substantially less than that of the nearest neighbour strategy indicating that drawing in groups may have a meaningful role to play. The measure is relatively constant (between 3-6 transition counts) for each mode with the exception of Tracing (between 5-10 transition counts). A t-test (one-tail, paired) between the first and the last session of the Tracing mode was found to be non-significant (p=.095) because of large variance. Non-significant results were also found for the Copying, Delayed Recall and Immediate Recall tasks.

A closer inspection of the sequence of patterns revealed that patterns from the *frame* group were always the first to be drawn in every diagram for all tasks and without exception. Twenty-three lines constitute the patterns of the *frame* group. The mean number (and range) of elements produced from the *frame* group before the start of any other groups for the Tracing, Copying, Delayed and Immediate Recall modes were 16.1 (11-21), 18.9 (16-21), 19.7 (18-22) and 19.8 (17-21) respectively. This suggests that the *frame* group of patterns had a primary role in all modes of production, including the Tracing mode, only to a lesser extent than the others.

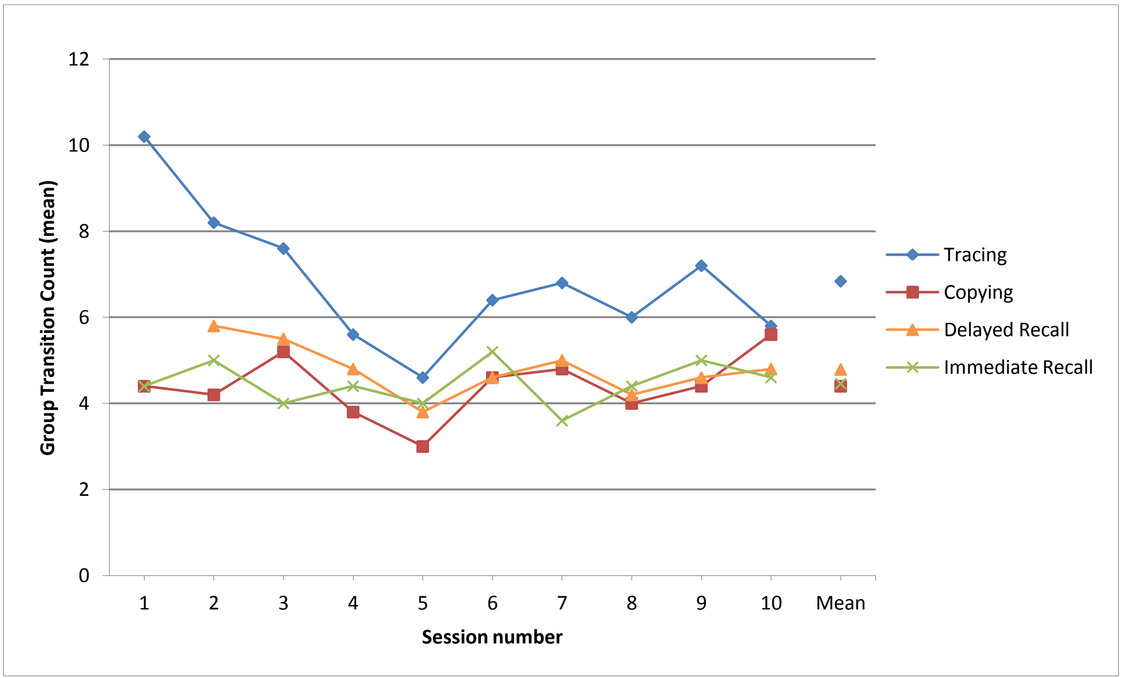


Figure 3.18: Transition count for groups of patterns

A t-test (one tail, paired) comparison of the group transition counts between the tasks across the 10 sessions only produced a significant effect for the Tracing task in comparison to the other modes of drawing. The results are as follows:

1) Tracing < Copying: $p < .001$
2) Tracing < Delayed Recall: $p < .001$
3) Tracing < Immediate Recall: $p < .001$
4) Copying – Delayed Recall: n.s.
5) Copying – Immediate Recall: n.s.
6) Delayed Recall – Immediate Recall: n.s.

To summarize, the group transition count data are comparable across the Copying, Delayed Recall and Immediate recall tasks, but not with the Tracing task. The patterns from the *frame* group that were always drawn at the beginning of all drawings may be related to the types of drawing strategies used by the participants.

### 3.4.5 Error rates

We analysed the frequency of errors occurring throughout the drawing sessions, aggregated from all participants.

During the drawing process, participants sometimes drew elements which were inconsistent with the actual Rey Figure, examples being lines that were too long or too short or lines drawn at incorrect positions. Occasionally, they would also produce dots, forget to insert lines, or add extra lines during the drawings. These types of elements are erroneous and are classified in three categories according to the level and type of error committed, as shown in Table 3.6. Examples of errors are shown in Figure 3.19. All errors were classified accordingly.

Table 3.6: Error classification

| **Level** / **Type** | **Pattern** **(groups of 13 patterns) e.g. fin, spike, aerial, box, etc.** | **Element** **(member of a pattern) e.g. an element from the fin pattern** | **Drawing** **(insignificant marks)** |
|---|---|---|---|
| *Structure* | Too short, too long, or misplaced elements drawn for the entire pattern | Too short, too long, or misplaced elements drawn for one element from a pattern | Dots, combination of elements, breaking within an element |
| *Commission* | Added pattern(s) undefined in the actual Rey Figure | Added element(s) undefined in the actual Rey Figure | |
| *Omission* | Forgotten pattern(s) defined in the actual Rey Figure | Forgotten element(s) defined in the actual Rey Figure | |

Erroneously drawn elements, called *drawing errors*, are not significant in the analysis, as they do not actually represent mistakes that substantially alter the figure drawn from the actual stimulus. Examples of these errors are slight marks or dots, two lines combined into one, or one line broken into two. These types of errors only cause inaccuracies to the drawings and are, thus, negligible.

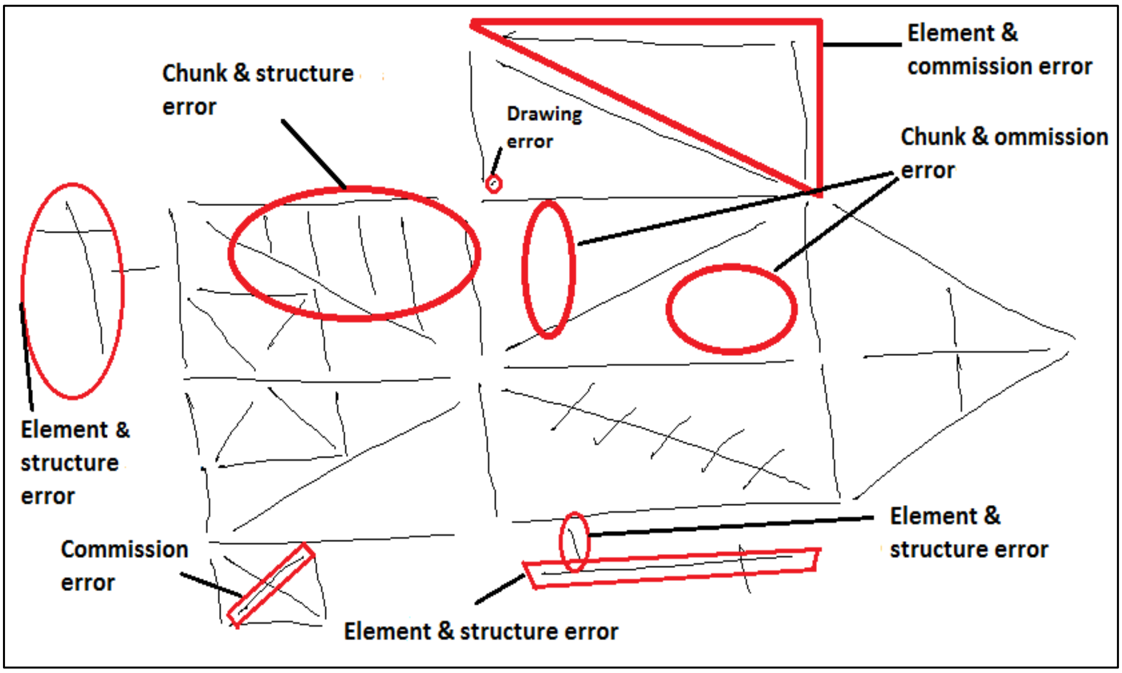
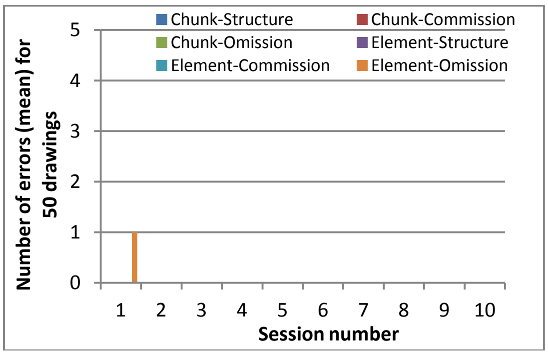
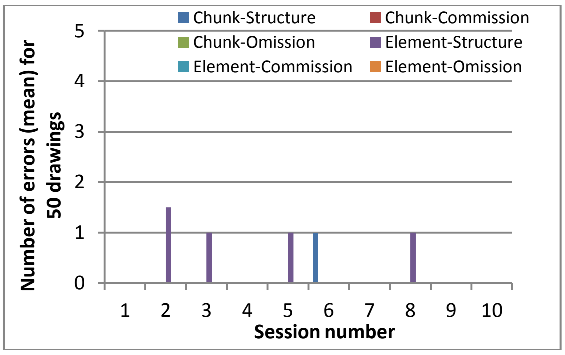


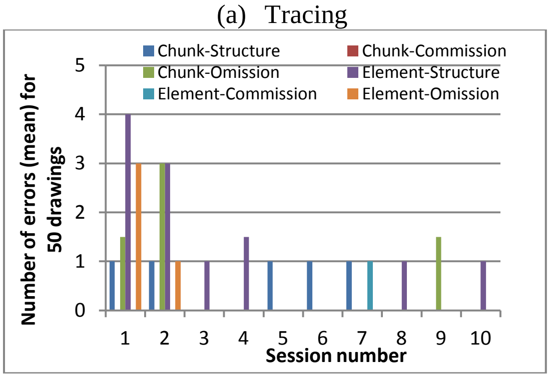

Figure 3.19: Examples of error classification



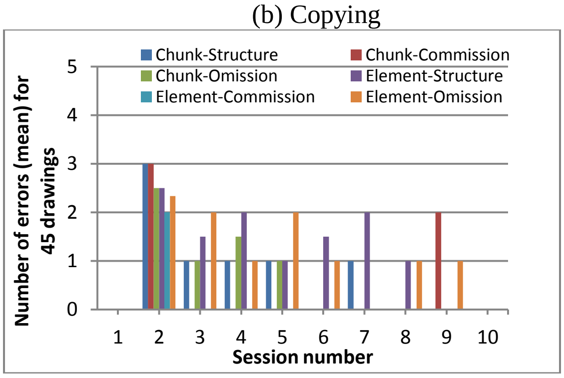

(a) Tracing




(b) Copying




(c) Immediate Recall



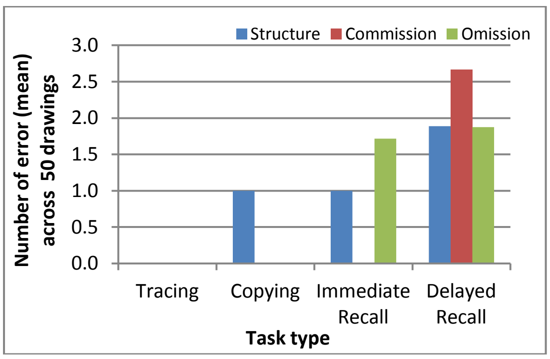

(d) Delayed Recall

Figure 3.20: Error rate distribution according to tasks

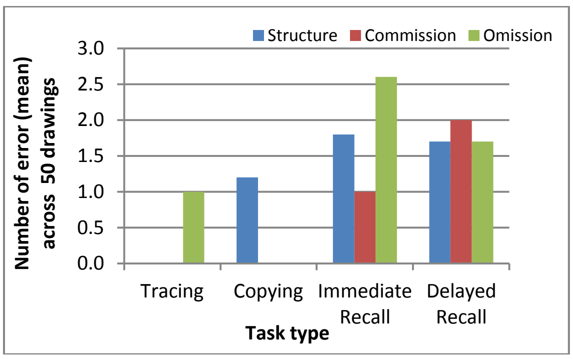
Figure 3.20 shows the error rates produced for each task across the 10 sessions. The errors are categorised according to the classification in Table 3.6. For example, errors at the pattern level denote that one or more patterns were either (1) drawn in the wrong position (structure), (2) forgotten (omission), or (3) added (commission) to the drawings. An example is chunk-commission that can be defined as the drawing of a new additional pattern, beyond what was shown on the actual diagram. Similar definitions apply to the errors at the element level. An example is element-omission, which refers to the absence of an element of a pattern of the original figure in the drawn copy.

The Delayed Recall task produced the greatest number of errors (at both chunk and element levels) across all sessions, followed by Immediate Recall, Copying and then Tracing. This was expected because after a delay of a few days the accurate recall of positions and shapes cannot be guaranteed. The confusion that is associated with the effort to remember half-forgotten things in detail leads to the commission of other elements or patterns. The Immediate Recall task produced the most errors in the first two sessions. Apart from an element-omission, the Tracing task did not record other types of errors. The Copying task produced one structure-chunk error and four occurrences of structure-element errors. This means that the errors recorded in the Copying task were only drawn in either the wrong position or involved inaccurate shapes. It is worth noting that the number of errors is few given the total number of 195 drawings, with less than the mean of 5 errors per drawing, as shown in Figure 3.20. Therefore, a statistical analysis between the types of errors would not produce meaningful results.

Figure 3.21 shows the error types across the tasks at the pattern and element level. Generally, more errors were produced at the element than the pattern level. At the pattern level the greatest commission errors were made in the Delayed Recall task. This also produced more structure and omission errors than the rest. At the element level, however, the structure and omission errors were greatest in the Immediate Recall task. The few errors produced at both pattern and element level, below the mean of 3 errors across the drawings for all tasks, may suggest that absorbing and learning the Rey Figure occurs quite rapidly.




(a) Pattern




(b) Element

Figure 3.21: Error types at (a) pattern and (b) element level across task types

## 3.5 Discussion

The discussion will address the major questions posed for this experiment (see Section 3.2: Questions).

1) **Do people use chunking during the drawing of abstract diagrams? If so, do they chunk in patterns similar to those defined by previous investigators?**

Findings from the experiment provide converging evidence that chunks are used and have a central role in the drawings of the Rey Figure. The longer pauses before the production of the first line of the default pattern, as compared to pauses for lines within a pattern, indicate that the participants were treating the patterns as chunks. As evident from the transition matrix analysis, the relatively low transition counts also support the claim that chunks have a causal role in the production of the diagram, as the participants on the whole tended to complete each pattern before moving on to the next.

The strong and robust temporal chunk signal observed in other writing and drawing tasks using the Graphical Protocol Analysis (GPA) method (Cheng, McFadzean, & Copeland, 2001; Cheng & Rojas-Anaya, 2005, 2006, 2007, 2008; van Genuchten & Cheng, 2009, 2010) was also clearly found in this experiment. This extends the scope of GPA for studying the nature of chunk-based phenomena in Cognitive Science. As shown in Figure 3.9, the magnitude of the L1 within chunk pauses was approximately 500ms across all the modes of drawing and remained fairly constant across sessions. In the latter sessions, the L2 between chunks pauses were approximately 900ms. These pauses are longer than those found in the drawing of simple geometric figures in which L1≈400ms and L2≈600ms ( Cheng, McFadzean, & Copeland, 2001). Possible reasons for the difference are the greater complexity of the stimulus used in this experiment and the larger physical size of the drawing.

The production of long L2 pauses and short L1 pauses is consistent with the findings of Chase and Simon (1973), Buschke (1976), Reitman et al. (1976), Egan and Schwartz (1979), McKeithen et al. (1981) and Card (1982) for other types of tasks, such as the recall of chess items, the drawing of electric circuit diagrams, the listing of words and the listing of programming keywords. Therefore, the similar pause level results obtained in this experiment extend the study of chunk patterns to drawing, at least to the drawing of complex abstract diagrams. This is true regardless of the mode of drawing employed.

Evidence from the L2 pauses and the number of pattern transitions that decrease significantly over time found in the Copying, Delayed Recall and Immediate Recall tasks has further extended the claim that the structure of chunks becomes more organized with learning. This is less likely to occur in the Tracing task where there was no substantial L2 pause decrease. This suggests the lesser use of chunks for this mode. The larger and more significant pattern transition counts for Tracing over Copying supports this finding. Therefore, the effects of chunks on the Tracing task were not as obvious as that found in the other tasks, possibly due to the very nature of that task, which does not constrain the participants to draw according to the default patterns. In Tracing, recall from memory is not necessary for the completion of the task, thus, leaving more flexibility in the selection of elements to draw.

The nearest neighbour strategy analysis for the patterns of transition counts provides further evidence that chunks are used during complex abstract diagram drawing. The smaller pattern transition count across the sessions for all tasks, compared to that estimated by the nearest neighbour drawing strategy, indicates that the participants may be using chunks during drawing regardless of the types of tasks. The Copying, Delayed Recall and Immediate Recall tasks produced transition counts 6 times less than the value of the nearest neighbour strategy, from the third session. This further strengthens the evidence that the patterns were treated as chunks, as the participants deconstructed the diagram into patterns based on perceptual similarity, an activity consistent with Gestalt principles. The chunking effect was most obvious in the Copying, Delayed Recall and Immediate Recall tasks, but showed fewer effects in the Tracing task.

In the present experiment, participants' drawings were compared with the experimenter's defined default pattern, which was consistent with the existing Rey Figure scoring criterion (Osterrieth, 1944; Lezak, 1983; Corwin & Bylsma, 1993). A potential alternative method of analysing the patterns of chunks produced by the participants, however, is by measuring the regularity of the recalled elements and comparing the patterns across the repeated sessions. While this contrasts with the present method, findings from this alternative method may verify the validity of our findings.

Furthermore, although we have found that components from the Rey Figure are treated as chunks, we have not, unlike Buschke (1976), been able to specify the nature of the chunk development, namely whether specific patterns of chunks amalgamate as learning improves, and if so, what is the likelihood of a consistent pattern emerging during recall and drawing? Buschke managed to present the chunk development due to the fewer items used in his experiment, which made the assessment on whether recalled items amalgamate at larger chunks easier. Our measures are not suited for an analysis of chunk development. This is because given the kinds of available data presently there are many possible combinations of how the chunks may integrate. Finding the common pattern calls for an advanced mathematical technique, which will require a lot more input data before regularity can be assumed. A potential method that could be considered is the automated calculation through the use of probability formulas proposed by Reitman and Rueter (1980).

### 2) How are the chunks of graphical elements organized in mental representations? What is the likelihood that these chunks will be structured in a hierarchical manner?

As the participants are proven to use chunks, the overall approach to drawing cannot be the nearest neighbour line strategy or any other that primarily operates at the level of individual lines. The early dominance of the frame group of patterns, as shown in Figure 3.17, suggests that a strategy based on a spatial schema or template (Gobet & Simon, 1996) is used. The participants draw the frame patterns first, which then provide spatial locations (or slots) as cues for the retrieval of particular chunks. This interpretation is preferable to a strategy in which the order of production of patterns is formed according to their perceptual salience or memorability. An advantage of this strategy is that it enables the working memory to function effectively in that only selected patterns appear more salient from a group, masking the rest during the process of drawing. Thus, the use of the three group patterns could have been one of the primary strategies to reduce the burden on the working memory as attention to each group is given serially.

The change in the process of drawing over successive sessions could be explained by an initial localized recognition of the patterns of chunks in the first few sessions of the experiment. In subsequent sessions, drawing actions become faster, as demonstrated by lower pauses shown in Figure 3.10. It is only after both processes are acquired that chunks are used extensively. This is supported by the decreasing group pattern transition counts over successive sessions. The higher number of group pattern transition counts that occur in the Tracing task, as indicated by the significant difference when compared with the other tasks, however, suggests that the three groups (i.e. frame, inner, outer) have a lesser role to play in Tracing. Thus, the drawing of the patterns could have been more random across the groups.

The nearest neighbour strategy analysis for the group patterns provides evidence that the complex abstract diagram is hierarchically structured. The lower value for the group transition count, for each type of task, compared to that of the nearest neighbour strategy shows that the group patterns, especially the frame group, had an influential role in all modes of production. This effect, however, showed a lesser influence in the Tracing mode. It may well be that the Copying, Delayed Recall and Immediate Recall tasks have a more structured pattern organization than the Tracing task due to the difference in the nature of these tasks. The former three may require the participants to access the underlying mental representation of chunk organization to a greater extent than the Tracing task. Drawing according to the patterns is not entirely necessary in the Tracing task. This is unlike the other modes where participants must comprehend the patterns in order to facilitate planning for the drawing execution.

The early dominance of the frame group, followed by the inner and outer groups, suggests that chunks of graphical elements are mentally represented in a hierarchical structure. The highest level of the hierarchy may consist of these three group patterns, while the lower levels may consist of patterns of elements as shown in Figure 3.22. This is consistent with van Sommers' (1984) proposal, and thus confirms his theoretical assumption that the Rey Figure is mentally organized in a hierarchical manner. This finding also supports similar claims by McNamara (1997), Palmer (1977), Smith (2002) and Cheng and Rojas-Anaya (2008).

All participants drew the frame group followed by the inner and the outer groups. Nevertheless, the order of the execution of individual patterns (e.g. box, body, fin, nose) on each level may change in each session for each participant. The group patterns (i.e. frame, inner, outer) at the highest level, however, are preserved, presenting a similar order in successive sessions. The drawing sequence is seldom haphazard and the ordering reveals regularity in the drawing performance. Based on the proposed hierarchical structure of the Rey Figure, it may well be the case that the participants employ both breadth- and depth-first searches as possible execution strategies. This is because they may first recall the most activated patterns using the depth-first search strategy and fall back to the breadth-first search in order to retrieve any missing patterns from the drawings, should any have been forgotten during the initial production. The group transition patterns may suggest the use of the breadth-first search strategy.

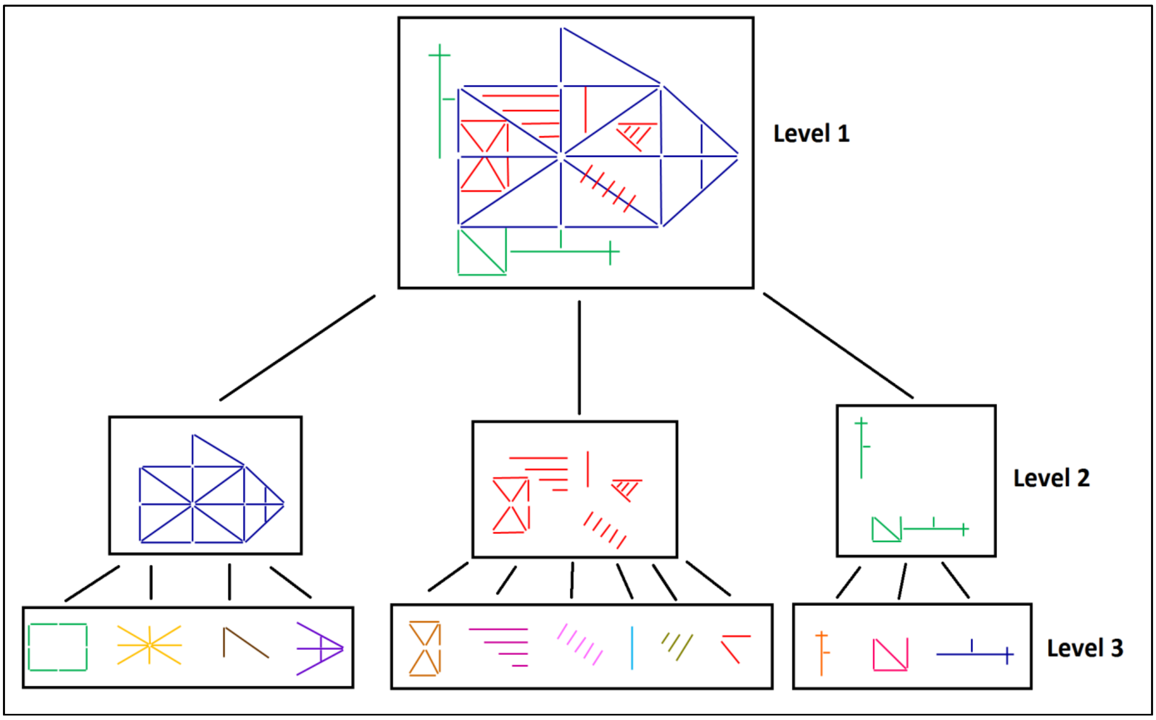


Figure 3.22: Hierarchical structure of the Rey Figure

Although it is clear that the Tracing task produced different outcomes compared to the other modes of drawing, it is too ambitious an attempt to determine the difference between the Copying and the Delayed and Immediate Recall tasks using the results from the present study. Therefore, this experiment is not able to specify the chunk organization representation for each type of task in any greater detail due to the lack of sufficient data. It is, thus, not possible to describe whether or not the recall-from-memory tasks have a more consistent hierarchical organization than the Copying task.

Given a more detailed analysis, we would be able to determine the consistency of the reproduced elements, such as the order of the elements retrieved within a pattern. This was not possible, however, with the present data as each element was not uniquely identified during data coding. A consequence of this type of analysis would be the specification of the chunk organization for each type of task.

### 3) What are the effects of practice for different types of drawing tasks? How fast does learning occur?

#### Over multiple sessions

In the early sessions, the transition count data suggests that the patterns were less important and that in the initial drawings participants have used something akin to the nearest neighbour strategy. Learning took place session after session in the experiment. It was expected that the participants would take a long time to learn due to the complexity of the figure. Surprisingly, however, the participants demonstrated rapid learning by drawing near-perfect versions of the diagram, consisting of 13 patterns and 56 lines for the Tracing, Copying and Immediate Recall from memory tasks by session 3 and for the Delayed Recall from memory task by session 6. The effects of learning are seen in the decline in the pause data (Figure 3.9) and the transition counts for the patterns (Figure 3.14). A learning curve is also suggested by the transition counts for the group patterns in the Tracing mode (Figure 3.18). The increasing number of lines (Figure 3.11) produced for all tasks also signify learning. This effect was noticeable from session 3 of the experiment, which consisted of 10 sessions in total. This finding, which illustrates that the participants demonstrated ceiling level learning by session 6, suggests that the experiment could have been run in fewer sessions. This will be taken forward in the following experiment.

Furthermore, the few errors produced across the sessions and tasks for the 195 drawings strongly suggest that rapid learning occurs in response to the strategies developed that are related to the effective use of chunks. Higher error rates for the Delayed Recall task than for the rest suggest that the participants had difficulty recalling the elements after an interval between sessions. Therefore, forgetting was likely to occur in the Delayed Recall task, as indicated by the fewest number of lines produced across the sessions for this type of task. The fewer errors recorded for the Copying and the Tracing tasks is obviously related to the opportunity given to participants to refer to the target diagram during the actual activity of drawing, thus enabling them to verify the intended drawing from the target diagram, reducing the chance of errors. In this way, they were able to produce perfect drawings without difficulty, as is shown by the number of lines measured in Figure 3.11. In addition, the more lines drawn for the Immediate Recall task than the Delayed Recall task also indicate that the elements remain activated in the memory following the Tracing and Copying tasks.

A few participants verbally reported that some parts of the figure were remembered because they were based on associations with previous knowledge of certain shapes (e.g. fish, rocket, warehouse). Therefore, the participants may have imposed some meaning, although the diagram was supposed to be abstract, thereby benefiting from the use of semantic information that associates particular patterns to specific meanings.

### Across different modes of drawing

In a recent study, Gonzalez et al. (2010) adopted a similar apparatus to this experiment, whereby adult participants were required to trace and copy line patterns followed by drawing based on recall from memory. All tasks were performed on a graphics tablet. Using a set of simpler patterns, the aim of their study was to find whether copying or tracing produces better learning outcomes in a short period. Gonzalez et al. concluded that none of these modes of drawing are more advantageous than the others.

Gonzalez et al., however, found no evidence of increased learning for tracing, but this could have been due to limited experimental sessions. For this reason, Gonzalez et al. posed the empirical question of whether tracing would be a more suitable training strategy than the copying method over longer periods. They further predicted that a longer training period would not only improve performance for copying, but also impair performance for tracing, due to the repeated use of the same stimulus. It was shown in our experiment, however, that repeated sessions with the same stimulus but with different types of tasks, arrived at a different outcome (at least between tracing and copying). If learning the same stimulus for copying over an extended period of time would affect the participants' learning performance for tracing, other learning measures, such as the temporal signal, would produce comparable results. The results from our study, however, have shown that tracing and copying are significantly different in terms of the lengths of pauses, number of transitions between patterns and groups and the early dominance of frame group within the drawings.

Gonzalez et al. did not have an explanation as to why the immediate advantages of tracing did not produce a steeper learning curve for this task when compared to copying. Given the additional parameter of the effects of chunks identified in the drawing tasks in this experiment, we venture the suggestion that a possible reason behind this could be the more limited use of chunks in the Tracing task and their more effective use in Copying. The larger number of transitions for the patterns and groups in the Tracing task provides supporting evidence for this claim. Furthermore, the performance for Tracing remained the same throughout, as indicated by the non-significant difference in pauses between the first and the last session of the experiment.

### Shorter L2 pauses for tracing, longer pauses for Immediate Recall and longest pause for Copying and Delayed Recall

As in previous studies (Cheng et al., 2001; Cheng & Rojas-Anaya, 2005, 2006, 2007, 2008; van Genuchten & Cheng, 2009, 2010) the constancy of L1 pauses and the variability of L2 pauses suggest that the drivers of the observed effects occur largely at chunk level. Tracing had the shortest L2 pause times, superseded by Immediate Recall, while those of the Copying and the Delayed Recall tasks were equally long. A plausible explanation for why L2 pauses for the Immediate Recall task are shorter than those for the Delayed Recall task can be found in the more recent and presumably greater activation of the chunks in memory under the former mode. The need to switch attention between the target diagram and drawing is one explanation for the greater L2 pauses observed in Copying as opposed to the Immediate Recall task. In the Copying, Delayed and Immediate Recall from memory tasks, the participants were forced to memorize parts of the figure, which presumably enhanced subsequent recalls. This effect is consistent with the theories that forcing participants to process information, such as memorizing parts of the figure, has the potential to produce better learning outcomes (Thorndike and Woodworth, 1901; Proteau et al., 1987). This information may be conceptualised as patterns of chunks in our experiment.

Tchalenko (2009) argues that the interaction between the head, eye and hand movement is responsible for the cognitive processes during a copying task. These cognitive processes range from perceiving the reference figure to the motor execution of the head, eye and hand movements during drawing. In this study, ‘encoding to visual memory’ is the process involved during the gaze at the target diagram. The ‘retrieval from memory and execution’ process is more involved in the process of reproducing the diagram on paper (Phillips et al., 1978; McMahon, 2002; Walker et al., 2006). In his study, Tchalenko concluded that drawing accurate shapes is only possible with the intervention of visuomotor mapping and that the accurate spatial positioning of drawing elements requires a vision of the drawing surface. Tchalenko also found that experienced drawers segment parts of the drawing into simple forms. This is consistent with our findings that chunks, or the segmentation of parts of the figure, occur during a drawing activity. Cubelli et al. (2000) further proposed that the motor processes of drawing production are only computed after other cognitive factors, such as planning for the drawing process, take place. This sequence of processing is also consistent with the graphic output system drawing model proposed by van Sommers (1989).

Tracing is the mode that one would expect to differ the most from the rest, as recall of chunks is not strictly necessary and shifts of attention to a remote target are not needed. Nevertheless, the difference between L2 and L1 pauses, as shown in Figure 3.9(a) indicates that chunking is present in the Tracing mode as well, even if chunks have a less important role than in other drawing modes. Note in Figure 3.10 that the magnitude for Copying converges with the Delayed Recall drawing element in later sessions, which is consistent with the participants' use of their recalled chunks from the Copying mode.

In relation to the L2 pauses, significant differences between each task (except between Copying and Delayed Recall) indicate that pauses for recall between the patterns for each task are substantially different. The non-significant effect between the Copying and the Delayed Recall tasks further supports the argument that these tasks are comparable, especially since the between patterns pauses are not considerably different.

This experiment employed a single figure. Although we have not tested our experiment with other stimuli, similar findings have been reported with the use of other graphical materials of simpler patterns, as demonstrated by Palmer (1977), Bouaziz and Magnan (2007), and Gonzalez et al. (2011). Thus, other graphical stimuli may potentially produce similar findings. At a more advanced and applied level, the results of this study can be utilised in specific scientific and technical domains involving conceptual knowledge, such as learning and drawing electronic circuit diagrams in physics.

## 3.6 Conclusion

In conclusion, this experiment has confirmed that chunking is present in drawing an abstract diagram using different types of tasks. In general, the chunks produced by the participants are similar to those of the proposed default patterns. The drawing strategy appears to have been based on a spatial schema, as a frame group dominated the drawing activity, which began by constructing an outline for the figure before more detailed elements were added. The speed of learning may be explained by the likely use of the spatial schema drawing strategy. The spatial schemas provide a systematic way of organizing the information that does not require drawing to follow a single rigid sequence of elements; an order, which is susceptible to breaking down if any one element is forgotten.

According to a few verbal reports, some participants associated the figure with semantic features, such as giving a familiar name to the figure, or parts of it, to aid recall. This raises the possibility that learning the figure did not only involve a spatial schema, (in other words, cannot be explained purely by the use of spatial information), but was also aided by semantic associations. Therefore, it would be interesting to manipulate the presence of the spatial and semantic information in the experimental stimuli to measure learning in relation to both conditions. This issue will be explored in greater detail in the following experiments.

# Chapter 4 Experiment 2: The effects of spatial and semantic schemas in learning

*You don't understand anything until you learn it more than one way*
*(Marvin Minsky)*

## 4.1 Introduction

In the previous experiment, it was shown that spatial schemas might influence the planning and processes of drawing. Findings from the first experiment have also indicated that participants could have imposed some degree of semantic representations to aid the process of learning, which affects their drawing preferences according to the associations made between parts of the figure and their corresponding meaning. This issue, which was not investigated in detail in the previous experiment, however, serves as the foundation for the experiment discussed in this chapter.

Previous studies, such as Merill & Baird (1978), van Sommers (1984) and Clayton & Chattin (1989) to name but a few, have raised the importance of the use of semantic and spatial information in learning and have argued that both have a significant role in the cognitive architecture of the human mind, which is unlikely to be absent or merely operate on an independent basis at a particular processing occurrence. Nevertheless, many of these studies have largely focused solely on the investigation of the human mind processes that relate to either of these types of information. Studies on the contribution of the strength of the relationship between semantic and spatial information have become increasingly important to the understanding of how the mind processes information with regards to learning. This led to a supplementary review of the literature leading to a direct contrast between the strength of semantic and spatial information while, to date, little research has directly compared the two. Thus, it is necessary to have a detailed study dedicated to the investigation of this issue, attempting to answer whether learning has a stronger influence from spatial, semantic or both types of information rather than leaving this possibility to chance (as was found in Experiment 1).

The Rey Figure, as used in Experiment 1, could have not provided a suitable experimental manipulation (i.e. the figure was redefined to emphasize the use of only semantic information) for this type of investigation, due to the lack of flexibility of the stimulus type, which is presumably regarded as highly spatial. It is, thus, less likely for the Rey Figure to adopt a highly semantic association without the intervention of spatial information. Furthermore, the verbal reports showed that some degree of semantic information was used, which indicated that the Rey Figure was not learned based on purely spatial information. Therefore, other types of stimulus presentation that would enable these kinds of manipulations may have to be considered, as we will see in the following discussion, in order to enable an appropriate assessment of the types of information that facilitate learning the most.

The present experiment will investigate the use of spatial and semantic information in drawings. In this context, spatiality is attributed by properties such as areas and the proximity between items. Space in graphics is used to represent relations between the elements within a context. Semantics convey meaning to graphics. For example, four lines of equal or different length that form a closed geometric shape could either represent a square or a rectangular shape. Recognizing the type of shape in question is determined by the associating verbal label. Therefore, semantic association is useful for the comprehension of geometric shapes. Hence, understanding graphical elements presupposes the integration of the use of spatial and semantic information.

In this experiment, we aim to induce the mental schema structure from the stimulus structure by manipulating the stimuli layout with the use of spatial and semantic information. It is hoped that the presented stimuli structure will invoke the organization of the underlying mental representations, which enable the assessment of whether spatial or semantic or their combined coding is useful for learning with the use of drawings. Therefore, in the context of this experiment, we devise these codings as spatial and semantic information.

Extending our general aim, we are motivated to investigate the relative contribution of these codings, such as the extent of using individual (i.e. either spatial or semantic) or combined codings (i.e. both spatial and semantic) in drawings. It is important to note that both codings have a role in drawings. A more specific question that interests this study, however, is to what extent these codings influence drawings and learning. In other words, is any one type of information (e.g. whether spatial is more influential than semantic or vice versa) able to provide improved learning over the other, or whether an interaction between their properties would produce a faster rate of learning. Finding the relative contribution of the respective properties of spatial and semantic is important to extend the current literature on understanding learning processes with respect to drawings.

### 4.1.1 Experiment related literature review

As reviewed in Chapter 2: Literature Review, a number of studies (Bousfield, 1953; Tulving & Pearlstone, 1966; Bower, Clark, Lesgold, & Winzenz, 1969; Collins & Quillian, 1969; Mandler, Pearlstone, & Koopmans, 1969; Pollio, Richards, & Lucas, 1969; Buschke, 1976) suggest that semantic relations serve as cognitive aids to memory, learning and information processing. For example, Bower et al. (1969) and Pollio et al. (1969) demonstrated that consistent category names among members or items of the respective category act as cues enabling participants to achieve a higher rate of item retrieval. On the contrary, non-existent or inconsistent category labels among constituent items rendered learning more difficult, thus, degrading the rate of retrieval. Therefore, recall improved with organized rather than with random presentation.

Evidence has been presented that category labels from semantic categories are associated with mental structures. This representation takes the form of a hierarchical organization (Tulving, 1962; Mandler, 1967; Bower et al., 1969). A possible method of studying the structure of retrieval and recall performance is by analysing latency or temporal patterns (i.e. measure the timing of successive items recall). This type of analysis supports the findings whereby retrieval was faster for items within the same category and slower for items between different categories. This effect is referred to as *response bursting* (Pollio et al., 1969; Patterson, Meltzer, & Mandler, 1971; Wingfield, Lindfield, & Kahana, 1998) or *categorical clustering* (Bousfield, 1953).

Among the most common stimuli used by previous investigators to study the role of semantic schema properties were word lists and pictures (Tulving & Pearlstone, 1966; Bower et al., 1969; Rosch & Mervis, 1975). These stimuli were often manipulated to withstand either categorized (sometimes referred to as *blocked*) or random presentation. Regardless of the type of presentation, however, such as in the case of “unrelated” word lists, the semantic factors were proven influential in the organization of retrieval (Tulving, 1962; Schwartz & Humphreys, 1973). This outcome, which is frequently demonstrated in free recall tasks where items are associated with a natural category, suggests that participants often attempt to organize related items into meaningful categories.

Furthermore, a number of studies, particularly on textual material, found that texts are recalled in a top-down manner (Waters, 1978; Britton et al., 1979; Yekovich & Thorndyke, 1981) through a hierarchical organization and that a complete chain of the related propositions is entirely recalled before those propositions at lower levels. This type of analysis has proven successful in predicting recall performances (Kintsch & Keenan, 1973; Meyer, 1975; Kozminsky, 1977; Thorndyke, 1977). Alba and Hasher (1983) also argued that items at a higher level in the hierarchical structure are more likely to be recalled before the retrieval of items at a lower level.

Apart from the semantic factor, the study of spatial information to facilitate retrieval and learning has received equal attention (Stevens & Coupe, 1978; Clayton & Chattin, 1989; McNamara, 1992; Tversky, 2001). Studies in this area investigate the role of space, such as relative distances (Cohen & Weatherford, 1980; Thorndyke, 1981), orientation judgement

(Hardwick, McIntyre, & Pick, 1976) and navigation (Anooshian & Young, 1981). The investigation of the use of spatial information in memory enables greater understanding of retrieval strategies and of how information is encoded in the memory. For example, Tversky (2001) reviewed the importance of space in graphical representations to convey meaning and how it serves to facilitate memory. Tversky further demonstrated that various spatial relations, such as proximity, could be used to represent spatial and non-spatial elements in the search for natural correspondences between space and thought. In a prior study, Tversky (1992) investigated the likelihood of people switching points of view from different angles of a scenario. It was found that participants would form separate mental models (consisting of information regarding properties, objects, scene, location and orientation) depending on which of four separate places the scenario was perceived.

In a different study but of a similar interest, Stevens and Coupe (1978) suggested that the mental representation of spatial information takes the form of hierarchical organization. This notion was also supported by Tversky (1981), Hirtle and Jonides (1985), McNamara (1992), and Holding (1994). In a series of different experiments, it was found that recall for objects within the same region was faster than retrieval of objects from different regions (McNamara, 1986; Clayton & Chattin, 1989; McNamara, Hardy, & Hirtle, 1989). The findings of Merrill and Baird (1987) further support the notion of a hierarchical structure for spatial information. In a card-sorting experiment containing the names of local buildings, Merill and Baird demonstrated that participants were prone to categorize the cards according to a multi-level hierarchy in which larger clusters of functionally related buildings consisted of smaller clusters of spatially related buildings. The study further supported the assumption that buildings at a close distance on the hierarchy were associated more closely in the memory and, therefore, had a greater probability for successful retrieval.

Mandler and Robinson (1978) used the term *schema* as referring to the content of mental representations developed through experience. They studied the role of schemas in the process of encoding and retrieval. The present experimental design builds on their work. In their study, participants were presented with line drawings and were given meaningful objects from real world scenarios in either an organized or unorganized manner. The participants, however, were tested on recognition tasks rather than the processes of drawing. Mandler and Robinson measured the spatial relatedness of objects, such as their location and the areas of filled and empty space in the scene. No attempt, however, was made to study the semantic relations between the objects, as they were already considered to share meaningful associations.

Although a wide array of studies contributes to the research in the field of semantic and spatial schemas, as mentioned in the literature review, there is no research (to date) that has investigated specifically the relative strength of the semantic versus the spatial schema. Therefore, this research is undertaken with the aim to address this issue in detail using drawing (both as an action and a stimulus presentation) and its effect on learning.

### 4.1.2 Definition of experimental terms

This section will define the common terms used in this study. We will start with the term *schema*, followed by *stimuli*, *task types* and *pause measurement*.

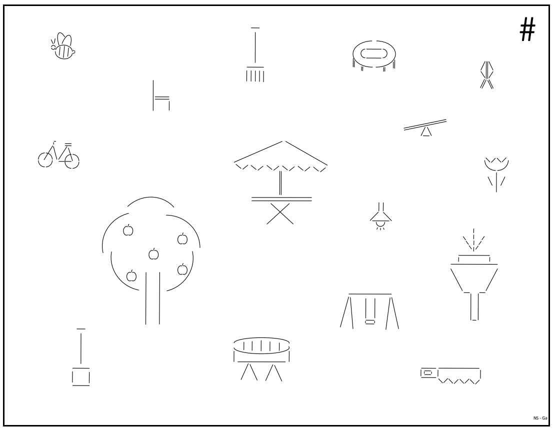
#### 4.1.2.1 *Stimuli*

As discussed in Section 2.4: Schema, a *schema* is often defined as organized knowledge relating to the world. This includes information about scenes, stories and events. The term *schema*, as used in this study, focuses on the investigation of structure rather than definition. We are aware that schemas consist of *slots* containing information known as *fillers*. In this experiment, we are interested in investigating how the structure of the presented stimulus invokes the organization of mental schemas. By stimulus structure we denote that the material included in the stimulus is presented at different complexity levels. To date (to the author's knowledge), little is known about how different levels of stimulus structures affect the organization of the underlying schemas. Furthermore, no empirical research has investigated whether learning material with more complex structure is more difficult to learn than learning material with less complex structure. Instead of assessing the depth of real-world knowledge, this study will attempt to investigate the effects of different structures of presentation using semantic and spatial information.

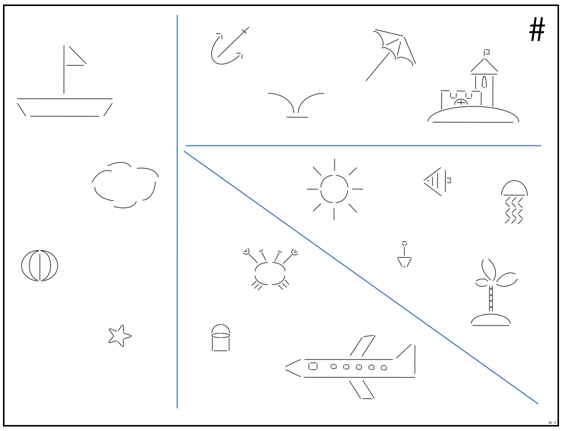
In order to assess whether the combination of semantic and spatial information is more influential for effective learning than an independent coding alone (either semantic or spatial) or vice-versa, we will deliberately manipulate these two types of codings under four drawing conditions. We define each drawing condition as a *stimulus*. These four stimuli are the following: (1) *No-Structure stimulus (NS)*, (2) *Spatial stimulus (Sp)*, (3) *Semantic stimulus (Se)* and (4) *Spatial-Semantic stimulus (SS)*. These differ in terms of the structure or relations between the spatial and semantic schema properties. Stimuli with more complex structure are categorised in an ascending order as follows: NS > Sp > Se > SS.

The Sp stimulus is defined by the spatial relation of the objects positioned in areas separated by borders that we called *divisions*. Except for the NS stimulus, all stimuli have divisions. Thus, each division has objects. The Se stimulus is defined by category labels that may potentially serve as cues for the constituent objects. The SS stimulus places the objects in a semi-realistic world scene by considering them in their typical spatial positions arranged according to their consistent categories.

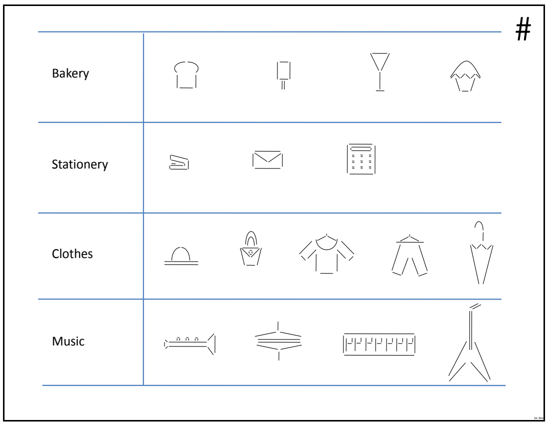
Examples of the stimuli are shown in Figure 4.1, where each has contents in the form of objects. For example, Figure 4.1(b) contains objects such as a castle, a beach umbrella, a bird and an anchor located at the top right area of the Sp stimulus. All of the stimuli are represented in four kinds of scenes, namely a house, the sea, a garden and a shop. Each has four divisions, as tabulated in Table 4.1. The complete set of the stimuli is shown in Figure 4.2. A category is a division of the scene, as exemplified in Figure 4.1 and Figure 4.3.



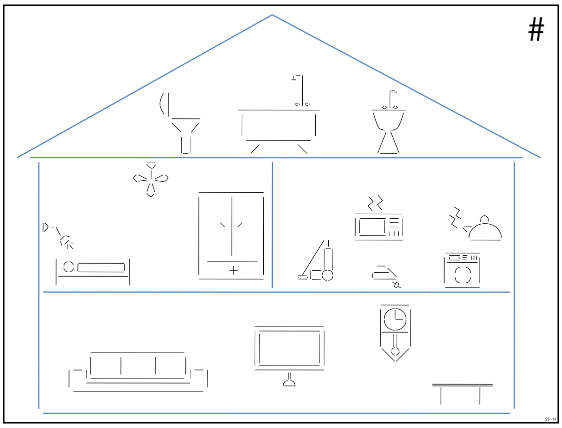

(a) No-Structure stimulus (NS)




(b) Spatial stimulus (Sp)




(c) Semantic stimulus (Se)




(d) Spatial-Semantic stimulus (SS)

Figure 4.1: Four types of stimuli represented in four scenes

Table 4.1: List of divisions for each scene

| **Scene** | **Divisions** | |
|---|---|---|
| *House* | 1) Bedroom<br>2) Bathroom | 3) Kitchen<br>4) Living room |
| *Sea* | 1) Sky<br>2) Underwater | 3) On the water<br>4) Beach |
| *Garden* | 1) Shed<br>2) Flowerbed | 3) Relaxing area<br>4) Play area |
| *Shop* | 1) Bakery<br>2) Stationery | 3) Clothing<br>4) Music |

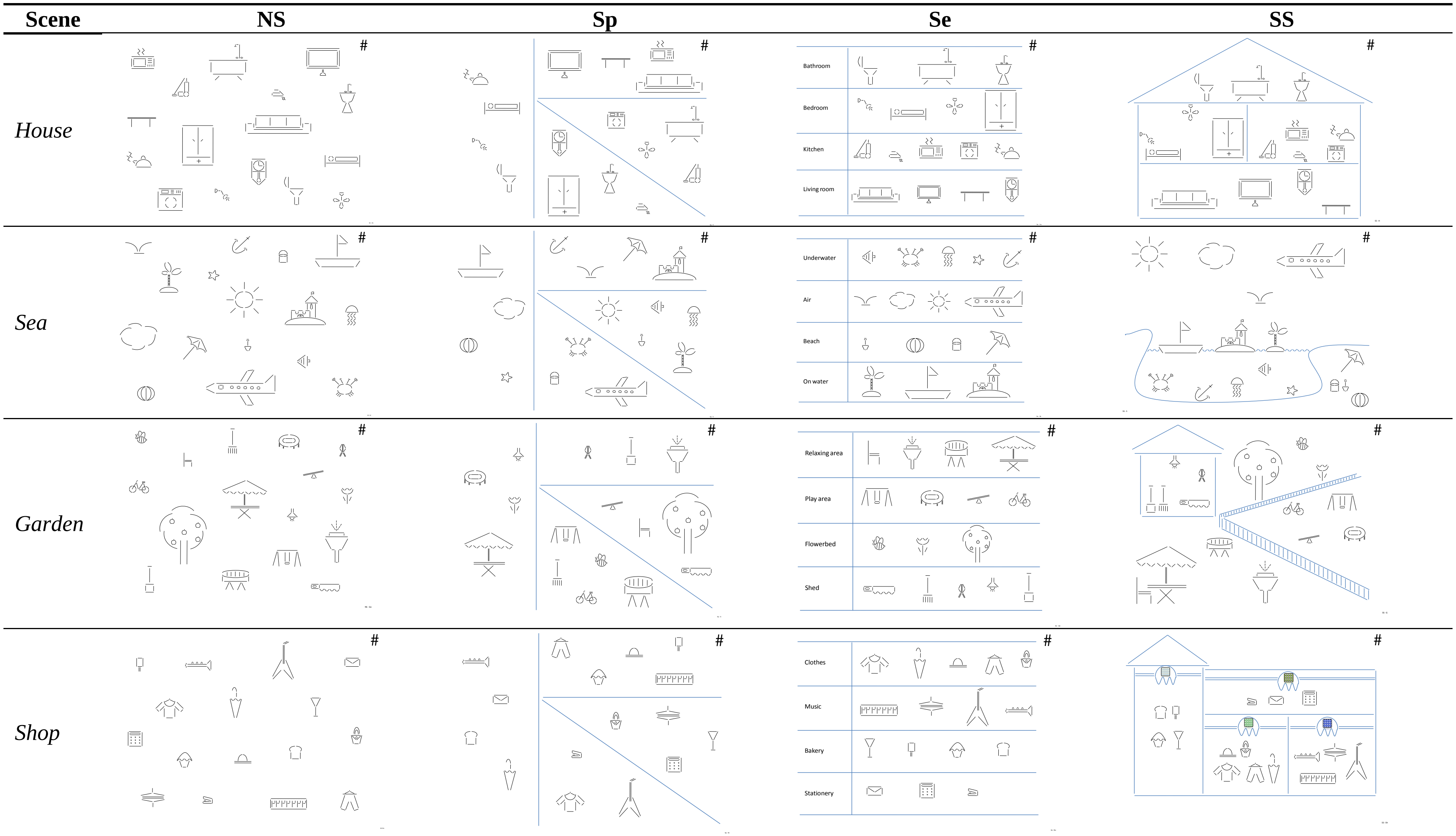



Figure 4.2: Examples of all scenes for each type of stimulus. There are four versions for each of the No-Structure and Spatial stimulus presentation.

The four types of stimuli are described below:

1) **No-Structure stimulus**: Figure 4.1(a) shows an example of a stimulus with no specific structure. Objects are positioned randomly in this type of presentation. “No structure” means that neither spatial nor semantic properties were deliberately imposed on the stimulus. By extent, this presentation does not associate any particular object with any particular location, nor assigns it in any meaningful category.

2) **Spatial stimulus**: Figure 4.1(b) shows an example of the Spatial stimulus. In this stimulus, the spatial property is deliberately induced by having distinct boundaries separating the objects. There are four areas (also known as divisions) separated by a horizontal, a vertical and a diagonal line, in which a few objects are arranged randomly. Other designs were considered but this type was selected not only for its simple layout, but also for its unique location.

3) **Semantic stimulus**: Figure 4.1(c) contains an example of the Semantic stimulus. This makes use of semantic properties by applying labels to categorize groups of related objects. Objects in this stimulus are grouped in named categories. These categories are organized in a tabular format across four rows. Objects are put together in the same row. The position of the rows is not fixed as the order changes in every experimental session. An appropriate label representing the category of the grouped objects is given on the left hand side of the corresponding row.

4) **Spatial-Semantic stimulus**: Figure 4.1(d) shows a stimulus that simulates an idealised real world scene. In this type of stimulus, both spatial and semantic properties are represented by a clear distinction of categories for each group of objects. Each of the scenes has four divisions that consist of semantically related objects within the particular scene. The spatial positioning of the objects is in the location where they would normally be found in an actual real world scenario. For example, the stimulus in Figure 4.1(d) shows a simplified example of a house, which consists of four common locations found in an actual house, such as bathroom, kitchen, bedroom and living room. Each of these categories/divisions has groups of related objects that are typical for the scene, such as a sofa, a TV, a table and a wall clock in the living room. Although the divisions in each scene are not labelled by categories (e.g. bathroom, kitchen, bedroom and living room), each of these divisions represents a common understanding for the association of the objects within its respective location and category.

#### 4.1.2.2 *Task types*

In the present experiment, participants were asked to draw the contents from each stimulus in two types of drawing tasks, *Recall from memory* and *Copying*, in a total of six sessions. The Recall from memory task was employed to test learning progress and technique, while the Copying task was used to provide an opportunity for the participants to learn and remember the contents displayed on the stimulus. The Recall from memory task data were analysed to trace learning behaviour among the participants. This was not the case for the Copying data, as this task was only used for practice and learning purposes.

#### 4.1.2.3 *Pause measurement*

Our analysis will measure the pause durations, the number of objects drawn, the count of transitions between divisions, and the types and rates of error across all sessions for all stimuli. As we will see, the pauses occur at different phases of the drawing. Taken together, these measurements are predicted to indicate the amount of processing occurring in the mind during learning via drawing. In this experiment, we defined and measured three levels of pauses, as we are interested to find evidence on whether divisions in different stimuli have a significant role in drawing. This can be evaluated from the changes in the pauses depending on whether differences occur between drawing individual objects and drawing between objects (within and between divisions) across the stimuli.

As previously explained in Chapter 3, a *pause* is the time duration computed between the end point of a line and the following starting point of a new line during drawing. Figure 4.3 illustrates the pause levels by using an example from a Se stimulus on the assumption that the participant draws the objects in the order labelled. The three types of pauses, as shown in Figure 4.3, are described as follows:

1) **Level 1 (L1)** is defined as the within object pause, which may indicate the time used to draw elements within an object. The L1 pauses are calculated for every transition occurring between the previous line and the following line that belong to the same object, as exemplified in the two successive strokes in object 1 (slice of bread) in Figure 4.3.
2) **Level 2 (L2)** is defined as the pauses between different objects within the same division. These pauses are calculated for every transition between the last drawn line of an object and the first line of the following object, such as between object 1 (slice of bread) and object 2 (ice lolly) in the L2 pause example in Figure 4.3.

3) **Level 3a and Level 3b (L3a and L3b)** are two different kinds of pauses, which are both associated to stimuli with divisions. These pauses, measured between the divisions, occur at different circumstances. The No-Structure stimulus does not have divisions in its design; hence, does not have L3a and L3b pause measures.
    a. **Level 3a (L3a)** is defined as the first transition between two divisions. The L3a pauses are measured for the first transition occurring between the last line of an object in a division and the first line of another object from a different division. This measure is taken during the first transition between two objects that each belong to a different division. An example of the L3a pause is shown between object 2 (ice lolly from the Bakery category) and object 3 (stapler from the Stationery category) in Figure 4.3.
    b. **Level 3b (L3b)** is defined as the second or subsequent transition between two divisions and is referred to as a return to the previously visited division. An example of the L3b pause is shown between object 4 (envelope from the Stationery category) and object 5 (wine glass from the Bakery category) in Figure 4.3. The L3b pause will henceforth be called a *return transition between divisions*.

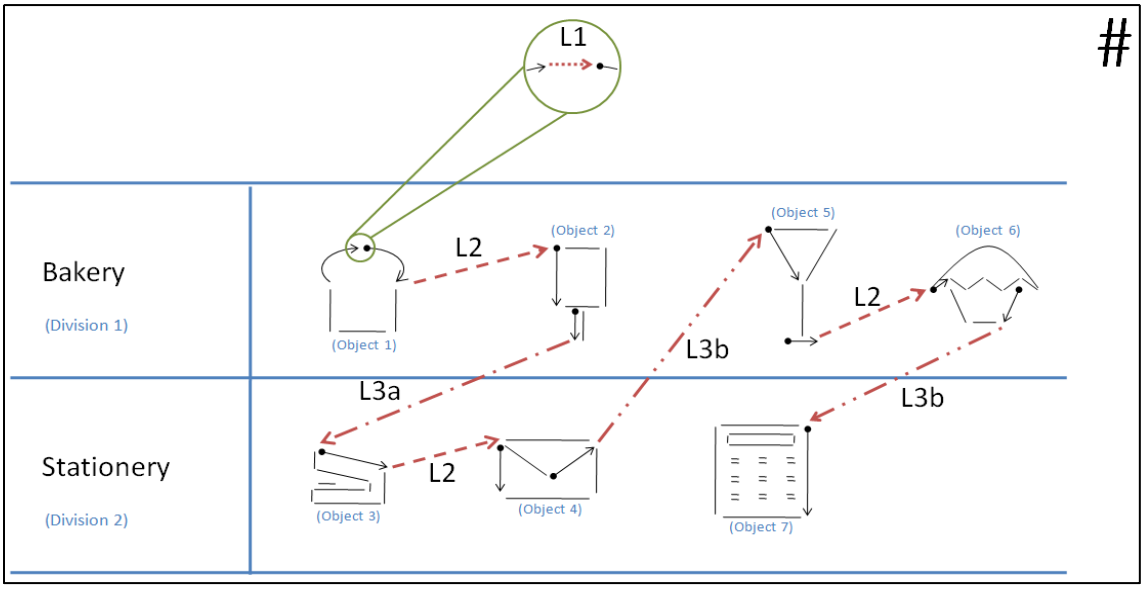



Figure 4.3: Illustration of the four pause levels

## 4.2 Hypothesis

It is predicted that speed of learning and accuracy will vary across all four stimuli. The SS stimulus is predicted to be the easiest type of stimulus for learning, as it incorporates both spatial and semantic properties. Hence, the association between these two properties would provide the most helpful cues for encoding and recoding information. On the other extreme, the NS stimulus is predicted to be the most difficult type of stimulus due to the absence of an obvious structure or divisions that could facilitate learning. As a consequence, there is no direct association between the objects facilitated by either semantic or spatial cues, as none are given. The Sp and Se stimuli, each associated with one type of property (either spatial or semantic), are theoretically predicted to pose an equal level of difficulty, which would lie in between the SS stimulus and the NS stimulus. We would expect that stimuli with more divisions structure (e.g. Sp, Se and SS) would generally be a better type of stimulus for facilitating memorisation, as they provide better cues for retrieval and help in developing chunks during learning.

The overall hypothesis outlined above will be tested using four measures or sub-predictions:

**Prediction 1**: <u>Pause duration</u>

It is predicted that there will be three levels of pauses during the process of drawing. The different levels of pauses are predicted to reflect the information retrieval process, where internal knowledge is possibly organized in a hierarchical manner across many levels, as shown in Figure 4.4. According to this prediction, each division (or category) corresponds to a higher-level category composed of objects for the particular division. For example, Figure 4.4 shows two divisions (division 1-in the shed and division 2-flowerbed area) with the order of the drawn objects and the corresponding hierarchical structure. The pause levels shown in the hierarchical structure of Figure 4.4 may suggest the amount of time used to recall objects at different occurrences, such as within an object, and within and between divisions.

It is predicted that the depth of the branch in the hierarchy indicates the amount of processing involved during retrieval. Given this type of representation, a participant may potentially recall an object in a top-down manner by going through the following order: whole-stimulus → specific division → particular object → lines within the object. It is, thus, reasonable to use the length of the branch to determine the amount of processing required at a particular stage during retrieval. For example, recall for lines within an object may only involve the shortest branch in the hierarchy, as only lines within a particular object are considered. Retrieval between two objects within a division has a longer branch, as processing includes the level of objects and lines. As participants recall the objects between different divisions, more processing will be required, which includes the level of divisions, objects and lines.

To summarize, the three pause levels (as described in Section 4.1.2.3: Pause measurement) are predicted to produce the following effects: the shortest L1 pauses for drawing elements within an object, longer L2 pauses for drawing between objects from the same division, even longer L3a pauses between objects from different divisions and the longest L3b pauses will be required to revisit a division, due to the search for the correct one. Therefore, the pause prediction follows the order of L1 < L2 < L3a < L3b. This prediction applies to all types of stimuli.

In the example shown in Figure 4.4, pauses used to recall elements of the shovel object are shorter than those used to recall elements between the shovel and the fork within the same division (division 1). Similarly, longer pauses are measured for the first transition between different divisions, (i.e. between the shears in division 1 and the apple tree in division 2), while the longest pauses are observed for the return transitions to the previously visited divisions (i.e. between the bee in division 2 and the saw in division 1). Therefore, this prediction claims that stimuli with divisions (i.e. Se, Sp and SS) use longer pauses to shift between divisions (L3a and L3b pauses). By contrast, stimuli without divisions (i.e. NS) use shorter pauses to shift between objects (L2 pauses).

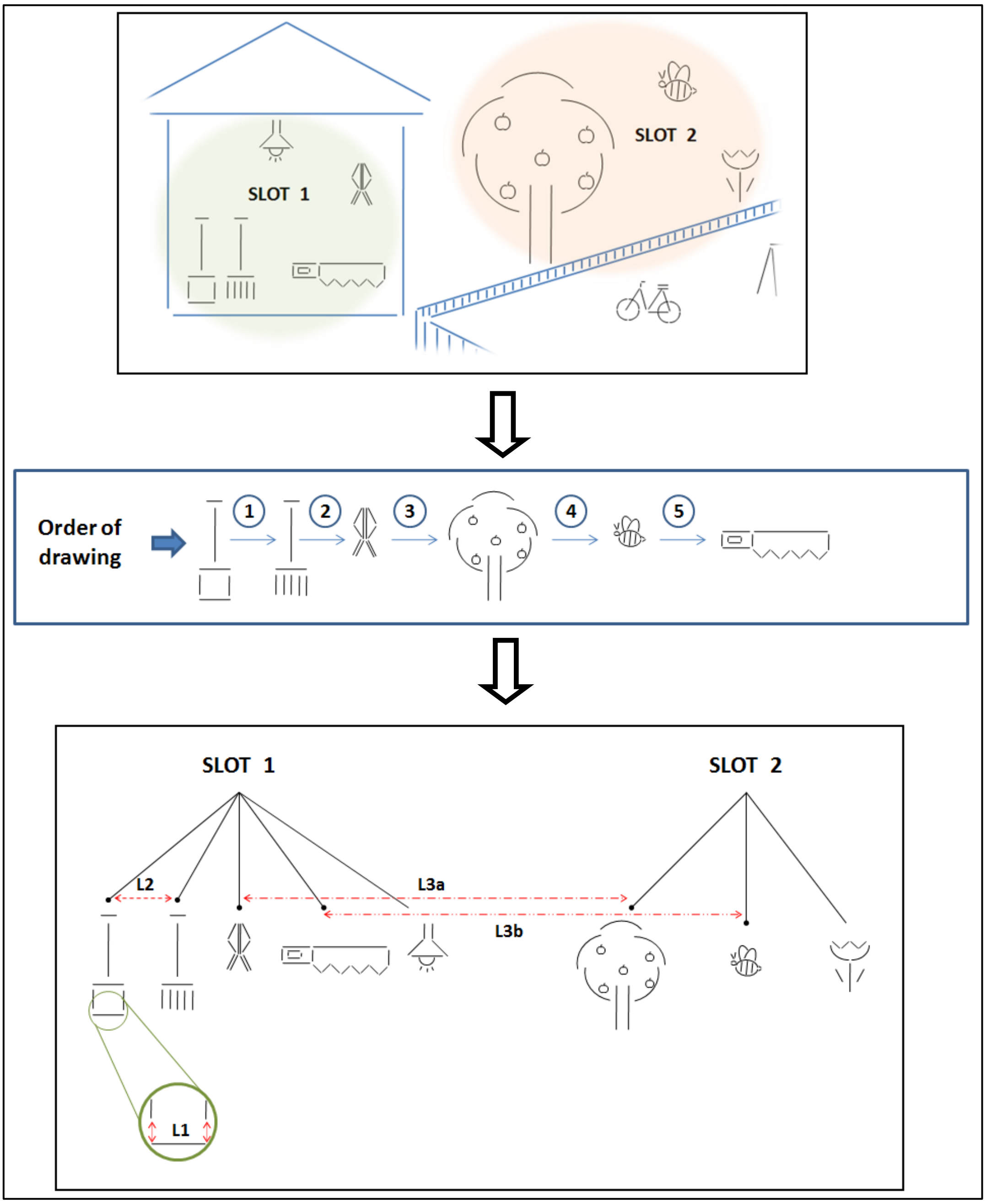



Figure 4.4: Example of hierarchical structure of the divisions for the Spatial-Semantic stimulus

**Prediction 2:** Number of objects

The total number of objects drawn for each type of stimulus is predicted to vary according to the level of difficulty as described above (i.e. most difficult for the NS, easiest for the SS and intermediate for both the Sp and Se). This translates to the greatest number of objects predicted to be drawn for the SS stimulus, as opposed to the lowest for the NS stimulus. The Sp and Se stimuli are predicted to have an approximately equal number of drawn objects.

A greater object count is also an indication that participants have learned the stimulus adequately. The learning rate is predicted to be influenced by the degree of manipulation of the spatial and semantic properties. It is posited that the SS stimulus will produce the fastest learning rate in contrast to the NS stimulus, which will have the slowest. The Se and Sp stimuli are both predicted to have an equal speed of learning.

**Prediction 3:** Number of transitions between divisions

The SS stimulus is predicted to have the least recorded transitions, whereas the Se and Sp stimuli are predicted to produce more transitions between the divisions, with an equal transition count between them. Fewer transitions for the Sp stimulus may indicate that participants treat objects as a group within its own division, thus, increasing the likelihood of drawing all the objects within the division before any others in the subsequent divisions. On the contrary, a higher transition count occurring between the divisions, which indicates their less successful use, may suggest that objects are randomly drawn across the divisions as shown in Figure 4.5.

The measurement of the transitions between the divisions indicates how participants categorize the objects. More transitions occurring between the divisions imply that participants may generate and use individually preferred categories by selecting objects from different divisions (or category). For example, as shown in Figure 4.5 (Part A), division 1 of the Sp stimulus consists of a yacht, a cloud, a ball and a star. A participant, however, could have encoded the yacht, the cloud, the star and the sun (from division 2) together as one group based on the participant’s own preferred category. Similarly, group 4 consists of the animal objects from divisions 3 and 4 as shown in Figure 4.5 (Part C).

On the contrary, fewer transitions, including the minimum number of possible transitions between the divisions, imply that objects belonging to a particular division are drawn together before objects from other divisions are drawn. An example would be if the yatch, the cloud, the ball and the star in division 1 were drawn together before the anchor, the bird, the umbrella and the castle from division 2 as shown in Figure 4.5 (Part B).

**Prediction 4**: Error rate

More errors are predicted to occur under the NS stimulus condition, due to its lack of structure. The lack of facilitating cues (such as semantic or spatial information) in this type of stimulus may cause confusion, thus hampering retrieval. At the opposite end, the SS stimulus is predicted to produce the least number of errors due to its highly structured presentation, in which the semantic and spatial information provided may strengthen the cues for retrieval. Both the Sp and Se stimuli may produce similar error rates due to the representation of their respective properties. Learning and retrieval may still be aided by these individual cues, although recall may not be as facilitated as that of the SS stimulus.

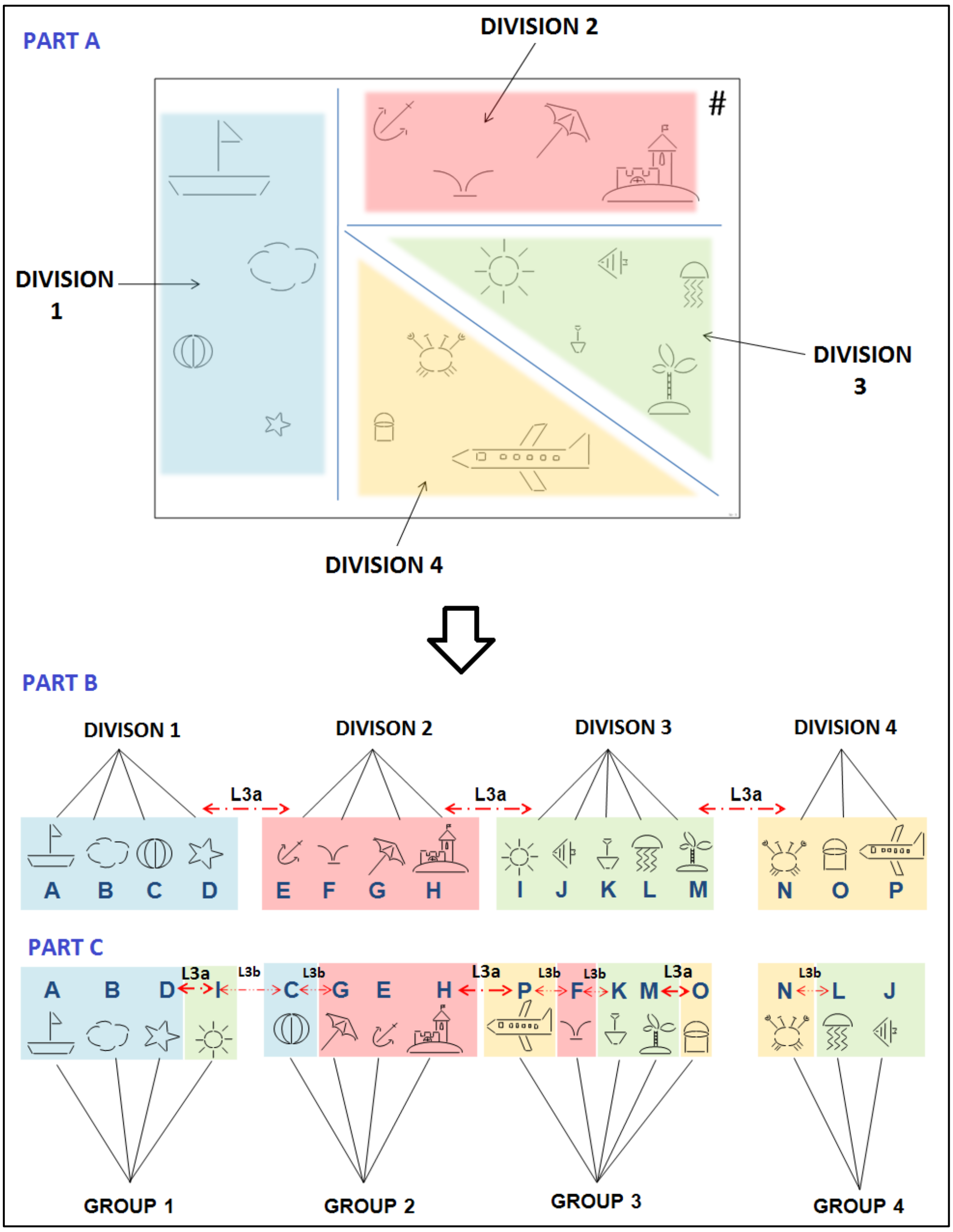


Figure 4.5: Example of the transitions between divisions of the Spatial stimulus

## 4.3 Method

### 4.3.1 Participants

Twelve paid adults participated in this experiment. Six were female and six were male. Their age ranged between 20 and 37 years old (Median: 25 years 7 months). The participants were undergraduate and postgraduate students (both Masters and PhD) from the University of Sussex. Eleven of them were right-handed and one was left-handed. There were no specific requirements for the selection of the participants. Each person possessed typical drawing skills, demonstrating no difficulties in drawing simple line figures during a practice task prior to the actual experiment. The total of twelve participants was selected to counterbalance the number of people required for the four sets of stimuli employed in this experiment. Each participant was paid £35.

### 4.3.2 Design

The experiment employed a fully within-subjects design with

1) Two independent variables:
    a. Four levels of *stimulus type* (i.e NS, Se, Sp and SS stimuli)
    b. Six *sessions* (i.e 1-6)
2) Four dependent variables:
    a. Pause duration (i.e L1, L2, L3a and L3b levels)
    b. Number of objects
    c. Number of transitions occurring between divisions
    d. Error rates

The independent variables were crossed producing 24 experimental conditions (4 stimulus types x 6 sessions). All participants performed in all experimental conditions where they did eight drawings (four for the Recall from memory task and four for the Copying) in each session. Therefore, this is a repeated measures design.

As mentioned above, the two drawing tasks used are Copying and Recall from memory. In the Copying tasks, participants were shown drawings from four stimuli, each consisting of different sets of objects as shown in Figure 4.1. They were asked to draw the objects on the respective empty sheet as shown in Figure 4.6. A similar procedure applied to the Recall from memory task, excluding this time any reference to the target diagram.

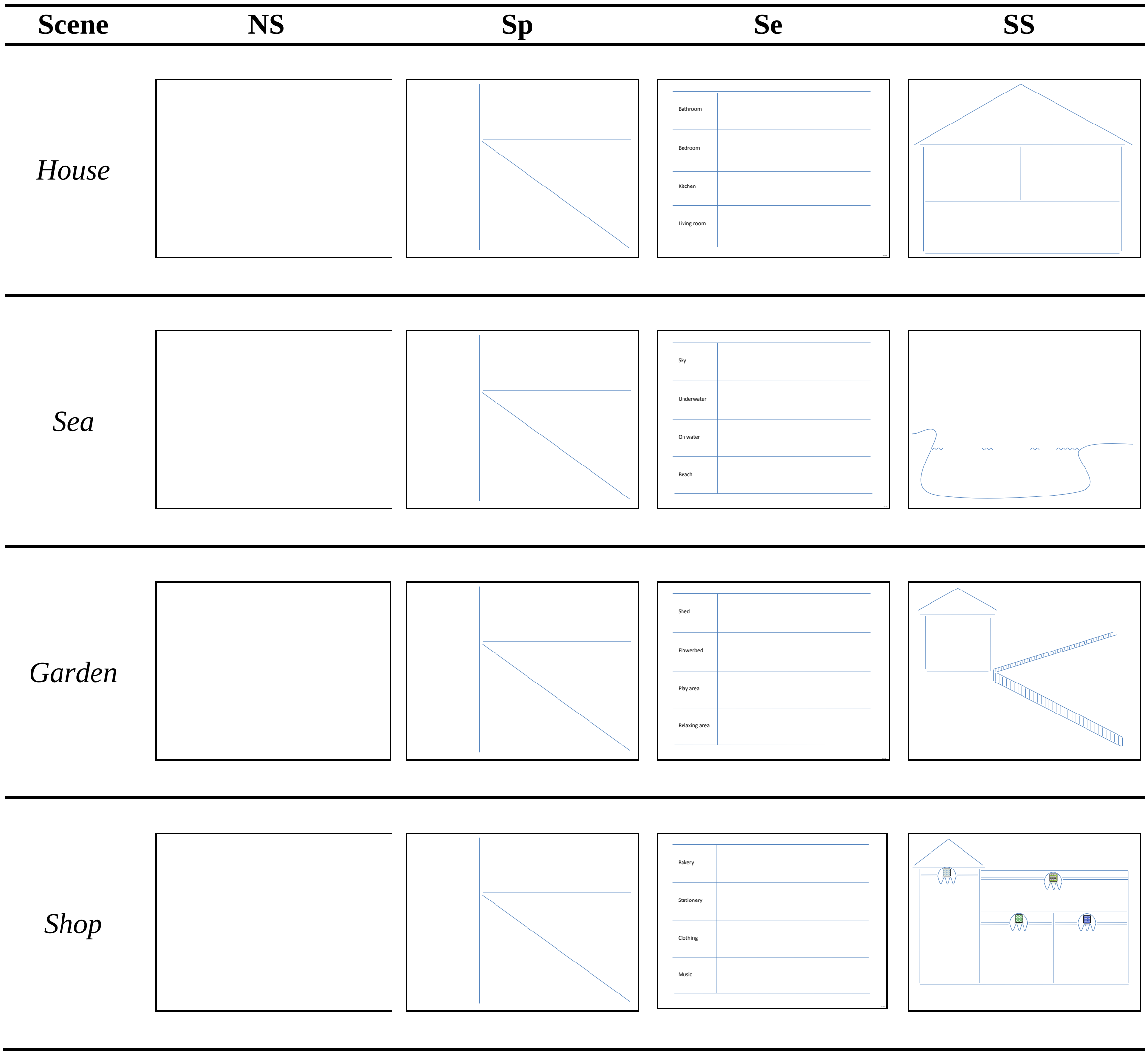



Figure 4.6: Empty stimuli sheet with all four scenes and four types of stimulus presentation

Table 4.3 shows the order of the participants' drawing tasks. The description below explains the change in the order of the drawing tasks given to the participants at certain phases of the experiment:

**Session 1**: In session 1, the participants were given a set of stimuli consisting of four types. The aim was to perform the Copying task first, in order to familiarise themselves with the content and stimuli structure presented before they were tested on Recall from memory.

**Session 2 to session 5**: During this phase, the participants began the sessions with the Recall from memory task based on what they have learned from the previous sessions. They did the Copying task after the completion of drawings based on Recall from memory.

**Session 6**: In the final session, the participants were only tested on Recall from memory tasks. Following the completion of all drawings for this task, they were interviewed with a few standard questions on the techniques they employed to remember the contents of each type of stimulus during a debriefing session. The debriefing session provided informal evidence on the participants' preferences for drawing the four stimuli.

### 4.3.3 Materials

The Wacom Intuous graphics tablet and a special inking pen were used during data collection. A blank A4 piece of paper was taped on the graphics tablet for each task. As previously described in Section 4.1.2.1: Stimuli, the four types of stimuli employed four types of scenes (i.e. a house, the sea, a garden, a shop). Each scene consisted of 16 objects and each stimulus contained only objects that belonged to a particular scene. Table 4.2 lists the objects for all scenes, as they are different in each. Every object was designed to have spaces in between the lines, so as to satisfy the requirements of the GPA method employed in this experiment. The sets of stimuli were printed in black ink on sheets of white A4 paper in a landscape orientation.

Table 4.2: List of objects for all scenes

| House | Sea | Garden | Shop |
|---|---|---|---|
| 1. Bath tub | 1. Aeroplane | 1. Apple tree | 1. Bread |
| 2. Bed | 2. Anchor | 2. BBQ pit | 2. Calculator |
| 3. Clock | 3. Beach ball | 3. Bee | 3. Cymbals |
| 4. Fan | 4. Beach umbrella | 4. Bicycle | 4. Envelope |
| 5. House lamp | 5. Bird | 5. Chair | 5. Guitar |
| 6. Iron | 6. Bucket | 6. Fork | 6. Handbag |
| 7. Kettle | 7. Castle | 7. Fountain | 7. Hat |
| 8. Microwave | 8. Cloud | 8. Garden table | 8. Ice lolly |
| 9. Sofa | 9. Coconut tree | 9. Saw | 9. Keyboard |
| 10. Table | 10. Crab | 10. Seesaw | 10. Muffin |
| 11. Toilet | 11. Fish | 11. Shears | 11. Stapler |
| 12. TV | 12. Jellyfish | 12. Shed lamp | 12. Trousers |
| 13. Hoover | 13. Spade | 13. Shovel | 13. Trumpet |
| 14. Wardrobe | 14. Starfish | 14. Swing | 14. T-shirt |
| 15. Wash basin | 15. Sun | 15. Trampoline | 15. Umbrella |
| 16. Washing machine | 16. Yacht | 16. Tulip flower | 16. Wine glass |

In each session, the participants were given a different combination of stimuli. The NS and Se stimuli changed throughout the experiment. They each had four versions, named (a), (b), (c) and (d) for all scenes and objects were reshuffled in each version. In the Se stimulus, objects were shuffled within a division. Similarly, the positions of the respective category labels were also rearranged on different rows in the tabular format stimulus. The reason the NS and Se stimuli were varied was mainly to ensure that the spatial arrangements of the objects were not preserved. This control was induced to reduce the possibilities of interference from the other stimulus properties (e.g. spatial and/or semantic). For example, if the same version of the NS stimulus was given to the participants in every session, there is a good chance that they would assign some degree of spatial and/or semantic properties to it, such as certain preferred learning strategies (e.g. categorization, object recognition by location, etc.).

The Sp and SS stimuli only had one version of each scene. Thus, the same Sp and SS stimuli were used throughout the sessions. This was done to control how participants learned the given stimuli, namely whether they associated the kind(s) of property(ies) presented on the stimuli. An example is the use of spatial proximity to locate objects on the Sp stimulus and the use of both meaningful categorization and spatial location to memorise the objects on the SS stimulus.

All stimuli with divisions had a different number of objects (i.e. 3, 4, 4 and 5) in each division. An exception is the house scene for the Sp stimulus, where each division had 4 objects due to an experimenter's error during design. This error, however, did not adversely affect the outcome of the experiment. The different number of objects in each division was used in order to reduce the chances of relying on the totality of the objects in each division as a drawing strategy.

As for the NS and Sp stimuli, the selection of objects was randomized across different categories from the same scene in order to minimize the likelihood of them sharing common semantic characteristics. The group of objects within a division from each of the Se and SS stimuli, however, potentially shared common categorical characteristics (e.g. the washbasin, bathtub and toilet all belong to the Bathroom category).

The order and selection of stimuli with respect to the different scenes were counterbalanced in each session. The pattern of the counterbalance is shown in Table 4.3.

Table 4.3: Example of the order of stimuli given to a participant

| **Stimuli combination** | **Session 1** | **Session 2** | **Session 3** | **Session 4** | **Session 5** | **Session 6** |
|---|---|---|---|---|---|---|
| | **Practice** | **Memory 2** | **Memory 3** | **Memory 4** | **Memory 5** | **Memory 6** |
| *NS-H* | **Copy 1** | | | | | |
| *Sp-S* | NS-H (a) | Sp-S | SS-Sh | Se-G (b) | Sp-S | NS-H |
| *Se-G* | Sp-S | NS-H | Sp-S | SS-Sh | NS-H | Se-G (c) |
| *SS-Sh* | Se-G (a) | SS-Sh | NS-H | Sp-S | Se-G (d) | SS-Sh |
| | SS-Sh | Se-G (c) | Se-G (a) | NS-H | SS-Sh | Sp-S |
| | **Memory 1** | **Copy 2** | **Copy 3** | **Copy 4** | **Copy 5** | **Debriefing** |
| | Se-G (b) | Se-G (b) | Sp-S | SS-Sh | NS-H (a) | |
| | NS-H | SS-Sh | Se-G (d) | Se-G (c) | Sp-S | |
| | Sp-S | NS-H (b) | SS-Sh | NS-H (c) | SS-Sh | |
| | SS-Sh | Sp-S | NS-H (d) | Sp-S | Se-G (a) | |

*Note*. NS = No Structure, Sp = Spatial, Se = Semantic, SS = Spatial Semantic. H = house, S = sea, G = garden, Sh = shop. Version = (a), (b), (c), (d).

### 4.3.4 Procedure

Each participant did six sessions. In total, there were four sets of stimuli recreating a different combination of scenes for each task (see Table 4.3). The order of stimuli presentation was counterbalanced to avoid confounding order effects among the stimuli. Each participant received the same set of stimuli throughout the experiment. Three out of the 12 participants shared the same set. There were a total of four sets of stimuli for all combinations of stimuli and scenes.

Prior to the execution of any of the drawing conditions in the first session, all participants engaged in a practice task, where they copied a stimulus of simple abstract figures in order to familiarize themselves with drawing on a graphics tablet. Similar to Experiment 1, pauses for all drawing events were recorded using the special software called TRACE (Cheng & Rojas-Anaya, 2004). The participants were instructed always to begin their drawings with a hash (#) symbol so that the first drawn line would be valid as a data point.

### 4.3.5 Analysis

The type of statistical analysis used in this experiment is the Repeated Measures ANOVA with two independent variables. Table 4.4 shows all of the statistical conditions for each of the variables. Three out of the six statistical analyses (i.e. L3a pause, L3b pause and transition between divisions) used stimuli that had divisions, while the remaining used all of the stimuli. Each of the ANOVA analyses had two main effects (i.e. stimulus type, session) and an interaction effect (stimulus type x session).

Table 4.4: Cross-over of experimental conditions

| Type of analysis | Dependent variables | | Independent variables |
|---|---|---|---|
| ANOVA Repeated measures with two independent variables | *Pauses* | L1 | stimulus type x session (4 x 6) |
| | | L2 | |
| | | L3a | stimulus type x session (3 x 6) |
| | | L3b | |
| | *Number of objects* | n/a | stimulus type x session (4 x 6) |
| | *Transition between divisions* | L3b | stimulus type x session (3 x 6) |
| Total count | *Error rate* | n/a | n/a |

The data recorded on TRACE includes (1) the point coordinates of marks produced on the tablet (each point consists of x- and y- coordinates) and (2) the time (in milliseconds) of each point. The time difference between two points was calculated as we are interested in the pause duration between the pen down and pen up of a mark, as shown in Figure 4.7.

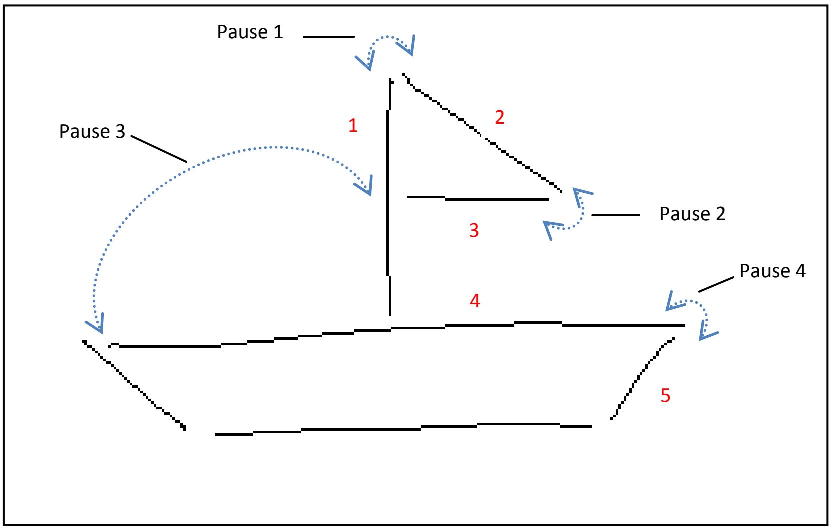



Figure 4.7: Example of pauses, shown as dotted arrows, occurring between strokes. Numbers shown in red denote the order of drawing

The data files were further processed using a special program written in Java (Obaidellah, 2010). This semi-automated program was used to label each drawn object with its corresponding name, such as labelling a set of lines that represent a swing with the label "swing", as shown in Figure 4.8. The program reads drawings' data points produced by the participants and plots the drawings to enable manual object naming. This procedure is necessary to facilitate the subsequent process of calculating the pauses between the objects within and between divisions.

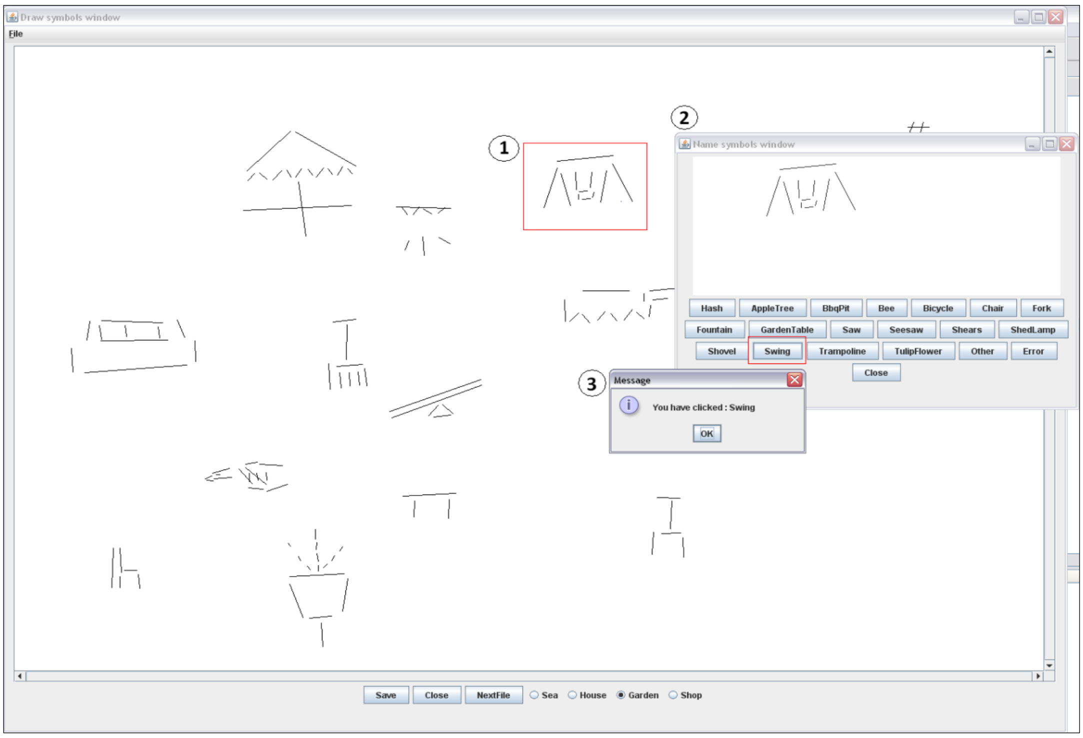



Figure 4.8: Object labelling using a Java program

## 4.4 Results

The results will be presented at an aggregated level for all participants. Each sub-section will be examined according to the hypothesis presented above and in the order of the predicted measures: (1) pause levels, (2) number of objects, (3) return transitions between divisions and (4) error rates.

We will now present a general overview of the Repeated Measures ANOVA, as all statistical measures in this experiment employ a similar type of analysis. In each ANOVA test, we began our statistical interpretation, where necessary, by applying Mauchly's Sphericity Test in order to find if the participants behaved in similar ways across sessions. As the data collected from this experiment are skewed, careful inspection of each dataset was necessary. The algorithm in Mauchly's Sphericity Test measures the equality of *variances of the differences* between the levels of each factor (e.g. comparison between stimuli NS-Se in sessions 1-2). This is called the *assumption of sphericity*. If the difference between the levels of each factor is significant, the *assumption of sphericity* is violated ($p<.05$). The degrees of freedom are adjusted using the *Greenhouse-Geisser* estimate of sphericity ($\varepsilon$) when $\varepsilon<.75$ or nothing is known about sphericity. On the contrary, if comparison between the levels of each factor is not significantly different, then the *assumption of sphericity is met* ($p>.05$) and, the differences between the levels are roughly equal. Thus, the *Sphericity Assumed* is employed, as no degree of freedom corrections are necessary.

More detailed tests were produced by the repeated measures ANOVA, such as contrast and pairwise comparison tests. Their purpose is to establish whether particular levels of the independent variables contribute extensively to the overall effects. In order to find out whether differences exist between the levels of each factor, we selected *simple (last)* contrast for the stimulus type factor, where each level of the factor (apart from the reference level itself) is compared to the reference level. The SS stimulus was selected as the reference level. The *repeated* contrast was selected for the session factor, where adjacent levels are compared to the next, with the exception of the last. Comparisons were made between sessions 1-2, 2-3 and so forth until all levels were compared to the last at session 6. Where necessary, we concluded our statistical analysis with a discussion of the post-hoc test, which consists of the Pairwise comparison. In this test, which is similar to the t-test, comparisons of *pairs of means* were performed in all different combinations of the levels in each factor. This test reveals which levels are significantly different across the factors. The Bonferroni correction was selected as the type of correction for the Pairwise comparison test because it controls the Type I error rate very well.

### 4.4.1 Pause order L1 < L2 < L3a < L3b

Consistent with our predictions, it was found that the shortest time is taken to draw lines within an object (L1), followed by longer pauses when drawing between objects (L2) in the same division, while the longest time is taken to draw between objects in different divisions or categories (L3a and L3b). We will use this result to examine whether drawings of different stimuli affect pause levels. An overview of the pauses for each stimulus will be discussed first based on the effects of stimulus types and sessions before we explain the statistical analysis for each pause type in greater detail. Figure 4.9 shows the mean for all pause types across six sessions for all stimuli.

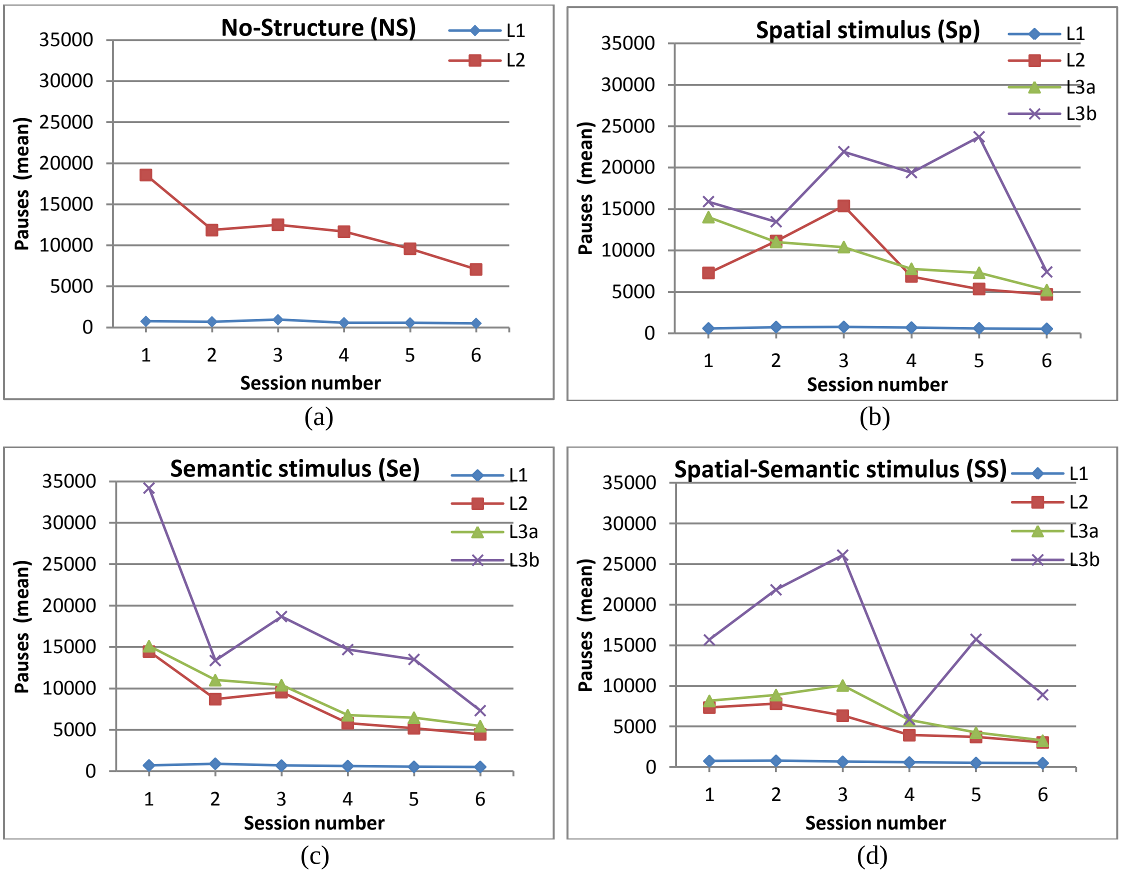



Figure 4.9: Means for L1, L2, L3a and L3b pauses for all stimuli across six sessions

#### 4.4.1.1 Effects of stimulus type

The graphs in Figure 4.9 show that the L2 pauses are greater than the L1 pauses, while the L3a and L3b pauses are both greater than the L2 pauses. Similarly, the L3b pauses are greater than the L3a, with an exception for the SS stimulus at session 4. This is consistent with the hypothesis that the pauses vary at different drawing phases, which suggests distinct processes. Overall, all types of pauses occur at separate levels in each stimulus type with a few exceptions (i.e. L2 pause: Sp stimulus at sessions 2 and 3, L3b pause: SS stimulus at session 4). Table 4.5, which presents the means for each pause level, indicates that pauses increase across the levels for all stimuli.

A closer inspection of the graphs in Figure 4.9(c) and (d) shows that the Se and SS stimuli exhibit similar pause patterns. Nevertheless, the Sp stimulus does not show a clear trend for these pauses. The similarities between the L2 and L3a pause patterns for both Se and SS stimuli may indicate that similar levels of processing may occur for both.

Table 4.5: Increasing pauses (mean) across the stimuli

| Stimulus type | Pause type | Mean | Median | Standard deviation |
|---|---|---|---|---|
| *NS* | L1 | 443 | 435 | 55 |
| | L2 | 6609 | 6213 | 1697 |
| *Sp* | L1 | 426 | 407 | 46 |
| | L2 | 6660 | 5910 | 3445 |
| | L3a | 7245 | 7047 | 1811 |
| | L3b | 14165 | 14254 | 4836 |
| *Se* | L1 | 430 | 426 | 42 |
| | L2 | 5948 | 6061 | 2163 |
| | L3a | 7931 | 7775 | 2889 |
| | L3b | 15663 | 14105 | 6959 |
| *SS* | L1 | 404 | 396 | 46 |
| | L2 | 4246 | 3906 | 1665 |
| | L3a | 5831 | 6387 | 2141 |
| | L3b | 14064 | 14287 | 9220 |

#### 4.4.1.2 Effects of session

Overall, pauses decline across the sessions. The L1 pauses are the shortest of all types of pauses, while the L3a pauses are greater than the L2 pauses, except in two cases for the Sp stimulus. These pauses were also higher in session 1 than in session 6, where all pauses converged for all stimuli. Across the stimuli, the L3b pauses showed the highest pause rate across all sessions, including that in session 4 (5879ms) of the SS stimulus.

#### 4.4.1.3 Effects of pauses

We will now turn our attention to the more fine-grained results of the three types of pauses under discussion.

**L1 pauses**

The means for the L1 pauses across all sessions and all stimuli are shown in Table 4.5. The L1 has the lowest pause level compared to L2 and L3 pauses. This result indicates that the participants were treating each object as a chunk. This is in accordance with the prediction that drawing lines from the same chunk does not require much cognitive processing.

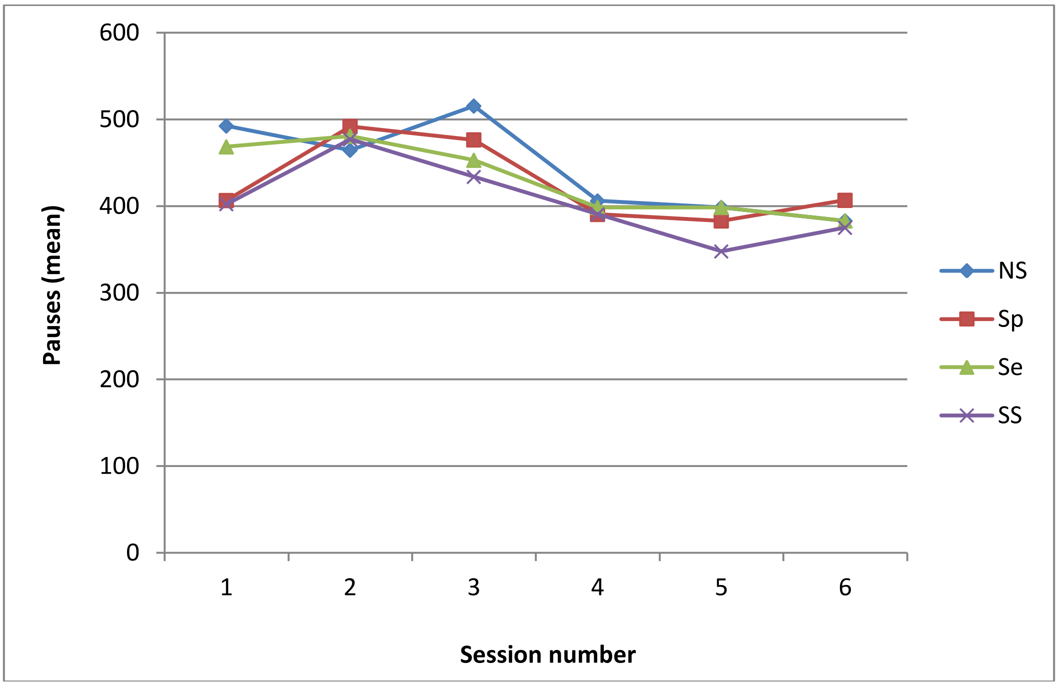



Figure 4.10: L1 Pauses for all stimuli across six sessions

A visual inspection of Figure 4.10 shows that no apparent differences exist for the L1 pauses between the stimuli. The repeated measures ANOVA confirms this finding although significant effects were found for the main effect of the session, $F(2.4,26.39)=13.67$, $p<.05$. The contrast tests, however, have largely shown non-significant effects suggesting that the differences between sessions are small. Nevertheless, this may indicate that the L1 pauses are different between the sessions due to improved low-level motor performance over time consistent with the Power Law of practice theory. Apart from the effects of practice, whereby drawing performance becomes faster as participants repeat figures in successive sessions, this may well be related to the stronger activation of the related elements belonging to the particular object at the lowest level of the hierarchy in the mental schema.

**L2 Pauses**

The L2-between objects pauses are analysed to investigate whether the stimuli across successive sessions have an effect on the time taken to proceed between objects. Figure 4.11 shows the L2-between objects pauses across all types of stimuli, where it is clearly visible that the L2 pauses gradually decrease from session 3 onwards as the stimuli become more structured from the NS to the SS stimuli.

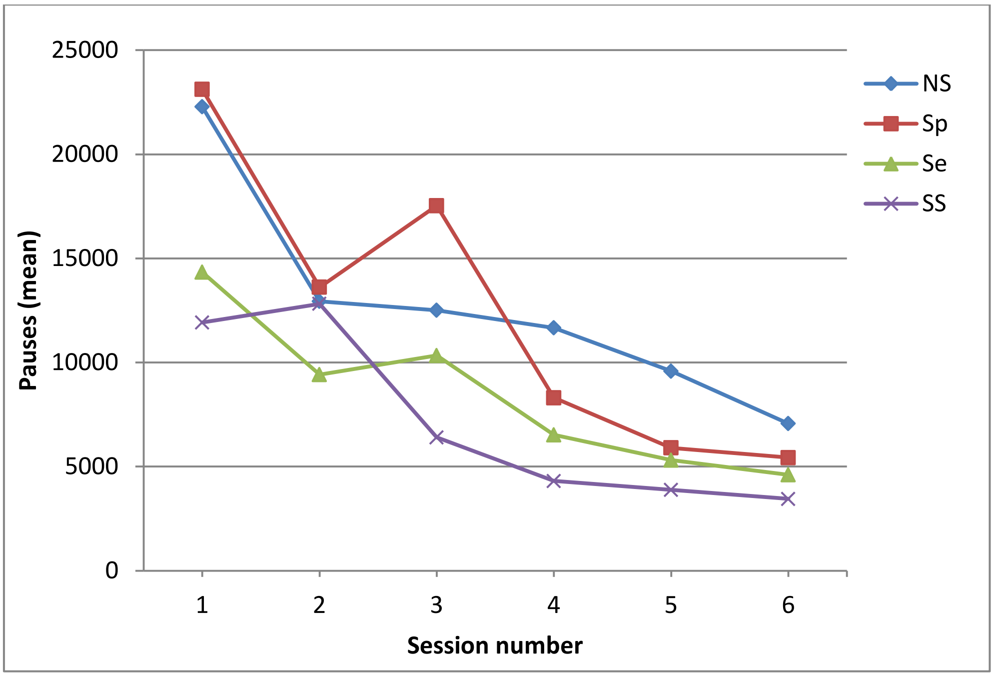



Figure 4.11: Between object (L2) pauses for all stimuli across six sessions

Although no simple pattern was shown in the first half of the sessions, patterns of pauses for all stimuli begin to converge from session 3 onwards. This may be due to the extensive learning that occurred in prior sessions. As soon as participants reached session 4 they had already learned well using the kind of properties for each stimulus. Therefore, the graph, which shows a more uniform pattern of pauses from session 4 onwards, further suggests that an interaction between the stimulus type and the session might be present for the L2 pauses.

The ANOVA test showed a significant main effect for the stimulus type, $F(3,33)=8.30$, $p<.001$ (with the assumption of Sphericity met, $\chi^2(5)=9.27$, $p>.05$, derived from Mauchly's test using the Sphericity Assumed). This indicates that the stimulus type factor had a significant influence on the L2-between objects pauses across the different stimuli. In other words, the pauses used to recall between objects are different for all stimuli. The contrast test for the stimulus type factor showed significant effects, $p<.05$ between NS and SS stimuli, $F(1,11)=9.36$, $r=0.66$, as well as between Sp and SS stimuli, $F(1,11)=9.68$, $r=0.68$. A comparison between Se and SS stimuli, however, proved non-significant. This suggests that Se and SS stimuli are comparable and may, thus, have a similar learning effect. On the contrary, each of the NS and Sp stimuli generally has different learning effects from the SS stimulus.

The ANOVA further showed a significant main effect for the session, $F(1.66,18.26)=9.92$, $p<.05$, [with a correction for the violation of sphericity using Mauchly's test for session, $\chi^2(14)=68.16$, $p<.001$) and the Greenhouse-Geisser corrected value for the degree of freedom ($\varepsilon=.33$)]. This is consistent with the graph in Figure 4.11 as the L2-between objects pauses decrease across the sessions. The contrast test for the session factor was non-significant between sessions 1-2 and between sessions 2-3. The remaining comparisons, however, [sessions 3-4, $F(1,11)=15.01$, $r=0.76$; sessions 4-5, $F(1,11)=11.91$, $r=0.72$ and sessions 5-6, $F(1,11)=11.43$, $r=0.71$] were all significant, $p<.05$.

Unlike the earlier interaction prediction from the graph in Figure 4.11, the ANOVA found no significant interaction effect between the stimulus type and session.

**L3a Pauses**

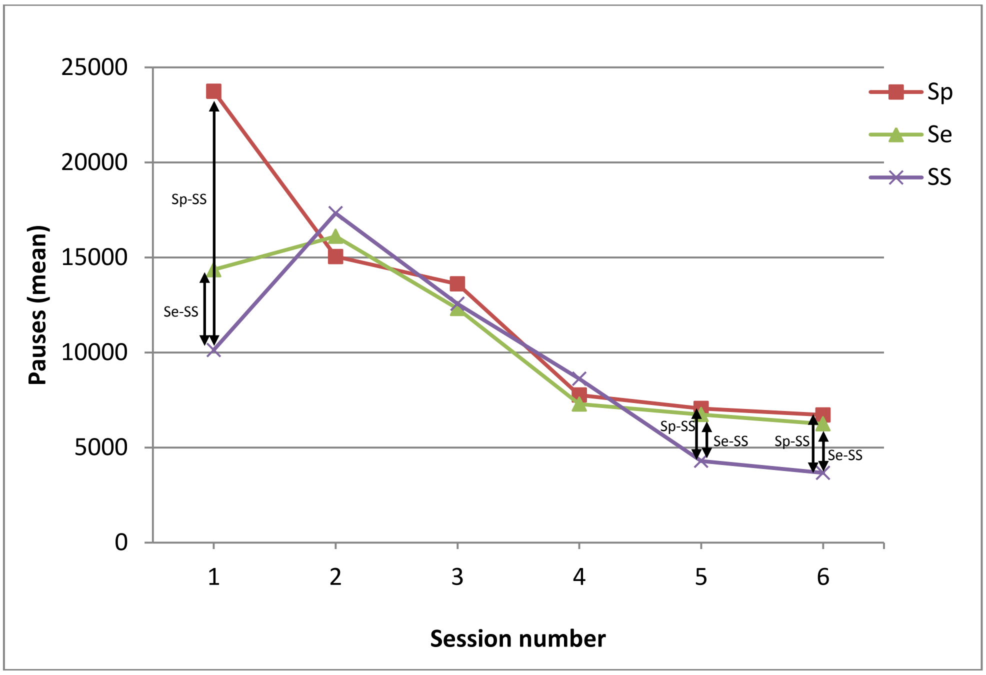



Figure 4.12: First transition between divisions (L3a) pauses for all stimuli with divisions across six sessions. Arrows indicate a significant effect (p<.05) between the stimuli at sessions 1, 5 and 6

The L3a pauses are analysed to investigate whether stimuli across the sessions have an effect on the L3a pause duration that occurs in the first transition between divisions. In other words, to examine whether each type of stimulus shows different effects for the L3a-first transition pauses occurring from an existing division to a newly visited division. If this were the case, it would mean that the stimuli could potentially have some degree of influence on the first transition occurrence.

As shown in Figure 4.12, there is a general trend of pauses decreasing for all stimuli with sessions. This indicates that pauses for L3a-first transition between divisions decrease across all types of stimuli. Immediate effects of the stimuli are found for the L3a pauses from the very beginning of the experiment. At the first session, the Se and SS stimuli showed lower pauses than the Sp. The L3a pauses pattern is similar from session 2 until session 4 across the stimuli. More interestingly, further decrease takes place in the SS stimulus, which is lower than the Sp and Se from session 5.

The ANOVA showed non-significant effects for the main stimulus type, $F(2,22)=3.05$, $p>.05$ [with no correction of degrees of freedom on the assumption of Sphericity Assumed ($\varepsilon=1.000$; Mauchly's test for stimulus type, $\chi^2(2)=0.81$, $p>.05$)]. This indicates that, generally, pauses occurring in the L3a-first transition between divisions do not have an effect, irrespective of the type of stimulus. Therefore, it can be concluded that the L3a pauses are not influenced by participants' drawings across the stimuli. This means that, regardless of the type of stimulus, the L3a-first transition pauses that occur from an existing division to a newly visited division make no difference in determining whether drawings on one type of stimulus are more structured than on other stimuli. The contrast test for the stimulus type factor, however, showed a marginally significant effect, $p=.054$ between the Sp and SS, $F(1,11)=4.66$, $r=0.55$. As we will see, the t-test confirms the significant effect between these stimuli (see Figure 4.12) in sessions 1, 5 and 6. The SS stimulus has a distinct categorization for its clusters of objects due to its enclosed spatial and semantic properties. Nevertheless, a contrast test between Se and SS was non-significant, $p=.344$.

A significant effect, $p<.05$, was found for the session, $F(2,22)=6.50$, $p<.05$ [using the Greenhouse-Geisser corrected values of the degrees of freedom ($\varepsilon= 0.40$; Mauchly's test for session, $\chi^2(14)=50.29$, $p<.001$)]. Further contrast tests showed a non-significant effect for comparisons between the sessions in successive order (i.e. sessions 1-2, 2-3, 4-5 and 5-6) except for sessions 3-4, $F(1,11)=7.63$, $r=0.64$, $p=.018$. The largely non-significant result between the sessions from the contrast test suggests that they are an unlikely influence on the speed of performance of the L3a-first transition made between divisions. It is probable that the significant effect found between sessions 3-4 has masked the general ANOVA results for the session factor. Therefore, the L3a pauses did not decrease substantially as participants performed drawings from the first session towards the sixth session, but only between sessions 3 and 4.

The ANOVA further showed non-significant effects for the interaction between stimulus type x session, $F(2,27)=1.45$, $p>.05$ [using the Greenhouse-Geisser corrected degrees of freedom ($\varepsilon= 0.25$; Mauchly's test for stimulus type x session, $\chi^2(54)=176.18$, $p<0.001$)]. The contrast test of the stimulus type x session was again non-significant. This means that if both factors were considered together, no effect was found in terms of the participants' performances for the duration of first transition between divisions (L3a) pauses in successive sessions across different types of stimuli.

Further, a t-test (one tail, paired) showed a significant effect, $p<.05$ found between (1) Sp and SS stimuli and (2) Se and SS stimuli for the comparison at session 1. A comparison between the Sp and Se stimuli, however, was non-significant. A significant effect, $p<.05$ was also found in the t-test between (1) both sessions 5 for (a) Sp and SS stimuli, (b) Se and SS stimuli and (2) both sessions 6 for (a) Sp and SS stimuli, (b) Se and SS stimuli, as shown in Figure 4.12. This result means that the pause duration decreases in a more structured stimulus (SS stimulus), indicating that participants are faster at shifting their drawing between an existing division to a newly visited division, compared to a slower shift occurring between drawings in lesser structured stimuli (e.g. Se and Sp stimuli).

**L3b Pauses**

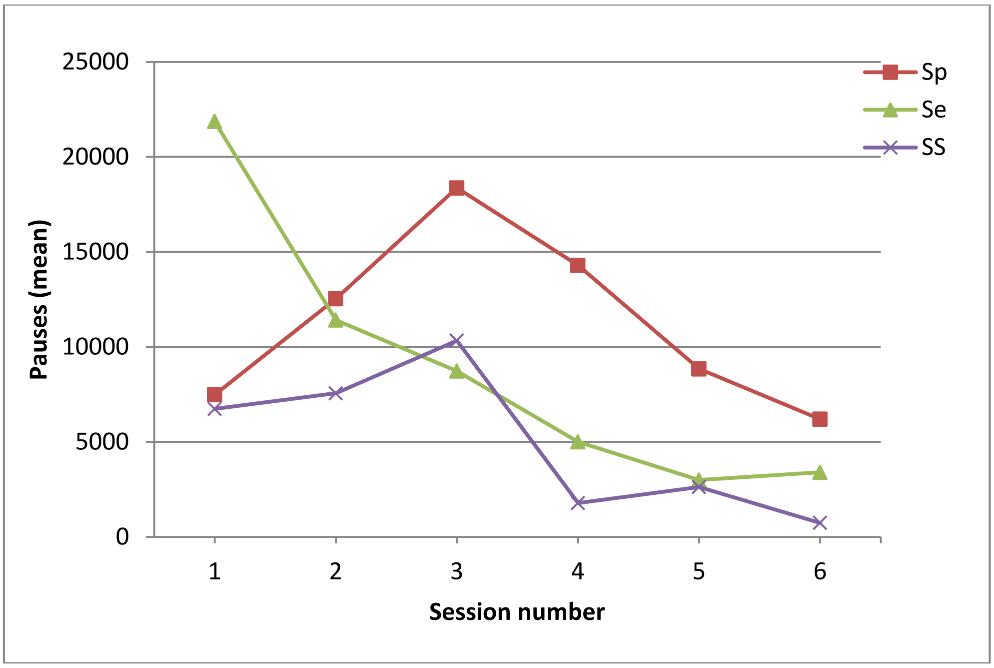



Figure 4.13: Return transitions (L3b) pauses for stimuli with divisions across six sessions

We continue with the analysis of L3b pauses in order to determine whether stimuli across the sessions show significant effects on L3b-return transitions between divisions. Figure 4.13 shows a pattern of decreasing pauses for the L3b-return transitions from the current division to the previously visited division for all types of stimuli. Interestingly, pauses for the SS stimulus are the lowest for all sessions apart from an anomaly at session 3. The Se stimulus begins with the highest pause at session 1 but decreases further than the Sp, although not as low as the SS in successive sessions (except at session 3). Generally, the highest L3b pauses occur for the Sp stimulus (except for session 1). The L3b pause decrease across the stimuli is consistent with the previous pause results from the L1, L2 and L3a pause levels. This pattern, which is most notable from session 3 onwards across all stimuli, may suggest that the individual stimulus types have influence over the return transitions pauses from the current division to the previously visited division.

The repeated measures ANOVA for the stimulus type showed a significant main effect, $F(1.34,14.79)=10.83$, $p<.05$ [with a correction for the degrees of freedom using the Greenhouse-Geisser estimates of sphericity ($\varepsilon$= 0.67; Mauchly's test for stimulus type, $\chi^2(2)=6.69$, $p<.05$)]. This indicates that the L3b pauses were different between stimuli. Contrast tests further revealed that L3b pauses of the Sp stimulus, $F(1,11)=20.50$, $r=0.81$ and Se stimulus, $F(1,11)=21.79$, $r=0.82$ were significantly different to the SS stimulus at $p<.05$. The pairwise comparison tests for the stimulus type factor were significant for the comparison between Sp and SS and also between Se and SS at $p<.05$. A non-significant effect was found between Sp and SS.

The ANOVA further showed a non-significant main effect for the session based on the L3b-return transitions between divisions pauses, $F(2.56,28.15)=1.64$, $p>.05$ [with corrected degrees of freedom using Greenhouse-Geisser estimates of sphericity ($\varepsilon$=0.51; Mauchly's test for session, $\chi^2(14)=29.06, p<.05$)]. This result suggests that the L3b pauses are not significantly different between sessions, which is consistent with the non-significant results from the contrast test and the pairwise comparison test between all sessions.

The ANOVA, however, found a significant interaction effect between stimulus types x session, $F(10,110)=3.11$, $p<.05$ [with no degrees of freedom correction using the Sphericity Assumed, ($\varepsilon$=1.000; Mauchly's test for stimulus type x session interaction, $\chi^2(54)=66.27$, $p>.05$)]. The significant interaction effect may be due to the odd pattern of the Sp stimulus, as shown in Figure 4.13 where a low L3b pause rate was observed at session 1, gradually increasing until session 3, before steadily decreasing towards session 6. Although the L3b pauses decrease for all stimuli, the Sp stimulus shows the fastest rate of decrease from session 3 onwards. The low L3b pauses at sessions 1 and 2 of the Sp stimulus are also influenced by the fewer objects recalled in these sessions (see Figure 4.14).

### 4.4.2 Number of objects

We performed the repeated measures ANOVA to find whether different numbers of objects were drawn across the stimuli. In Figure 4.14, there is a clear trend for an increasing number of objects drawn on all stimuli, as sessions progress. Generally, the highest number of objects was drawn in the SS stimulus (with the exception of the first session) followed by the Se. In the last three sessions, more objects were drawn in the Sp stimulus than the NS. This result supports the hypothesis that more objects were produced in an ascending order for NS < Sp < Se < SS. This might indicate that the structure (e.g. stimulus layout) of these stimuli could have influenced learning. Although the degree of structure of the stimuli may indicate a definite effect, the number of objects in the Se stimulus was higher (7-16 objects) than the lower number of objects

(3-14 objects) produced for the Sp. This is inconsistent with the hypothesis, which predicted that the Sp and Se would be comparable.

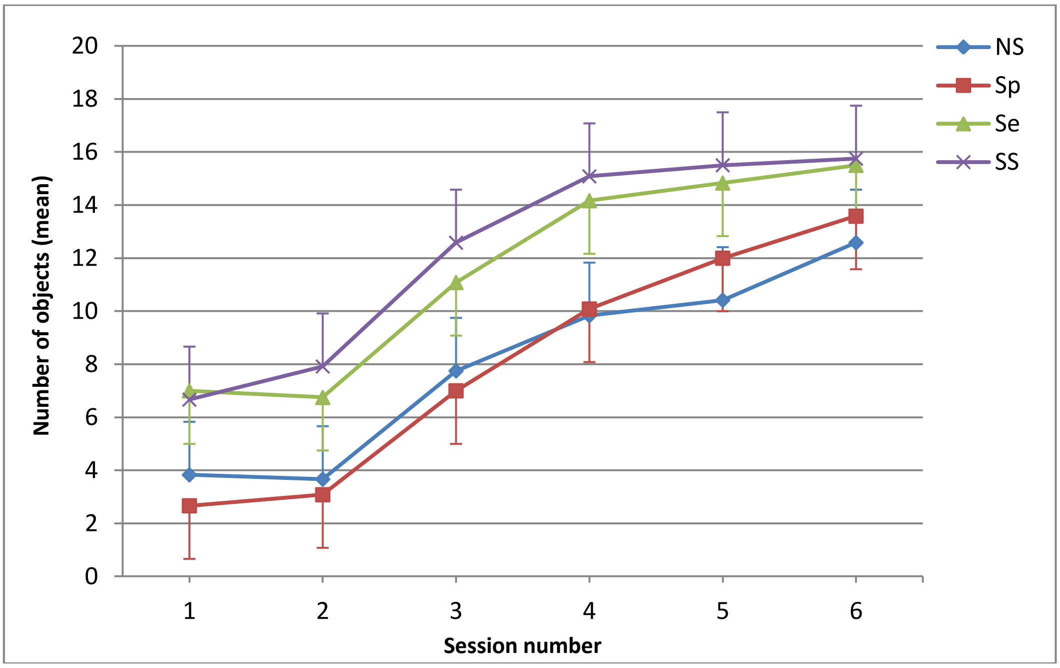


Figure 4.14: Number of objects drawn in each stimulus across six sessions with standard errors. Only one side of the error bar is shown at each session for clarity reasons.

Apart from session 1, where fewer objects than the Se stimulus were drawn, the SS produced more as the sessions progressed. This suggests that across stimuli, the objects in the SS stimulus were the easiest to remember as participants could have used both spatial and semantic properties during learning. The Se is the second easiest type of stimulus for learning as the category labelling of the objects could have proven helpful. The number of objects drawn on the Sp stimulus was slightly lower than the NS in the first half of all the sessions, but increased towards the end of the experiment.

The ANOVA test showed a significant effect for the stimulus type, $F(3,33)=16.23$, $p<.001$ [with no correction for the degrees of freedom using the sphericity assumed ($\varepsilon=1.000$; Mauchly's test for the stimulus type, $\chi^2(5)=9.53, p>.05$)]. This effect suggests that different types of stimuli have an effect on the number of objects drawn, which is consistent with the findings in Figure 4.14. This means that each type of stimulus has a different total number of objects drawn. A comparison of the contrast test between NS and SS showed a significant difference, $F(1,11) =18.62$, $r=0.79$, $p=.001$. A significant difference was also found for the comparison between the Sp and SS, $F(1,11)=25.64$, $r=0.84$, $p<.001$. The comparison between Se and SS, however, was non-significant, $p>.05$. Further, pairwise comparisons for the main effect of stimulus type were significant, $p<.05$ for all stimulus comparisons except between NS and Sp and between Se and SS. These non-significant findings provide additional evidence that these two pairs of stimuli may share some common similarities, namely ease of learning.

A significant main effect is found for the session, $F(1.55,17.10)=103.75$, $p<.001$ [with a correction for the degree of freedom using the Greenhouse-Geisser, ($\varepsilon=0.31$; Mauchly's test for the session, $\chi^2(14)=61.33$, $p<.001$)]. This result signifies that more objects were drawn in later sessions.  Further, a contrast test performed on the session factor showed significant effect, $p<.001$ between successive sessions (i.e. sessions 2-3, $F(1,11)=62.13$, $r=0.92$; sessions 3-4, $F(1,11)=45.37$, $r=0.90$; sessions 4-5, $F(1,11)=29.78$, $r=0.85$; sessions 5-6, $F(1,11)=24.23$, $r=0.83$) except between sessions 1-2, $p>.05$ confirming that more drawings were produced as the sessions progressed. In addition, the pairwise comparison findings for the main effect of the session are significant for all sessions comparisons (11 at $p<.001$, 1 at $p=.001$ and 2 at $p<.05$) except between sessions 1-2. This coincides with the hypothesis that more drawings were produced as the participants did more sessions.

The interaction between stimulus type x session was significant, $F(15,165)=2.09$, $p<.05$ [with no correction for the degree of freedom as the assumption was met, ($\varepsilon=1.000$; Mauchly's test for the interaction between stimulus type x session did not produce results)]. A contrast test for the interaction between the stimulus type x session was again significant for the following: (1) NS and SS between (a) sessions 1-2, $F(1,11)=4.82$, $r=0.55$, $p=.05$; and (b) sessions 5-6, $F(1,11)=18.02$, $r=0.79$, $p=.01$; and (2) Sp and SS between (a) sessions 4-5, $F(1,11)=6.91$, $r=0.62$, $p<.05$; and (b) sessions 5-6, $F(1,11)=14.08$, $r=0.75$, $p<.05$. A marginally significant effect was found for the interaction between Se and SS and sessions 1-2, $F(1,11)=4.57$, $r=0.54$, $p=.056$.

### 4.4.3 Return transition counts

In order to find if the participants were treating divisions as individual categories (e.g. bedroom, kitchen, living room and bathroom for the house scene of the SS stimulus) we performed an analysis by counting the number of the second and subsequent transitions (also referred to as return transitions) that occurred between divisions. Overall, the graph in Figure 4.15 shows the second and subsequent transitions occurring between divisions, referred to as L3b-return transitions between divisions.

The graph shows a percentage of the return transitions count over the number of objects drawn across the session for each stimulus. As can be seen from Figure 4.15, there is a consistent decreasing pattern of the return transitions in an ascending stimulus order of SS > Se (including session 4) > Sp. The decreasing trend of return transitions throws an exception at session 1 for the Sp stimulus, which is the result of fewer objects recalled during this session (see Figure 4.14).

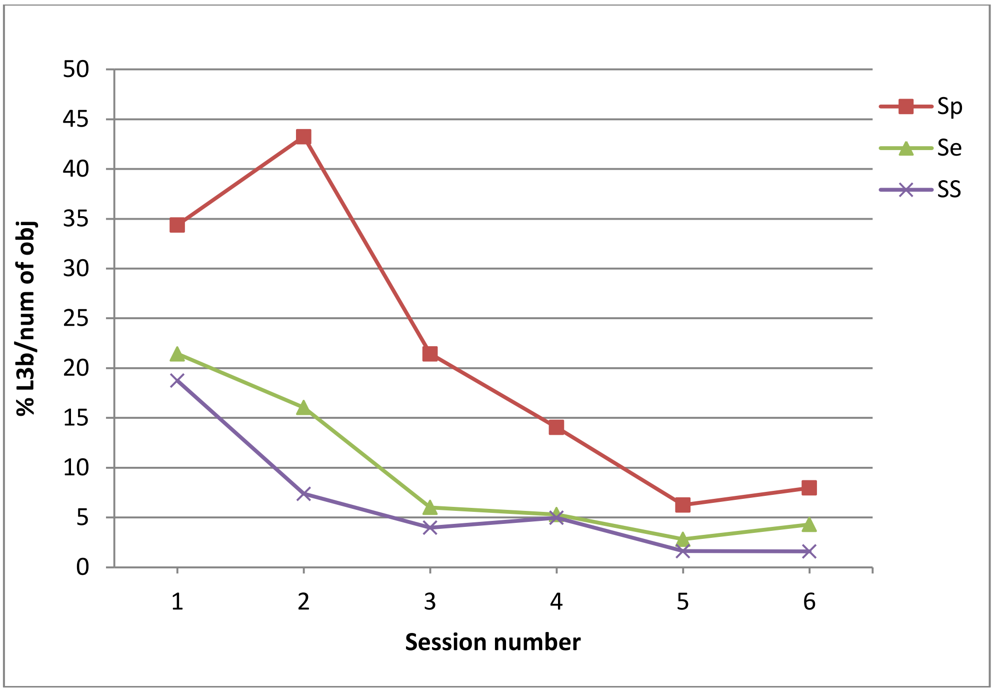



Figure 4.15: L3b return transitions between divisions across stimuli with divisions

The SS stimulus has the lowest percentage of transitions in all sessions, claiming the least return transitions count occurring between the divisions. This result may also suggest that participants could have possibly treated each group as an individual category producing drawings of the objects in each division before drawing more objects in other divisions. In contrast, the Sp stimulus shows the highest percentage of return transitions in all sessions indicating the greatest return transition counts occurring between the divisions. In this case, objects may have been drawn more randomly across divisions. The Se stimulus, which has a lower percentage of L3b return transitions than Sp, demonstrates a percentage closer to that of SS. This suggests some degree of similarity in the processing involved between Se and SS.

The pattern found in the transition between divisions, as shown in Figure 4.15, is similar to that found in previous results from the pauses and number of objects analyses.

The repeated measures ANOVA showed a significant effect for the stimulus type, $F(1.1, 12.2)=7.75$, $p<.05$ [with a correction for the degree of freedom using the Greenhouse-Geisser estimates of sphericity ($\varepsilon=0.55$, Mauchly's test for the stimulus type, $\chi^2(2)=16.3$, $p<.05$)]. This means that the number of return transitions relative to the number of drawn objects is different between the stimuli. Contrast tests revealed a significant effect for stimulus type, $F(1,11)=8.70$, $r=0.66$, $p<.05$ for the comparison between Sp and SS and $F(1,11)=6.06$, $r=0.60$, $p<.05$ for the comparison between Se and SS. The pairwise comparison, however, only showed a significant effect between Sp and SS for the stimulus type factor at $p<.05$. This indicates that comparison between Sp and SS showed a large difference regarding the number of return transitions, relative to the number of drawn objects between these stimuli.

A significant effect, $p<.05$ was also found for the session, $F(2.0, 22.2)=5.17$, $p<.05$ [with a correction for the degree of freedom using the Greenhouse-Geisser estimates of sphericity ($\varepsilon=0.40$, Mauchly's test for the session, $\chi^2(14)=50.5$, $p<.05$)]. This result may signify that the number of return transitions is different across sessions. The contrast tests that showed a largely non-significant effect, except for one comparison between sessions 4 and 5 for the session, $F(1,11)=10.37$, $r=0.70$, $p<.05$ may suggest, however, a dominant significant effect between these sessions, rather than a different number of return transitions across the sessions. The pairwise comparisons between the sessions were all non-significant.

There was no significant effect, $p>.05$ for the interaction between the stimulus type x session, $F(2.9,31.8)=1.86$ [with a correction for the degree of freedom using the Greenhouse-Geisser estimates of sphericity ($\varepsilon=0.29$, Mauchly's test for the stimulus type x session, $\chi^2(54)=113.6$, $p<.05$)]. The contrast test for the interaction between stimulus type x sessions was non-significant.

### 4.4.4 Error rates

In the process of learning, the participants drew incorrect objects during the drawing sessions. This is expected, as interference occurs between stimuli and scenes. Analysing the incorrectly drawn objects may evaluate the speed of learning, or else how efficient learning is when scenes interfere with the stimuli. We will also assess the accuracy of drawings by reporting the number of wrong entries or the error rates from each stimulus.

Errors produced during drawing were either errors of commission or omission. Both could occur in any of the three categories defined below:

1) *Drawing error*: random marks or dots, unrecognizable or incomplete objects drawn by the participant

2) *Other objects*: recognizable objects drawn by the participants, which are not defined in the actual stimulus in the particular scene or in any other scenes. These are objects other than the 64 listed in Table 4.2

3) *Objects from other scenes*: these are recognizable objects that originate from other scenes or other stimulus types, but have been mistakenly drawn on a different type of stimulus.

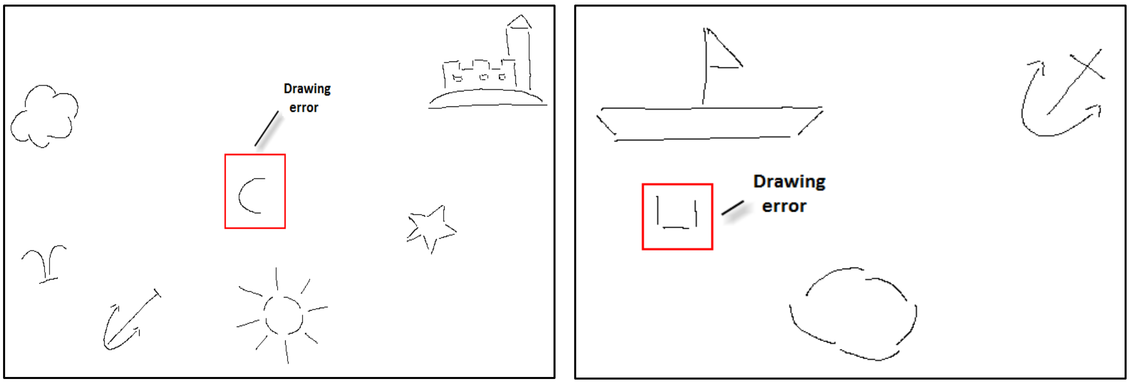
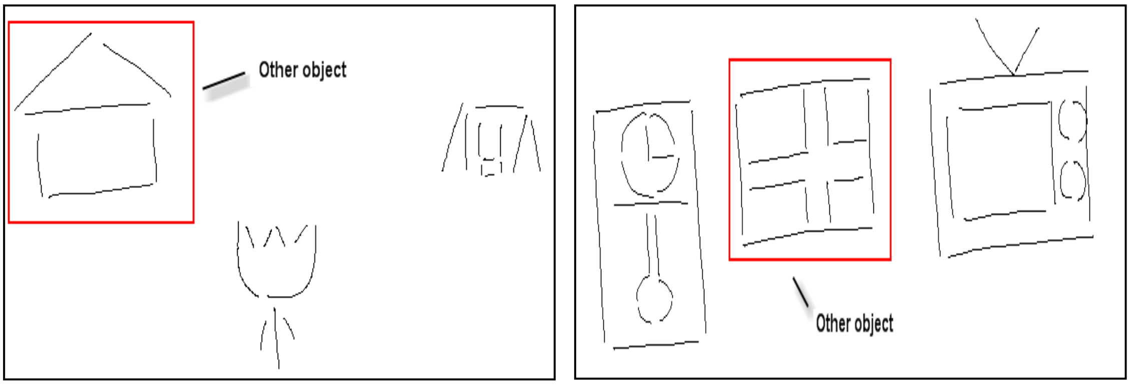
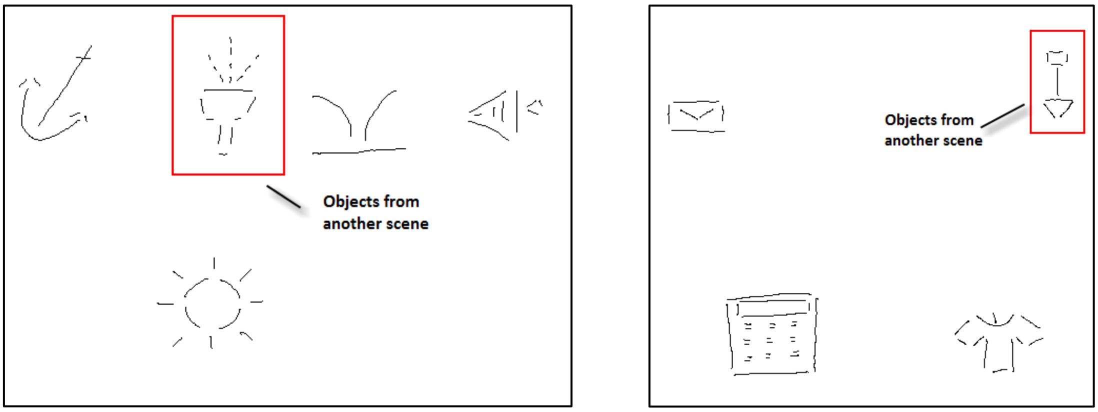



Figure 4.16: Drawing error (e.g. an arbitrary line or incomplete object drawn in the sea scene)




(a) (b)

Figure 4.17: Other object error. (a): a house is drawn amongst the garden objects from the garden scene, (b): the flag does not exist in any of the predefined scenes, but is drawn among the objects from house scene




(a) (b)

Figure 4.18: Objects from other scene error. (a): the fountain from the garden scene is drawn amongst the sea scene objects, (b): the shovel from the garden scene is drawn amongst the shop scene objects.

Examples of these errors are shown in Figure 4.16-Figure 4.18. Figure 4.19 shows the distributions for the three types of the errors discussed. Due to the few errors committed in each stimulus, these were analysed across all participants for each of the four stimuli. The three types of errors are each represented by a set of four stimuli. Note that each set of error type shown in Figure 4.19 is independent of the other sets. These are computed based on the total count of errors across 72 drawings (12 participants x 6 sessions) for each type of stimulus.

**Drawing error:** Consistent with the hypothesis, the greatest number of erroneous objects was drawn in the NS stimulus giving a total number of 17 errors. This is due to various marks produced on the paper in an attempt to draw uncertain objects. The Se stimulus produced a total of 7 errors followed by 4 and 2 errors respectively for the Sp and Se.

**Other object:** The Se stimulus shows the greatest number of incorrect but recognizable objects (24). This suggests that participants could have mistakenly recalled some objects from memory that they were more familiar with their predefined personal schemas based on the labelling cue given on the Se stimulus. The remaining stimuli (i.e. NS, Sp and SS) were almost at the same level in terms of this type of error.

**Objects from other scenes:** There are two bands of stimuli representing higher and lower *objects from other scenes* errors. The NS and Sp had a higher error count as opposed to the lower of the Se and SS. This suggests that the interference of the scenes across stimuli is most likely to occur in the Sp and NS, where participants were potentially confused with the correct objects from a particular stimulus. The lower band of errors represented by Se and SS implies that higher order stimuli, which have properties such as label cueing in the Se stimulus and distinct categorization in the SS, might reduce the occurrence of this type of error. Apart from a few minor instances, the majority of this type of error was produced in the first and second sessions across all stimuli.

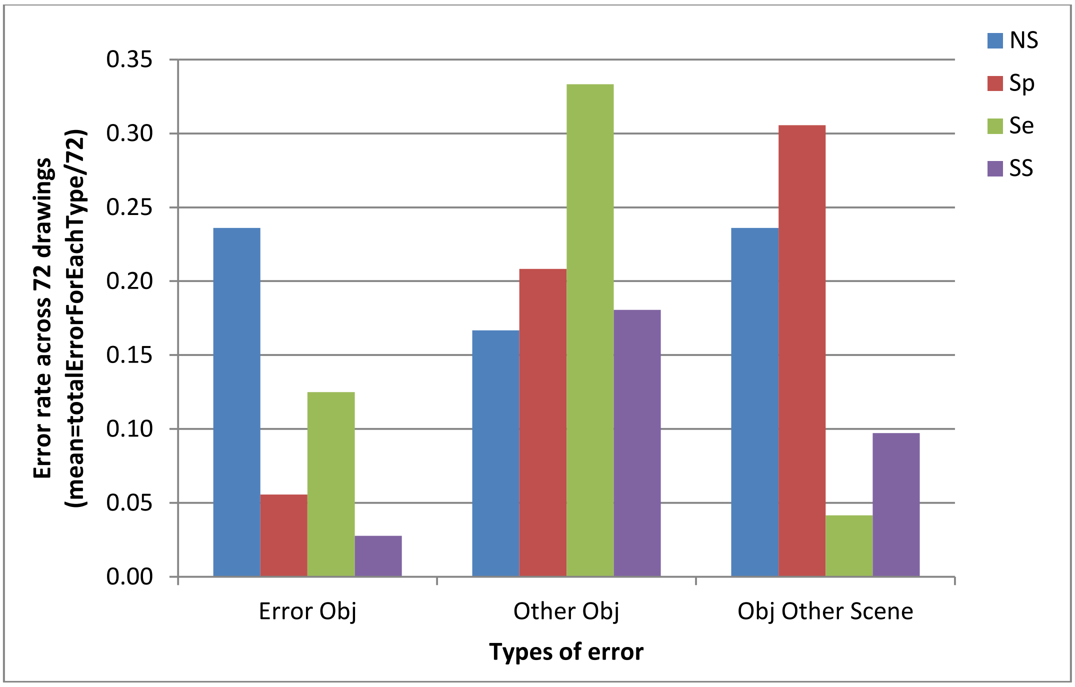



Figure 4.19: Error distribution across all stimuli

Although these findings are inconsistent with the hypothesis that predicted that Sp and Se would have a similar number of errors, the results are generally consistent with the hypothesis that the least errors would occur in the SS stimulus.

As there were very few errors produced across the 72 drawings for all sessions, as shown in Figure 4.19, it was not appropriate to perform a statistical analysis. The observation made on all types of errors across all stimuli, however, revealed that although interference of scenes in the stimuli occurs throughout the sessions (e.g. each participant receives different scenes for each stimulus type), the participants were still able to learn quickly and the accuracy of their drawings reached ceiling levels towards the end of the experiment. Their improved drawing performance from the third session onwards in all stimuli may indicate that knowledge may become structured over time, as processing becomes faster (given that they were not familiar with any of the stimuli before the experiment).

### 4.4.5 Scene analysis

In order to find out if the scenes used in the stimuli were influential in the learning process we analysed them (i.e. house, garden, sea, shop) across each type of stimulus. Figure 4.20 shows the mean distribution of the number of objects drawn in each scene for the respective stimulus. Generally, the graph shows a similar pattern of an increasing number of objects across the stimuli for all types of scenes. Although the house and the sea scene exhibit a trend that potentially gives them off as the most effective type of scenes for learning, the ANOVA showed no significant main effect, $p>.05$ for neither type of scene, nor an interaction effect for the type of scene x session. In other words, none of the scenes and the choices of objects significantly affected learning performance. Therefore, the scene effect on learning performance is trivial as opposed to other findings already discussed, such as pause levels, number of objects, transition counts and error rates. Consistent with the findings from the number of objects measure, however, a significant main effect was found for the session, $F(5,55)=103.75$, $p<.001$ [with a correction for the violation of sphericity (Mauchly's test for session, $\chi^2(14)=61.33$, $p<.001$) using the Greenhouse-Geisser estimates of sphericity ($\varepsilon=0.31$)]. This means that learning improves over successive sessions for all types of scenes.

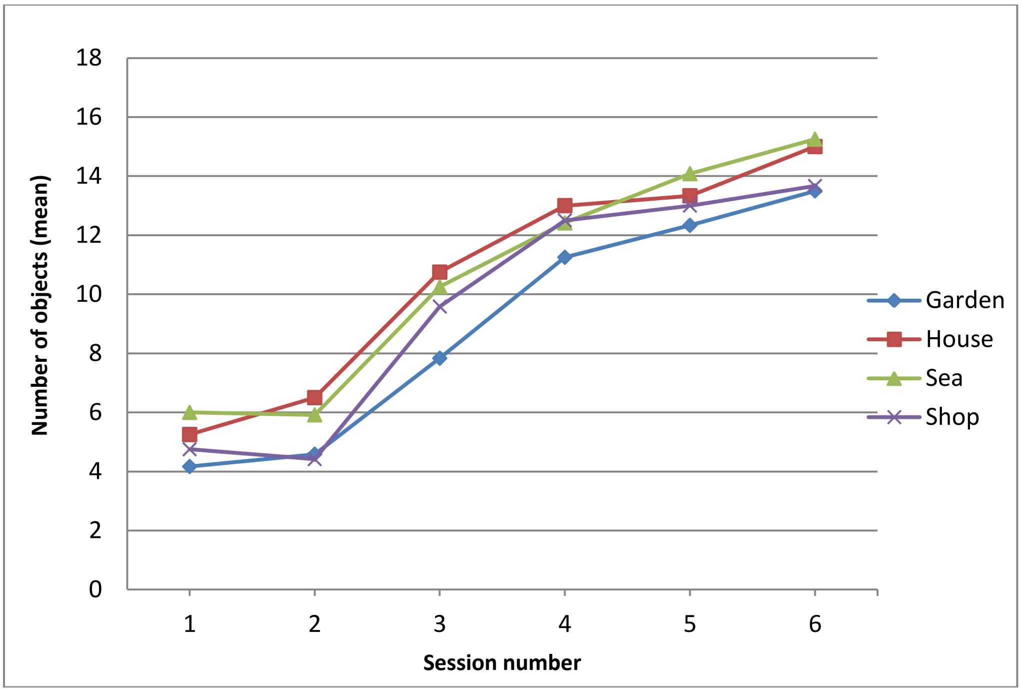



Figure 4.20: Distribution of the total number of objects in each session across the scenes

### 4.4.6 Retrospective verbal reports

A debriefing session was conducted after each participant completed the experiment at the end of session six. The participants were asked a set of general questions and all verbal reports were recorded in written notes by the experimenter. The participants were also asked to rank the stimuli according to their level of difficulty as shown in Table 4.6. The self-reports were consistent with the findings that the majority (at least 7 participants out of the 12) thought that the easiest type of schema for learning was the SS stimulus. By contrast, the most difficult was the NS stimulus. The Se stimulus was considered easier than the Sp.

Table 4.6: Stimuli difficulty levels as rated by the participants

| **Difficulty level** | **NS** | **Sp** | **Se** | **SS** |
|---|---|---|---|---|
| *Easiest* | 0 | 0 | 5 | 7 |
| *Less easy* | 2 | 1 | 5 | 4 |
| *More difficult* | 4 | 6 | 1 | 1 |
| *Most difficult* | 6 | 5 | 1 | 0 |

More detailed questions during the debriefing session revealed that the participants were using strategies for learning. Although these were not described by all, many reported common strategies, such as classifying objects in a category, counting, relating objects to their own personal experience and applying mnemonic methods, such as creating stories (a narrative) by which to remember the objects, as shown in Table 4.7. A few participants mentioned specific strategies used for specific stimuli, such as using counting in stimuli with divisions (e.g. Se), whereas the categorizing strategy was more commonly reported in the SS and NS.

Table 4.7: Types of strategies used by participants during learning

| Stimulus type | Categorization | Counting | Generate & test | Space & location | Narrative |
|---|---|---|---|---|---|
| *NS* | 9 | 3 | 3 | 3 | 1 |
| *Sp* | 4 | 5 | 2 | 5 | 3 |
| *Se* | 2 | 8 | 2 | 2 | 2 |
| *SS* | 9 | 5 | 6 | 0 | 0 |

## 4.5 Discussion

The main aim of this experiment was to investigate the effects of spatial and semantic properties on learning through drawings. More specifically, this study targets the relative contribution of these properties, which might lead to different learning outcomes. It was predicted that a higher stimulus structure would produce better learning. Furthermore, we predicted that learning would take place more efficiently in the following stimulus order: SS > Sp = Se > NS.

In accordance with the overall hypothesis, there is a general effect of improved learning with increasing stimulus structure. Learning becomes easier with more structured stimuli. Thus, across the stimuli, learning is the easiest with the SS and most difficult with the NS. Inconsistent with the prediction, however, the Se stimulus was found to be easier than the Sp. Thus, the experiment showed that the stimulus learning order was in fact: SS > Se > Sp > NS.

The discussion will address the validity of the hypotheses and predictions made in Section 4.4: Hypothesis, based on collective evidence from all measures including pause analysis, number of objects, return transitions between divisions, error rates, scene analysis and retrospective verbal reports. Table 4.8 summarises the results of these measures.

Table 4.8: Summarised results of Experiment 2

<table>
<tr><th>Measures</th><th>NS</th><th>Sp</th><th>Se</th><th>SS</th></tr>
<tr><td rowspan="2">Pauses</td><td colspan="4">L1 < L2</td></tr>
<tr><td>n/a</td><td>pattern not obvious</td><td colspan="2">L2 < L3a < L3b</td></tr>
<tr><td>L1 pause</td><td colspan="4">Over time: constant</td></tr>
<tr><td rowspan="2">L2 pause</td><td colspan="4">Over time: decrease; uniform pattern from session 4</td></tr>
<tr><td colspan="4">SS < Se < Sp < NS</td></tr>
<tr><td rowspan="2">L3a pause</td><td colspan="4">Over time: decrease</td></tr>
<tr><td>n/a</td><td colspan="3">No stimulus effect, only session effect</td></tr>
<tr><td>Number of objects</td><td colspan="4">NS < Sp < Se < SS</td></tr>
<tr><td>Return transition between divisions</td><td>n/a</td><td colspan="3">SS < Se < Sp</td></tr>
<tr><td>Error rates</td><td colspan="4">Few across stimuli</td></tr>
<tr><td>Scene analysis</td><td colspan="4">No scene effect</td></tr>
<tr><td>Verbal reports</td><td colspan="4">Stimuli ratings (easiest to most difficult): SS > Se > Sp > NS</td></tr>
</table>

### 4.5.1 No scene effect

The ANOVA for the types of scenes (i.e. house, sea, garden and shop) used to represent the stimuli did not show significant effects. This analysis, however, did not imply that there is no influence from prior knowledge of these scenes to help with mental schema development during learning. It is expected that the participants will associate the scenes from these stimuli, particularly the SS stimulus, with their existing knowledge. This analysis specifies that no particular scene has greater influence over the others. In other words, no collection of objects from any particular scene was particularly unique in making learning significantly easier than objects from other scenes used in this experiment. Therefore, the effects found in the data are more likely to be due to the structure of the stimuli rather than the types of scenes.

### 4.5.2 Pauses analysis used to access the schema structure

Outcomes from the pause analysis are consistent with previous work that used GPA as a method to probe the nature of learning (Cheng et al., 2001; Cheng & Rojas-Anaya, 2005, 2006, 2007; Cheng & Rojas-Anaya, 2008; van Genuchten & Cheng, 2009, 2010; Obaidellah & Cheng, 2009). Pauses, hence, can be used to evaluate the structure of mental schemas based on learning from the stimuli.

It was found that pause levels were in the order of L1<L2<L3a<L3b across the stimuli, although slight variation of pause pattern occurs for the Sp stimulus. From this finding, the L1 pause, which was not only the lowest but also constant across all sessions and stimuli, indicates that the participants were treating each object as a chunk. Drawing elements within a chunk is less demanding; hence, does not require much internal processing. On the other hand, more time spent on recall between two objects, as indicated by the L2 pauses, would mean that more processing was needed. These results are consistent with Experiment 1 and other similar studies, some of which focus on the drawing of electronic circuit diagrams and the recall of word lists and programming keywords (Buschke, 1976; Egan & Schwartz, 1979; McKeithen et al., 1981). Surprisingly, the return transition between divisions (L3b) pauses occur at higher values than pauses between objects (L2) and the first transition between divisions (L3a) pauses. This suggests that L3b-return transition between divisions pauses were probably important in structuring the hierarchical categorization of the objects.

The significant decrease of L2, L3a and L3b pauses between the first and the last session suggests rapid retrieval, which is then reflected by faster drawing performance as a result of improved learning obtained over time. Generally, in the initial three sessions, which showed higher values for all pauses, objects retrieval may be caused by forgetfulness and confusion. The convergence of the three later sessions (as we will see), however, demonstrated that the participants learned the stimuli adequately. Consequently, this produced faster recall, improving drawing performance.

### 4.5.3 Order of learning: SS > Se > Sp > NS

Consistent with the retrospective verbal reports, it was found that the stimuli were learned in the following ascending order of difficulty: SS > Se > Sp > NS. We will describe this pattern of learning using pause measures, number of objects and error rates across all sessions. Only L2 and L3b pauses will be used, however, as the L1 and L3a were both found to be comparable across all stimuli (see Summary table). Overall, all considered measures supported the aforementioned order of learning.

The learning pattern can be initially observed from the L2 pause, which indicates that recall between two objects was the shortest for the most structured type of stimulus (i.e. SS) and the longest for the least structured stimulus (i.e. NS). Surprisingly, unlike our predictions, longer L2 pauses occur for the Sp rather than the Se stimulus suggesting that the Sp stimulus was more difficult to learn. The reason could be because the objects from this stimulus may not have been activated in the memory during retrieval. Longer time is, hence, needed during retrieval to search mentally for the relevant objects in the respective divisions. Confusion and uncertainty over the objects' positioning may also contribute to this effect. On the contrary, the collection of objects shown on the scenes for the SS stimulus may have received greater activation in the memory during drawing. This increases the likelihood of their faster retrieval. Similarly, the category labels on the Se may have provided better cues for greater activation of the associated category members.

As for the L3b pauses, a similar pattern is found, as the SS stimulus required the least time for return transitions to the previously visited division. Again, more time was needed for the Sp than the Se, which indicates that this type of stimulus is more difficult to learn. The explanation from the L2 pauses above is also applicable for the pattern of L3b pauses, where it can be argued that more time is needed to produce a transition to a revisited division if the relevant objects have weaker activation in the long-term memory. This may be likely to occur in the Sp stimulus. By contrast, faster transition to a revisited division is probable if objects remained activated during retrieval, as for the Se stimulus. The fastest transition would occur for the SS stimulus, as objects were the most activated across the experiment.

The greatest number of objects produced for the SS stimulus may be an effect of the presence of both spatial and semantic information on the stimulus, which provide better cues that become the source of strong mental activation due to priming. This produces more structured encoding and easier retrieval, thus facilitating learning. In effect, it increases memory performance as it provides more organized information to the memory. It may well be that prior knowledge for a particular scene influences the activation of the relevant objects, as one familiar object may prime the others, which are most consistent with the scene. Therefore, this enables faster retrieval of a larger number of objects. By contrast, the presence of only semantic information based on category labels produced fewer objects, as shown by the Se stimulus. The consistent category labels paired with the objects, however, provided better cues; hence, greater object activation and easier retrieval than the NS and Sp. Although the object counts were small, more objects drawn in the NS stimulus, as compared to the Sp stimulus in the first three sessions, indicates that these stimuli may have been treated similarly in terms of the mental structures involved in remembering them. Furthermore, the absence of restrictions in positioning the objects for drawing in the NS stimulus may have been another contributing factor. By contrast, the more objects produced in the Sp stimulus than the NS in the remaining three sessions may indicate the improved use of spatial location as a strategy to memorise the objects. In other words, the participants could have progressively used the divisions shown on the Sp stimulus, as shown by the fewer return transitions between the divisions on Figure 4.15. This strategy has, thus, improved the encoding of mental structures, which become more structured over time.

Palmer (1975), Mandler and Robinson (1978), Mandler and Ritchey (1988) reported that recognition of objects in an unorganized scene is more difficult than recognition of objects in an organized scene. This is because meaningful relationships between the objects are less obvious in the unorganized scene, thereby resulting in less effective cues for the activation of the necessary stimuli. This finding is similar to ours, where the objects from the NS and Sp, both with no labels, are the most difficult to learn, as opposed to objects from Se and SS, which have more meaningful categorical and spatial location cues, such as semantic and spatial information.

Although the SS stimulus produced the fewest errors, the general findings from the error rates are not consistent with the predictions, as their pattern varies according to the types of errors produced. The NS produced the greatest number of drawing errors, while the Se exhibited the most commission objects, potentially derived from idiosyncratic schematic knowledge due to interference. Both NS and Sp produced a greater number of objects from other stimuli due to confusion. The total amount of errors across the 72 drawings (6 sessions x 12 participants) for all participants was few. Thus, the low error count for all stimuli indicates that the participants achieved ceiling level learning quite rapidly.

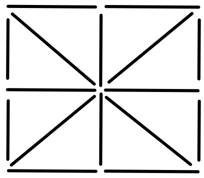
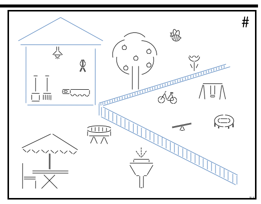
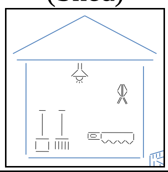
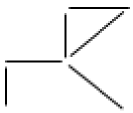
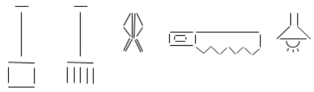
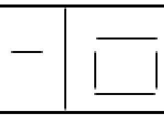
Although the participants were expected to progress sufficiently with learning, they were not expected to remember all presented objects. It is rather surprising, however, that these participants demonstrated rapid learning that reached ceiling level, in which they remembered almost all of the objects, at least for Se and SS, by the fourth session. Learning rates for both Sp and NS was also remarkable given that these stimuli were considered difficult.

### 4.5.4 Hierarchical representation

As we have described earlier in this chapter, the pauses can be used to access the underlying structure of mental representations. Findings from the pause analysis are consistent with the expected time used to retrieve the information at different levels of the proposed hierarchical structure, as shown in Figure 4.4 (see Prediction 1 of Section 4.4: Hypothesis for description). For example, at the second highest level (below the whole stimulus level) for the SS, each section may be divided on the basis of spatial location and semantic category (e.g. underwater objects for the sea scene), while similarly for the Sp, each section may be represented by the four distinct divisions. Equally, four category labels may represent the divisions for the Se. As no specific divisions are given for the NS, however, objects may not have been separated at either regional or categorical levels. On the contrary, they all may have been considered as one large chunk.

If the participant achieves retrieval according to the strategy proposed in Figure 4.4, this approach further confirms Buschke's (1976) findings that retrieval in free recall learning is organized. In a different experiment, Reitman and Rueter (1980) and McKeithen et al. (1981) further found that the organization of internal representations employs a hierarchical scheme. This hierarchical structure organizes groups of information on many levels, which are referred to as *structural units* or *chunks* (Palmer, 1977; Cheng & Rojas-Anaya, 2008). Two possible approaches to traverse the hierarchy network are depth-first-search or breadth-first-search (Palmer, 1977). In this experiment, participants are more likely to recall the information in a top-down strategy manner (e.g. depth-first-search), where higher levels of the hierarchy cue the object classification (e.g. division 1: shed, division 2: garden) and lower levels integrate semantically related objects (e.g. shovel, fork, shears, saw, lamp). This supports the findings from McLean and Gregg (1967) and Cheng and Rojas-Anaya (2008), who also confirmed Palmer's (1977) hypothesis that stimuli are used to integrate chunks into hierarchical networks. Considering a stimulus of simple grids, Palmer proposes that three levels of hierarchy represent the mental schemas in the order of (1) whole figure, (2) multi-segment parts, (3) individual line segments. With the more complex stimuli, however, used in the present experiment, we further propose that the stimuli with divisions produce four levels of mental structure in the order of (1) whole stimulus, (2) regions, (3) objects from each division, (4) lines for each object. The NS may produce three levels, potentially without the separation at the division level, thus taking the order of (1) whole stimulus, (2) object, (3) lines for each object. Hence, all objects may be recalled in a single large chunk in the NS stimulus. This could contribute to a more difficult retrieval for this type of stimulus, as cues are far less facilitated compared to the others. The comparison of our findings (for stimuli with divisions) with Palmer's is summarised in Table 4.9.

Table 4.9: Example from Palmer (1977) and Experiment 2

| Level | Palmer's hypothesis | Palmer's Example | Findings from Exp 2 | Experiment 2 Example |
|---|---|---|---|---|
| 1 | *Whole figure* |  | *Whole stimulus* |  |
| 2 | *n/a* | n/a | *Category/ division* | (Shed)  |
| 3 | *Multisegment parts* |  | *Objects* |  |
| 4 | *Individual line segments* |  | *Lines to form objects* |  |

It may well be that participants also employed the breadth-first-strategy at times when objects from a stimulus were forgotten to be drawn. Thus, searching for these objects across the divisions (or categories) may necessitate the use of this type of strategy. This is consistent with the findings from Experiment 1.

Another finding that supports the potential use of hierarchical format to represent the information is the measure from the return transition between the divisions. This measure determines whether the divisions are influential with learning, such as the likelihood of the participants performing frequent transitions between the divisions during the drawings. These transitions imply that they were likely to choose and group certain objects from different divisions based on idiosyncratic grouping preferences, hence producing a greater count of smaller chunks. Conversely, fewer transitions between the divisions indicate that the participants have a preference for drawing the objects in their own division (e.g. treating these objects as a bigger chunk), suggesting that they account for more organized internal representation. Semantic relatedness among the objects that share common characteristics or functions, such as the use of categorization, might be a cause for objects from different divisions to be considered as a chunk (see Prediction 3, Section 4.4: Hypothesis). This is a reasonable explanation, as this strategy facilitates the retrieval process.

Across the stimuli, few return transitions for both SS and Se may indicate the successful use of their respective structure. The fewer return transitions that occurred for the SS, however, suggest that in the highest structure stimulus, the participants had a preference for drawing groups of objects as a more coherent whole before drawing objects in other divisions (or categories). Although the Se stimulus has labels representing categories for the groups of objects, the participants seemed to treat parts of the entire category as smaller chunks. This is demonstrated by more return transitions occurring between categories for the Se stimulus than for the SS. This is also the case with Sp, where even more return transitions occur across the sessions consistent with predominantly higher L3b pauses. Therefore, more return transitions between divisions for the Sp may suggest that objects were remembered in groups of smaller chunks, thereby implying that some form of semantic categorization was used among the objects that override the divisional partitions shown in the stimulus. This shows that the participants could have generated an idiosyncratic conceptual schema during learning to aid retrieval at the time of reproduction. This is further supported by verbal evidence, where a few of the participants mentioned that they associated certain objects with their own previous experiences or developed their own sets of categorization to aid learning for the Sp stimulus. Nevertheless, the decreasing number of return transitions may further indicate that the divisions in the Sp stimulus could have been successfully used from session 3 onwards (see Figure 4.15).

Pollio et al. (1969) proposed that structured materials are organized hierarchically, which potentially facilitates encoding and retrieval in terms of speed and easier access of information. Based on the results already discussed, the SS confirms this finding. Tulving and Pearlstone (1966) suggested that categorical names are effective retrieval cues for which Broadbent (1971) further proposed that the properties of a category are recalled before the category members. This confirms our claim that the second highest level of the hierarchy for the Se and SS consists of category names, such as bedroom and kitchen and that it may well be that a participant will first recall these category names before their constituent objects. It also appears reasonable that this type of organized retrieval strategy enables objects from the same category to be recalled together, thus producing faster recall of objects from the same category, than from different categories. This finding is consistent with that reported by Cutting and Schatz (1976).

### 4.5.5 Why learning was easiest for SS, progressively difficult towards NS?

Thomson and Tulving (1970) and Bäuml (1998) proposed that strong stimuli would enhance memory performance more than weak stimuli, due to their provision of more effective cues for encoding and recoding. Based on the stimuli used in this experiment, SS and Se may be regarded as the strong stimuli, while Sp and NS as the weak.

The SS and Se are considered as strong stimuli as they not only provided better but also more facilitating cues, such as strong categorical and spatial relationships among objects. These cues induced strong activation in the memory for encoding, thus producing easier retrieval. This resulted in better learning, as shown by the findings across the sessions based on the greater number of objects drawn, decreasing pauses, fewer errors and return transitions between divisions, as well as by verbal reports.

On the other hand, the NS and Sp were regarded as weak stimuli due to fewer cues for NS and potentially weaker cues for Sp, resulting in weaker activation of the relevant objects in the memory and hampered retrieval. Poorer learning was demonstrated by the less obvious pause pattern for Sp, higher pause values, fewer objects drawn, higher transitions between divisions, as well as by verbal reports.

Comparing the SS and Se, the former may have provided more facilitating cues as it consists of both semantic and spatial information, while the latter only of semantic. Furthermore, prior knowledge of the scenes may be helpful during learning, on account of the presence of high frequency category items. Our findings from Se are consistent with those reported by previous investigators (Bousfield, 1953; Bower et al., 1969; Collins & Quillian, 1969; Pollio et al., 1969), where consistent categorical names and their constituent items enable a greater rate of retrieval due to facilitating cues.

As for the SS being the easiest form of learning, if participants did not rely on the use of spatial and semantic properties, another possible explanation would be meta-memory (knowledge about an individual’s own memory). Using this method, the participants almost automatically know the types of objects that normally exist in familiar scenes, based on their existing knowledge of the world. Relying on their own feeling of knowing or the degree of familiarity with the scenes, they are able to judge whether or not a lot of cognitive effort is needed for the process of learning. The more familiar they are with a particular scene, due to increased knowledge, the easier it is for them to identify a meaningful association between the objects.

Although the Se and Sp were predicted to produce an equal learning performance, the findings showed that the Se stimulus was easier than the Sp. This could imply that meaning has a more influential role than spatial information. It is important to note, however, that the Se and Sp were not designed to enable a fair comparison. This is because the Se stimulus can be regarded as a strong type of stimulus due to the consistent correspondence of category names with items. The Sp stimulus, on the other hand, may be regarded as a weak type of stimulus due to its unfamiliar design (i.e. unconventional divisions presentation). Therefore, Sp may invoke a less structured mental organization, as demonstrated by the greater L3a and L3b transitions between divisions, than the more structured organization of Se, as shown by the fewer transitions between divisions.

The potentially less structured mental organization of the Sp has led us to compare it with the NS. It may be that these two stimuli were treated similarly during the initial stages of learning. This can be observed by the fewer objects (Figure 4.14) and higher L2 pause values (Figure 4.11) in sessions 1 and 2, where these measures do not show any difference between these stimuli. This means that the participants were possibly ignoring the spatial properties, such as the four divisions given on the Sp. Differences between these stimuli, however, became apparent, as shown by the lower L2 pauses and greater number of objects, from session 4 onwards indicating a more successful use of the spatial information in the Sp over the NS.

In order to learn effectively, the participants employed certain useful strategies, as those shown in Table 4.7. For example, consistent with the other findings for the SS, the participants commonly employed the categorizing method, which associates objects with the given divisions. This strengthens the evidence that categorical membership has a significant role in learning the SS. Counting, however, was a more preferred method for the Se, at least for 8 people. This is surprising, as we would expect them to use a similar method (i.e. categorizing) to the SS. Nevertheless, this may be due to the design of the Se, which is akin to a tabular format that makes the number of items along each row more salient, thus encouraging the use of the counting method. Note that this explanation is speculative.

As for the Sp, the participants also preferred to use the counting method alongside their consideration of the space and location of the objects. Examples of the reported remarks on using spatial information include: “I tend to focus on symbols (objects) at specific locations,” and “I tried to associate items (objects) in space with each other.” Again, these strategies are consistent with those previously discussed for the Sp. Furthermore, the counting strategy (i.e. 3, 4, 4 and 5) in each division, which was easily spotted at the second session, revealed that the number of objects in each division were of a less successful design. This will be improved in the following experiment. Interestingly, the categorizing method was also commonly preferred over the others for the NS stimulus. It may well be that when no cues are visually given in the stimulus, participants are prone to use idiosyncratic categorizing.

These results agree with similar findings by  Flavell (1970), Dirks and Neisser (1977), Mandler and Robinson (1978) and Mandler and Ritchey (1988), which report that mnemonic strategies facilitate learning and retrieval. Furthermore, Mandler and Johnson (1977) argued that mnemonic strategies, such as using verbal materials involving the use of stories, have a tendency to facilitate encoding. In a later study, Mandler (1983) claimed that memory for scenes are similar between adults and children. Dirks and Neisser (1977) found that older children were able to remember more objects because they have mastered the use of a variety of mnemonic strategies, such as category organization, association and rehearsal. As described above, these effects were largely present in this study.

## 4.6 Conclusion

In this experiment, we have considered the use of semantic and spatial information in learning through graphical materials. Although we have identified the effect of different levels of stimulus structure, which determine the level of learning, we have not been able, with the present data, to distinguish between the effect to learning that derives from the different levels of stimulus strength (i.e. weak or strong, with semantic or spatial properties). As discussed, it may well be that the Sp stimulus used in this experiment is a weak type of stimulus, due to the random positioning of the unrelated objects across the unconventional divisions, which potentially provide limited cues for encoding and retrieval. On the other hand, the Se stimulus could have been considered as a strong type of stimulus, due to the strong association between the meaningful categories represented by the labels (e.g. bathroom), which, in turn, provide strong associations between the objects themselves (e.g. bath tub, toilet and wash basin). In the present experiment, however, each of the Sp and Se stimuli only demonstrated one level of stimulus strength, either weak or strong.

The design of the stimuli used in this experiment did not provide sufficient evidence for the investigation of the effects of learning under different levels of stimulus strength. Therefore, it would be interesting to investigate further these levels for both types of Se and Sp stimuli (weak and strong) in order to verify the present findings. A possible approach is to manipulate the level of stimulus complexity, such as divisions, and semantic and spatial information, to enable the assessment of the different stimuli strengths. This will be considered in more detail in the following experiment.

# Chapter 5 Experiment 3: The effects of spatial and semantic schemas of different strengths in learning

*I have learned that what I have not drawn I have never really seen,*
*and that when I start drawing an ordinary thing, I realize how extraordinary it is, sheer miracle*
*(Frederick Franck, The Zen of Seeing)*

## 5.1 Introduction

Findings from Experiment 2 suggest that learning using different types of stimulus presentation is influenced by the presence of some degree of spatial configuration and semantic information. The findings, however, did not indicate the effects of learning using spatial and semantic information of different levels of strength. Moreover, the participants' adopted learning strategies were not investigated in detail. These limitations serve as the basis of the experiment discussed in this chapter.

In Experiment 2, we investigated how semantic and/or spatial relations between objects in the different stimulus layouts are encoded in memory. The extent to which, however, the strength of semantic properties and spatial configurations facilitate learning was unclear. This is because the data and results obtained from the previous experiment were not sufficient for this evaluation. Therefore, the principal goal in the present experiment is to test whether the learning rate varies between different levels of strength (i.e. weak vs strong). The types of stimuli presentation that will be applied in this experiment are the semantic and spatial stimuli adopted from Experiment 2.

Similar to Experiment 2, Experiment 3 aims to induce the predicted mental *schema structure* from the *stimulus structure*. The *stimulus structure* refers to the divisions presented in the material, while the *schema structure* to the mental schema in the minds of the participants. It is known (particularly in semantic memory research that strong stimuli, such as organised information, are perceived and encoded into the strong schema structure in the mind (Collins & Quillian, 1969, 1970; Tulving, 1972). This facilitates retrieval, which in turn, produces better learning. Strong stimuli presentation commonly provides better and more cues, inducing a higher activation from the memory (i.e. employs high strength connected paths with greater weight). This also promotes easier retrieval. On the contrary, the opposite applies to weak stimuli, which produce more difficult recall due to the lower activation of information searching in the mind resulting from the weak schema structure. This leads to poor learning rates.

### 5.1.1 Experiment related literature review

Smith (1978) made a distinction between semantic theories, in that relations between categories could either be computed (Smith, Shoben, & Rips, 1974) or "prestored" (Glass & Holyoak, 1975). Anderson (1983) further argued that propositional representations are more useful in presenting semantic knowledge, rather than spatial configurations. None of this research, however, specified whether the different level of semantic cues affects learning performance.

Various tasks have been employed in the study of spatial representation that provide information on spatial cognition and spatial behaviour. Among the most common empirical tasks were distance estimation, orientation judgements, map drawing and navigation. These tasks, however, furnish a limited explanation for the structure and content of spatial information in the memory. In order to assess the properties of mental representation more accurately, Siegel (1981) proposed that experimental tasks involving spatial representation should minimize performance demands. McNamara, Ratcliff and McKoon (1984) employed priming in spatial memory tasks that met this requirement, in order to test knowledge about maps. The experiment reported in this chapter also uses a similar method (i.e.: priming) with drawing tasks. According to McNamara (1992), priming from memory is a suitable type of task for the study of mental representation, as it is automatic; hence, informative about what types of knowledge are encoded and how knowledge is organized in the memory.

McNamara et al. (1984) performed an experiment in which participants learned the locations of objects spatially placed in four regions. Two groups of subjects identified the location of objects by using either maps or by navigating in a spatial layout where regions were divided by transparent boundaries so that the participants would encode spatial relations hierarchically. The participants later performed three tasks: recognition of object names (spatial priming task), judgement on the direction between objects and *Euclidean* distance estimation. The experiment reported in this chapter differs in that it has opaque boundaries in its spatial layout. The aim is to investigate whether a similar effect is present in tasks related to drawings. McNamara, Halpin, and Hardy (1992) later performed an experiment that integrated spatial and non-spatial information (e.g. facts about the stimulus – for instance, a building's location) with the aim to investigate whether the non-spatial cues (akin to semantic information as defined in this experiment) are integrated in the memory. They found that priming was faster when cued by facts from close proximity objects than recalled from distant buildings.

To date (to the author's knowledge), no research has studied whether the spatial configuration or the semantic content has a stronger influence on learning. If one type of stimulus presentation, whether spatial or semantic, facilitates learning better than others, we are further motivated to investigate if the degree of difficulty of the stimulus also has a role in learning performance. Therefore, in this study, we divide each type of stimulus presentation into two levels, referred to as ‘strong’ and ‘weak’. We define strong stimuli as the type of stimulus structures that provides strong cues, which are effective in facilitating encoding and retrieval during learning. Conversely, the weak stimuli provide less accessible cues that are less effective for learning. This means that the configuration of encoding in the stimuli presentation that has strong cues is more structured in comparison to the less structured encoding configuration in stimuli presentation with weaker cues. In an experiment performed by Thomson and Tulving (1970), it was found that lists of words-to-be-remembered according to pairs of strong or weak cues were more easily recalled when there was a strong association between the words; hence, providing stronger cues for encoding and retrieval. Similarly, Gattis (2001) and Tversky (2001) emphasized that learning spatial-related information could be facilitated by its presentation in a tabular format that consist of rows and columns.

The encoding and retrieval process during learning is related to how information is internally organized in the memory. Previous investigators found evidence that spatial memories are hierarchically organized (Stevens & Coupe, 1978; Tversky, 1981). This finding is supported in tasks related to the memorisation of names of objects in various map layouts (Hirtle & Jonides, 1985; McNamara et al., 1989). The hierarchical encoding of spatial relations gives clues about the organization of clusters of information in the memory. Based on recall protocols, the hierarchical organization, or trees, specifies clusters and sub-clusters of recalled information upon which object names are recalled. Although this finding has been established in tasks such as memorizing programming keywords (Reitman & Rueter, 1980), no experiment fully involves drawings. It will be interesting to find out whether similar hierarchical organization applies to the natural and simplistic drawing of objects. This serves as our second motivation for this study. Questions that interest us include how did the participants organize the execution of their drawings and whether clusters and sub-clusters of graphical information (referred to as chunks and sub-chunks in this experiment) are retrieved in a consistent manner over time.

### 5.1.2 Definition of experimental terms

The section introduces the common terms used in this experiment, which are *stimuli*, *task types* and *pause measurement*.

#### 5.1.2.1 Stimuli

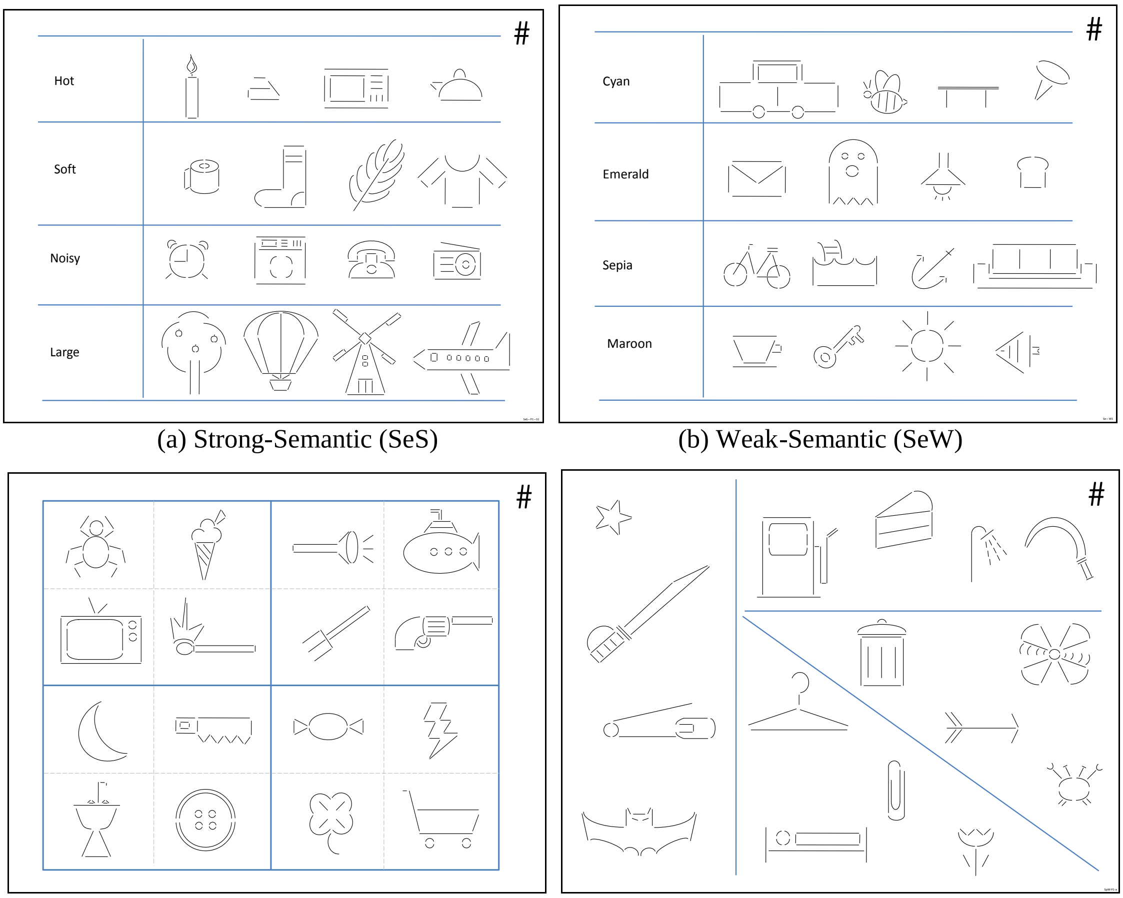
The three stimuli used in this experiment were adopted from the Semantic (Se) and Spatial (Sp) stimuli of Experiment 2. Semantic stimuli have labels representing categories, while Spatial stimuli use spatial layouts to organize information. These Semantic and Spatial stimuli are each divided into two types according to strength (i.e. weak and strong). Therefore, the four stimuli used in this experiment are: (1) *Strong-Semantic (SeS)*, (2) *Weak-Semantic (SeW)*, (3) *Strong-Spatial (SpS)* and (4) *Weak-Spatial (SpW)*. They are described below.

1) **Strong-Semantic stimulus** (SeS): Figure 5.1(a) shows an example of the Strong-Semantic stimulus. This presentation adopts the tabular format and contains four rows, each of which represents a category of meaningful labels (i.e. hot, soft, large and noisy) that is consistent with all its constituent objects (e.g. alarm clock and washing machine for the 'noisy' category). The SeS stimulus is characterised by a strong association between the individual objects and the corresponding category label. The label 'hot' for instance, gives a strong cue for the constituent 'hot' objects that have the same properties. There are four objects in each row. The position of rows and their respective objects is not fixed and can change in each drawing session for all participants. The objects, however, are always associated with the same label.

2) **Weak-Semantic stimulus** (SeW): Figure 5.1(b) shows an example of the Weak-Semantic stimulus, which adopts the same tabular format as the SeS. The labels in the SeW stimulus, however, are selected from a range of uncommon colours (i.e. maroon, cyan, emerald and sepia). Each colour label in each row contains four arbitrary objects, which it does not have a strong association to. This type of stimulus presentation, therefore, is characterised by a weak association between the objects and their colour label. For instance, the category label 'maroon' on its own (without the intervention of other learning strategies) may not have a strong semantic association with its objects. Therefore, each colour label category does not necessarily represent attributes consistent with the respective objects (e.g. bread and ghost for the 'emerald' category). The order of the rows and objects for the colour label changes in each drawing session, but the objects associated with each colour label remain the same.

3) **Strong-Spatial stimulus** (SpS): Figure 5.1(c) shows an example of the Strong-Spatial stimulus, whose layout consists of four large boxes each constituted of four smaller boxes. This type of stimulus presentation adopts a tabular format that consists of rows and columns. The large box is outlined by bold lines and has a more salient appearance than the smaller boxes within, which are divided by dashed lines that form grids. The objects in the boxes must not be semantically related so as to reduce the participants' reliance on semantic associations. For this reason, four random objects were selected for each large box. The position of these objects does not change in each cell. This type of stimulus presentation, hence, has a fixed hierarchical structure. Each participant is shown the same SpS stimulus presentation in every session.

4) **Weak-Spatial stimulus** (SpW): Figure 5.1(d) shows an example of the Weak-Spatial stimulus. This stimulus presentation corresponds to the Spatial (Sp) stimulus used in Experiment 2. There are four divisions arranged in an unconventional layout. Each division has four random objects, which remain as a group for each division. The position of the objects in each division, however, is randomised in each session, thus producing weak groupings of objects within each area.




(a) Strong-Semantic (SeS) (b) Weak-Semantic (SeW)

(c) Strong- Spatial (SpS) (d) Weak-Spatial (SpW)

Figure 5.1: Example of strong and weak stimuli

### 5.1.2.2 Task types

As in Experiment 2, this experiment uses the *Recall from memory* and *Copying* drawing tasks in a total of four sessions. The motivation behind using these tasks is similar to that described in Section 4.1.2.2: Task types (see Chapter 4).

#### 5.1.2.3 Pause measurement

Similar to the measures used in Experiment 2, this experiment also uses pause duration to reveal how drawings are processed. This indicates the amount of processing involved at different stages of the drawing as described below. A *pause* is defined as the time between the pen coming off the paper at the end point of one stroke and the pen landing on the paper again at the beginning point of the next stroke. Consistent with the pause levels definition from Experiment 2, the three pause levels (see Figure 5.2) for this experiment are defined as follows:

1) **L1-within-object pause**: Pauses between two successive strokes of an object are calculated from the time between the end point of the last drawn line and the following start point of the next line of the same object.

2) **L2-between-objects pause**: Pauses between two different objects are calculated from the time between the end point of the last drawn line of an object and the first point of the first drawn line of the following object.

3) **L3a-first transition between divisions**: Pauses for the first transition occurring between the divisions are calculated between the time that lapses between a current division to the first visit of the subsequent division. The pauses are measured between the end point of the last drawn line of an object in the current division and the first point of the first drawn line of an object in the first visited division.

   **(L3b-return transition between divisions**: Compared to Experiment 2, there are no L3b measures reported in this experiment. The small number of L3b return transitions data rendered such an analysis not meaningful.)

It is worth noting that any returns to the previously drawn but incomplete object are calculated as L2-pauses. Second and subsequent lines for this return to the previously drawn but incomplete object, however, are defined as L1-pauses. These return transitions are also shown in Figure 5.2.

Compared to Experiment 2, the experiment reported in this chapter incorporates a brief study time of 15 seconds. This allows some time for the participants to learn the stimulus but not enough to enable them to develop a sophisticated learning strategy. Furthermore, a pilot study with 30 seconds of study time showed that the participants quickly reached ceiling level learning performance, as early as the second session. 15 seconds, however, is enough for the participants merely to recognize the types of objects that exist in each division.

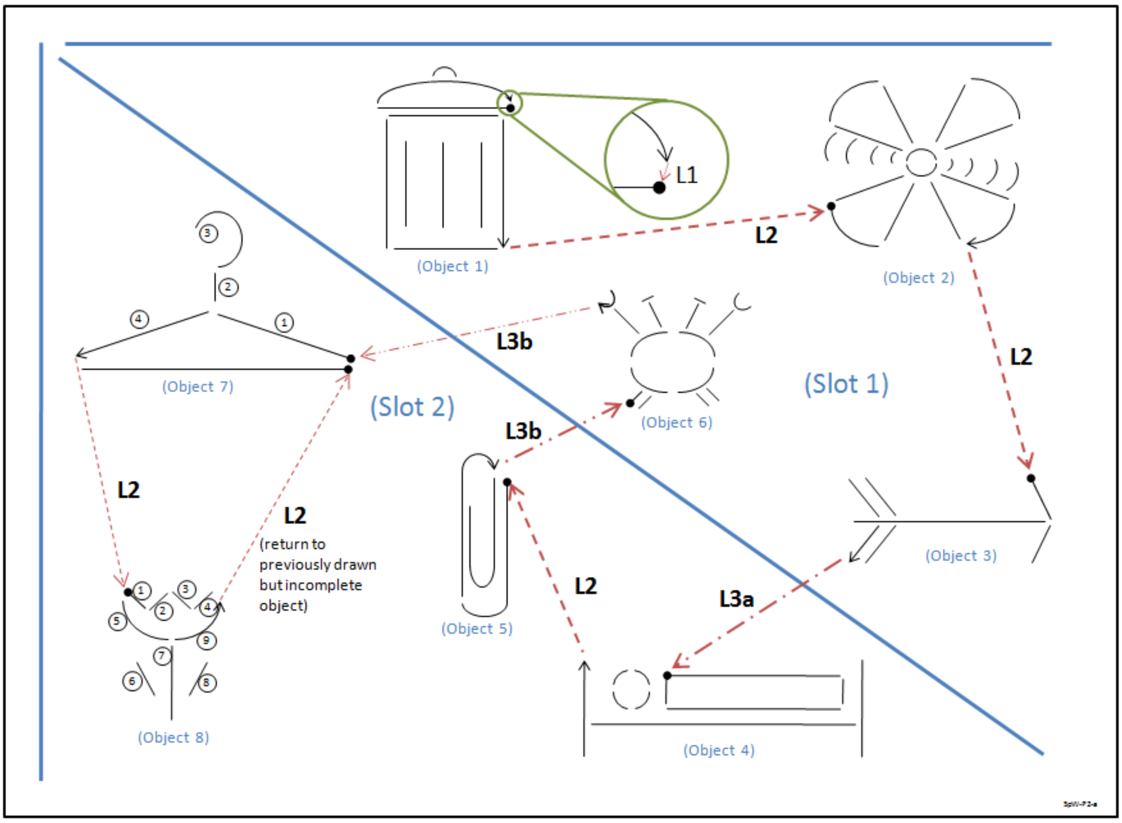



Figure 5.2: Examples of L1, L2, L3a and L3b pause levels between the objects using the divisions from the Weak-Spatial (SpW) stimulus

## 5.2 Hypothesis

We predicted that the strong stimuli (i.e. SeS and SpS) allow easier learning than the weak stimuli (i.e. SeW and SpW). Therefore, the SeS stimulus is predicted to be as easy as the SpS stimulus, while the SeW stimulus as difficult as the SpW stimulus. In addition, the SeS stimulus is predicted to be easier than the SeW stimulus. The same is predicted for the Spatial-stimuli (i.e. SpS > SpW).

The strong stimuli are predicted to facilitate learning more because they contain strong cues, such as a meaningful label relative to its contents in the case of the SeS stimulus and the position of the objects at specific locations in the SpS stimulus. On the other hand, the weak stimuli contain weaker cues; hence, a weaker association between labels and objects for the SeW stimulus and unfamiliar division structures for the SpW stimulus.

This prediction will be tested using five measures:

1) **Number of objects**: The number of objects recalled for strong stimuli are predicted to be greater than that for weak stimuli (strong stimuli > weak stimuli), with more objects recalled in later sessions for all stimuli. Therefore, the SeS and the SpS stimuli will each

produce a greater object count than both the SeW and the SpW in all sessions with comparable object counts between the strong and the weak stimuli.

2) **Number of divisions usage**: The division usage count calculates the total number of divisions in which objects are drawn. This measurement replaces the transition count measurement used in Experiments 1 and 2 because of the relatively small number of objects drawn across the sessions in this experiment (as we will see). Therefore, the division usage is a more reasonable measure to examine how the divisions in the stimuli influence the participants' rate of learning. It is predicted that more divisions will be used for both types of strong stimuli than for the weak. Furthermore, the number of divisions used is predicted to be comparable between both types of weak and strong stimuli.

3) **Pause levels**: The strong and weak stimuli are predicted to have pauses in the following order, L1 < L2 < L3a. This pattern is predicted for all stimuli. Pauses are the shortest for L1-within object followed by L2-between objects. Furthermore, the L3a-first transition between divisions pause is greater than the L2-between objects pause.

   Different pause levels may indicate the distinct amount of processing involved during drawing, as shown in the different branch length or levels of the predicted hierarchical organization in Figure 5.3. If the pause pattern is explained according to depth-first serial processing, longer branches of the hierarchy indicate longer pause duration. It is predicted that to enable a successful drawing, a participant needs to recall in the order of: whole-stimulus → divisions → objects within divisions → lines within an object (see Figure 5.3). Thus, it is expected that the time used to retrieve lines (L1 pauses) within an object is the shortest and has shorter branch length due to the lesser amount of processing required. Instead, more time is needed to recall between two objects (L2 pauses) within a single division, as it includes cognitive processing for the lowest level and the level above (i.e. lines and objects) in the hierarchy with longer branch length (see Figure 5.3). Moreover, the recall of objects between the divisions (L3a pauses) takes the longest because more processing is associated with transitioning between divisions, which involves retrieval at the level of lines, objects and divisions. All pauses are predicted to decrease across sessions for all types of stimuli, as learning improves.

4) **Error rates**: The weak stimuli will produce more errors across the sessions than the strong, due to interference. This is because, for lack of strong cues, the weak stimuli will result in weaker mental activation; hence, poorer recall. This causes confusion, as

participants may not retrieve the correct objects for a particular stimulus. For example, the weak association between the colour labels and the constituent objects in the SeW stimulus, as well as the uncommon division presentation of unrelated objects in the SpW stimulus, may be confusing and hinder the drawing of objects in their correct divisions. This happens because these stimuli do not effectively associate the labels of categories with objects, unlike the SeS and SpS stimuli with their stronger cues of meaningful labels and defined divisions respectively. This makes learning harder. Errors produced for both the strong and the weak stimuli are likely to be comparable. Errors for all stimuli, however, may decrease over time as learning improves.

5) **Division transitions and division preferences:** As mentioned above, this experiment aims to induce the chunk structure from the stimulus structure. Assuming that the underlying mental schemas for these stimuli are in the format of hierarchical representations, the division transition count will provide evidence on whether or not the stimuli are organized in a structured manner formed of small units of graphical information chunks. This is based on the assumption that each division is treated as a chunk. Therefore, fewer transitions occurring between the divisions indicate that participants may draw the objects as a group within each division. On the other hand, a larger number of transitions may suggest that the participants are not using the division structures. Instead, they might draw random objects across the divisions, not treating them as chunks. This hints at less graphical information organization structure for the weak stimuli, as objects are loosely associated with these types of stimuli making encoding more difficult. Therefore, it is predicted that the weak stimuli will have more divisions' transitions than the strong. As a result, the retrieval of the relevant objects may potentially be more difficult, as access to these objects is affected in a random manner.

   The division preference measure will describe the pattern of learning with regard to the preferred use of divisions at the start of each session. This measure will determine if the participants are treating the stimuli as expected, namely using the given labels for the semantic stimuli and the regions for the spatial stimuli. It is predicted that for the strong stimuli, participants will have more flexibility to retrieve divisions in no particular pattern of recall, as each division is equally weighted in terms of the strength of retrieval from memory. On the contrary, the recall of objects from the weak stimuli may potentially produce certain preferred patterns, which will be associated with some idiosyncratic learning strategy, as these types of stimuli may not provide effective cues on their own, which would facilitate retrieval.

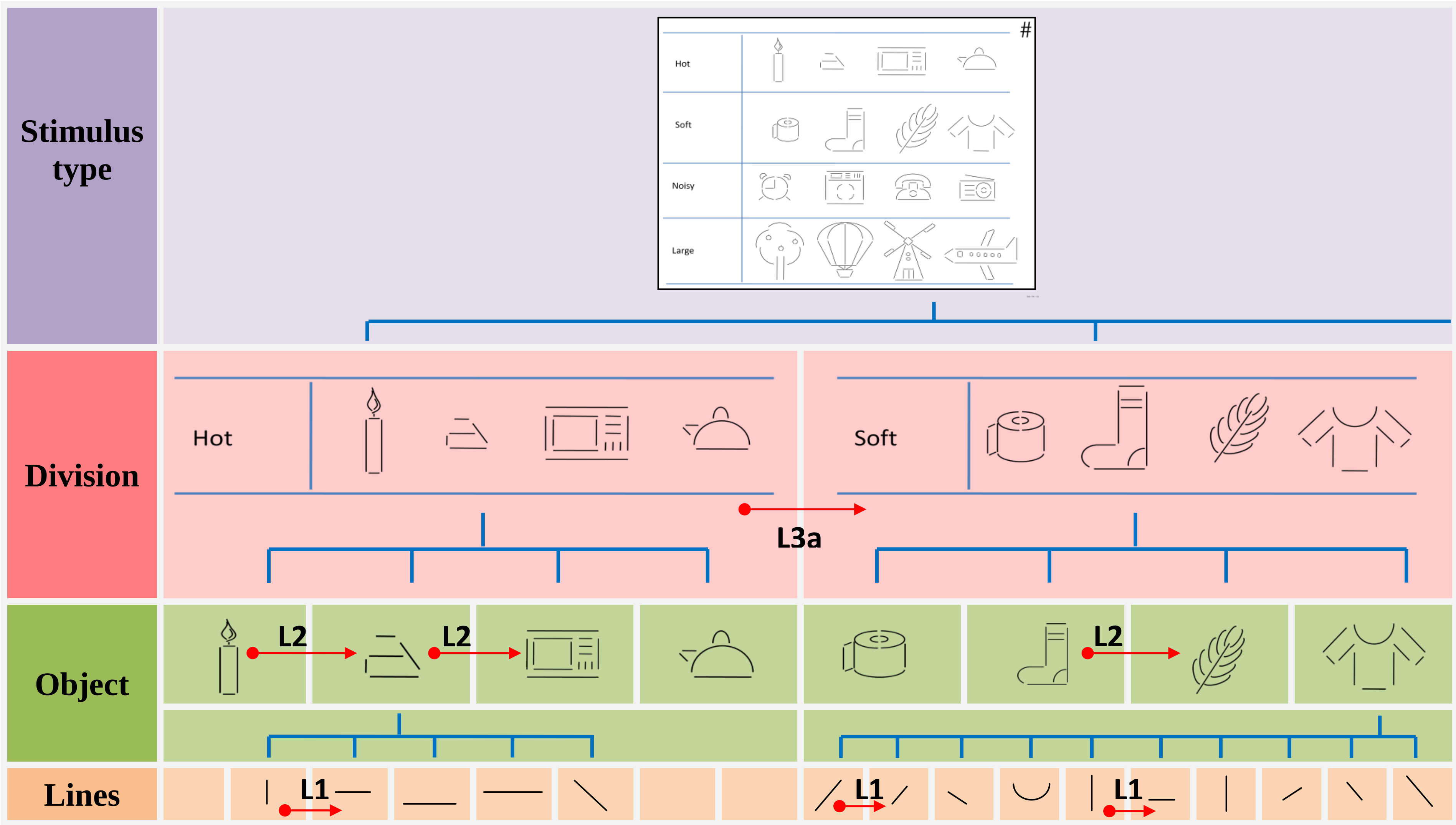


Figure 5.3: Hierarchical order of the mental schema (e.g. pause vs divisions)

## 5.3 Method

### 5.3.1 Participants

Twelve (6 male and 6 female) undergraduate and postgraduate students of the University of Sussex responded to an advert and were each paid £25 for their participation in this experiment. The course of study varied among the participants (e.g. Engineering, Psychology, Media Studies, English etc.). The age of the group ranged between 18-47 years old (median: 24 years 7 months). None of them had any psychomotor deficit that would affect their drawing and all had sufficient drawing abilities demonstrated during a practice task (before the experiment commenced), where they copied a stimulus that consisted of lines of various lengths and shapes that formed parts of the objects used in the tested stimuli. All of them were right-handed.

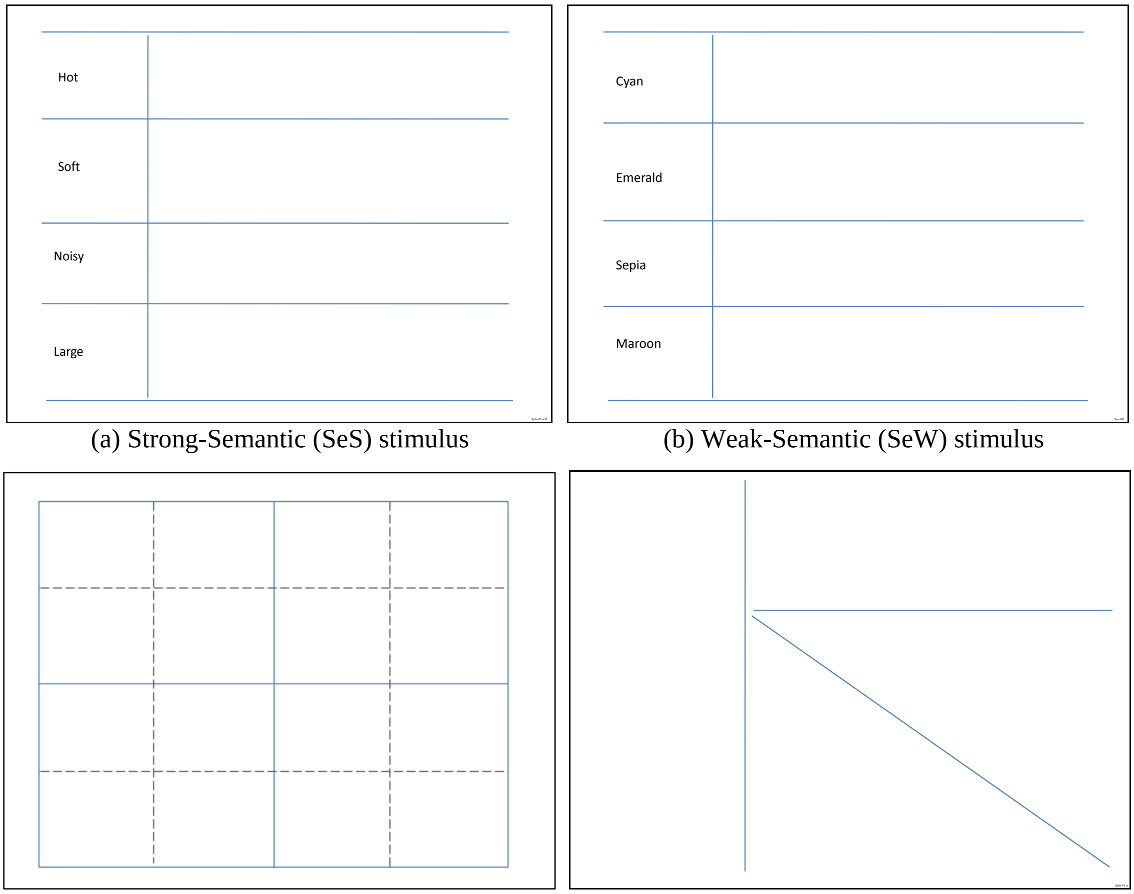
### 5.3.2 Design

This experiment employed a repeated measures within-subject design, with

1) Three independent variables:
    a. Two *stimulus types* (i.e. semantic and spatial stimuli)
    b. Two levels of difficulty or *stimulus strength* (i.e. strong and weak)
    c. Four *sessions* (i.e. 1-4)
2) Six dependent variables:
    a. Number of objects
    b. Number of divisions usage
    c. Pause duration (i.e. L1, L2 and L3a levels)
    d. Error rates
    e. Division transitions
    f. Division preferences

The independent variables crossed producing 16 experimental conditions (2 stimulus types x 2 stimulus strength levels x 4 sessions). All participants performed in all of the experimental conditions. Excluding an additional practice task at the beginning of the experiment, they performed eight drawings (four for *Recall from memory* and four for *Copying* tasks) between sessions 1 to 3 in the order shown in Table 5.1. The participants only did four Recall from memory drawings in the last (fourth) session, which was followed by a debriefing where the participants were interviewed with a few questions on the techniques used to memorise the objects on each stimulus structure. This session provides informal evidence about whether or not the participants used strategies associated with the types of stimuli structures presented to them.

The Copying and Recall from memory tasks were chosen as the former allows the participants to learn the figures, while the latter measures their rate of learning. In the Copying tasks, the participants were shown four types of drawings (one at a time, each corresponding to one type of stimulus structure) that consisted of different objects, as shown in Figure 5.1. They were then asked to draw the objects in the respective divisions on the blank stimulus templates, as shown in Figure 5.4. The participants were allowed to look at the reference figure of the corresponding stimulus structure throughout the Copying tasks. In the Recall from memory tasks they were asked to draw the correct objects in the empty divisions without given any reference figure.




(a) Strong-Semantic (SeS) stimulus
(b) Weak-Semantic (SeW) stimulus
(c) Strong-Spatial (SpS) stimulus
(d) Weak-Spatial (SpW) stimulus

Figure 5.4: Blank templates of the four types of stimuli

Table 5.1: Example of the order of tasks and stimuli given to the participants in Experiment 2

| Session 1 | Session 2 | Session 3 | Session 4 |
|---|---|---|---|
| *Practice task* | | | |
| *Copy 1* | *Memory 2* | *Memory 3* | *Memory 4* |
| SpW (v1) | SeW (v2) | SpS (v1) | SeS (v4) |
| SeS (v1) | SpW (v2) | SpW (v3) | SpS (v1) |
| SeW (v1) | SpS (v1) | SeS (v3) | SeW (v4) |
| SpS (v1) | SeS (v2) | SeW (v3) | SpW (v4) |
| *Memory 1* | *Copy 2* | *Copy 3* | *Debriefing* |
| SeS (v1) | SeS (v2) | SpS (v1) | |
| SpW (v1) | SeW (v2) | SeW (v3) | |
| SpS (v1) | SpS (v1) | SpW (v3) | |
| SeW (v1) | SpW (v2) | SeS (v3) | |

*Note*. SpS = Strong Spatial, SpW = Weak Spatial, SeS = Strong Semantic, SeW = Weak Semantic. Version = v1; v2; v3; v4.

### 5.3.3 Materials

Each stimulus structure has a total of 16 objects and four divisions, where each division consists of four different objects. The objects differ between the stimuli and none appears twice. There were a total of 64 objects for all stimuli (16 objects x 4 stimuli), as shown in Table 5.2 where 22 of the objects were taken from the stimuli in Experiment 2. The 64 objects were selected based on 16 different categories. Four sets of 16 objects share, thus, similar semantic characteristics, each representing one of the following categories for the SeS stimulus: hot, soft, large and noisy. The remaining objects were randomly selected from 12 categories to form three more stimuli.

Table 5.2 : List of objects for all stimuli

| SeS | SeW | SpS | SpW |
|---|---|---|---|
| 1. Aeroplane | 1. Anchor | 1. Button | 1. Arrow |
| 2. Alarm clock | 2. Bee | 2. Clover | 2. Bat |
| 3. Apple tree | 3. Bicycle | 3. Fork | 3. Bed |
| 4. Candle | 4. Bread toast | 4. Gun | 4. Cake |
| 5. Feather | 5. Car | 5. Ice cream | 5. Crab |
| 6. Hot air balloon | 6. Coffee cup | 6. Lightning | 6. Fan |
| 7. Iron | 7. Drawing pin | 7. Match | 7. Hanger |
| 8. Kettle | 8. Envelope | 8. Moon | 8. Paper clip |
| 9. Microwave | 9. Fish | 9. Saw | 9. Petrol pump |
| 10. Radio | 10. Ghost | 10. Spider | 10. Rubbish bin |
| 11. Shirt | 11. Key | 11. Submarine | 11. Safety pin |
| 12. Socks | 12. Lamp | 12. Sweet | 12. Shower |
| 13. Telephone | 13. Sofa | 13. Torch | 13. Sickle |
| 14. Toilet roll | 14. Sun | 14. Trolley | 14. Star |
| 15. Washing machine | 15. Swimming pool | 15. Television | 15. Sword |
| 16. Windmill | 16. Table | 16. Washbasin | 16. Tulip flower |

All participants received the same set of stimuli presentation. Each stimulus had the same collection of objects. Each participant, however, received a combination of different stimulus versions for the SeS, SeW and SpW in each session. There was a total of 24 versions for each of these three stimuli. The SpS stimulus did not change throughout the experiment. In order to ensure that the definition of each stimulus condition was met, counterbalancing was adopted for the stimuli, as described below:

1) **SeS and SeW stimuli**: The order of the labels with their corresponding objects changed in each drawing task, as did the order of the objects in each category. The objects were arranged randomly in 24 different orders. Each change is called a version. Figure 5.5 shows examples of four versions of the SeS stimulus. None of the participants received the same order of stimulus content (i.e. objects). The order of the labels and objects was randomised with each division, as were the divisions themselves. This design was employed to eliminate the use of spatial positioning of the divisions or objects during learning.

2) **SpS stimulus**: There was only one version of the SpS stimulus. An object in each division remained in the same position within the grid-like presentation. All of the participants received the same version in each drawing task. This design was adopted to emphasize the spatial configuration of the divisions and objects.

3) **SpW stimulus**: Each division had the same collection of objects. These were randomised in each version so that the participants would not use the location of each object within the division as a cue. This left only the divisions to support learning.

As a method of counterbalancing, none of the participants received the same order of stimuli versions, although the order of the stimuli themselves (e.g. SeS, SpW, SpS, SeW) remained the same. It is noteworthy that a participant only received three versions (one version for each Copying task) of each type of stimulus structure (with the exception of the SpS stimulus) for completing the experiment across 4 sessions.

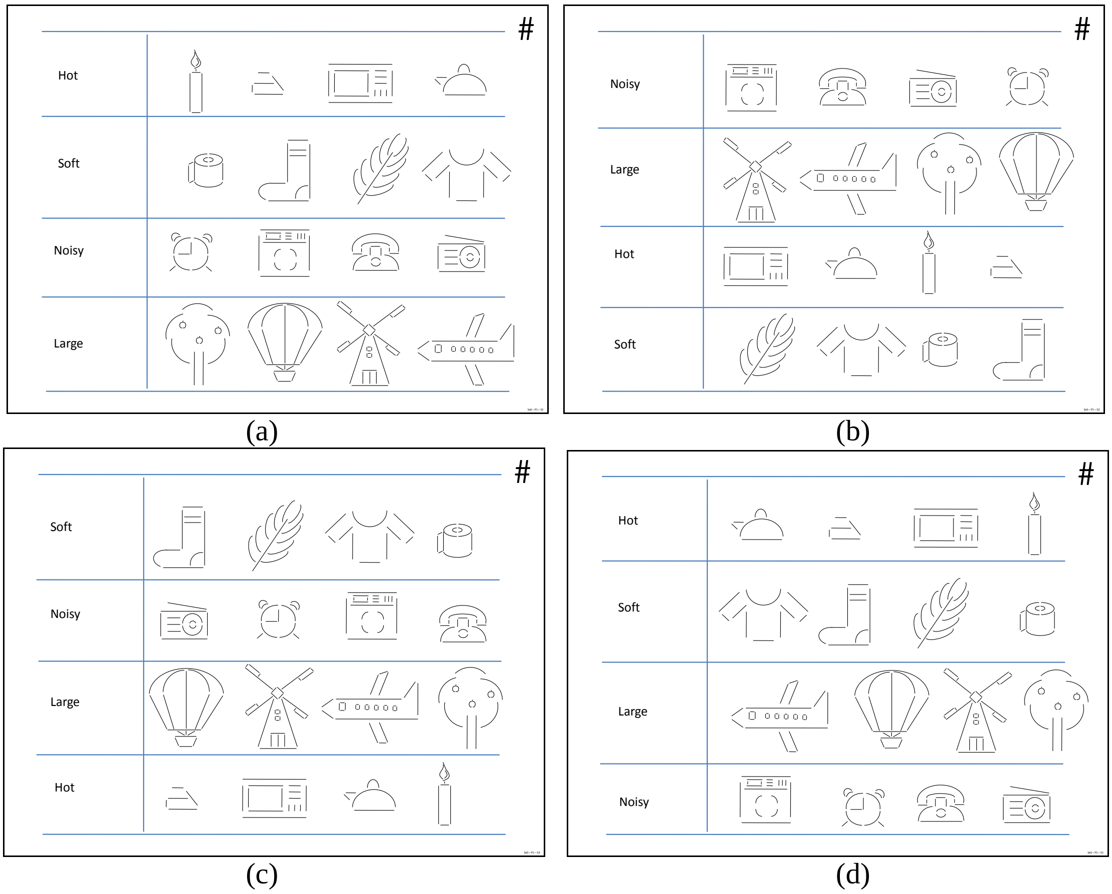



Figure 5.5: Example of four versions of the SeS stimulus

### 5.3.4 Procedure

All participants were tested individually. During the experiment, they were seated at a table in front of a graphics tablet in a quiet room, where an empty template for the respective type of stimulus structure was taped on the tablet in a landscape orientation. All drawings were done using the Wacom Intuos graphics tablet with a special inking pen using the TRACE software (Cheng & Rojas-Anaya, 2004) to record all drawing actions. The participants drew on separate sheets for each drawing task.

The participants were first given a sheet of instructions. Further verbal explanations were given if they did not understand any part of the instructions. As in the previous experiments, the participants were instructed to begin with a hash (#). In the first session they performed a practice task to become familiar with drawing on the tablet. Upon completion of each Copying task, the participants were shown an additional instruction printed on a card that allowed 15 seconds of study time.

Each stimulus structure had different instructions. The experimenter recorded the time during this brief study period and reminded the participants to stop looking at the stimulus when the study time lapsed. The instructions for each stimulus structure were as follows:

SpS stimulus: *You have 15 seconds to look at this. Try to associate each object with its labels to the left.*

SeW stimulus: *You have 15 seconds to look at this. Try to associate each object with the colour labels to the left side of each row.*

SpS stimulus: *You have 15 seconds to look at this. Try to associate each object with its own cell in each of the four large squares.*

SpW stimulus: *You have 15 seconds to look at this. Try to associate each object with its respective area*.

There was no time restriction on the duration of the drawings. The participants drew until they had nothing else to draw. If a participant paused for a brief period during a task, they were asked "Can you still remember?" or "Do you have anything else to draw?". They were given another minute and were told they could stop if they could remember nothing else. Most participants did not recall more objects after the pause. Each drawing task took approximately 5 minutes.

In the last (fourth) session, all participants were individually interviewed after they completed the drawings from memory. The aim was to find if they had been using the expected types of strategies associated with each stimulus structure, such as the labels for the semantic stimuli or the spatial location and positions of the objects for the spatial stimuli. Each interview session was video-recorded and participants were asked: "What strategy did you use to remember the objects?" or "How did you remember these objects?".

### 5.3.5 Analysis

Only the four drawings from the memory task were analysed in this experiment. Drawings from the Copying tasks were not analysed, as they do not contribute to the research questions that interest this experiment. Table 5.3 shows all the experimental conditions for each of the statistical analyses. Similar to Experiment 2, the type of statistical analysis used to test this fully within-subject design experiment was the repeated measures ANOVA. Each of the ANOVA has three main effects (i.e. stimulus type, stimulus strength and session) and four interaction effects (i.e. stimulus type x stimulus strength, stimulus type x session, stimulus strength x session, stimulus type x stimulus strength x session).

Table 5.3: Cross over of experimental conditions

<table>
<tr><th>Type of analysis</th><th colspan="2">Dependent variables</th><th>Independent variables</th></tr>
<tr><td rowspan="6">ANOVA Repeated measures with independent variables</td><td rowspan="3">Pauses</td><td>L1</td><td rowspan="5">stimulus type x stimulus strength x session<br>(2 x 2 x 4)</td></tr>
<tr><td>L2</td></tr>
<tr><td>L3a</td></tr>
<tr><td colspan="2">Number of objects</td></tr>
<tr><td colspan="2">Number of divisions</td></tr>
<tr><td colspan="2">Error rate</td><td>stimulus type x stimulus strength x error type x session<br>(2 x 2 x 2 x 4)</td></tr>
<tr><td>Mean</td><td colspan="2">Division transitions</td><td>-</td></tr>
<tr><td>Total count</td><td colspan="2">Division preferences</td><td>-</td></tr>
</table>

Similar to the previous experiments, explained in Chapters 3 and 4, the time difference (pause duration) was calculated between each pair of data points (in a x- and y- coordinate system). These raw data files were pre-processed using a special program written in Java (Obaidellah, 2010). The same analysis program (with slight modifications to suit the stimuli) as that explained in Section 4.3.5: Analysis, was used for the pre-analysis in this experiment.

The analysis was focused on the way the execution of the drawings was organized, rather than the graphic quality of the production. Therefore, as long as the produced graphical elements had a good resemblance to the actual objects shown on the stimulus, the drawing of an object was scored as correct. This was regardless of how the participants interpreted the objects. For example, if a participant thought the sofa (actual object on stimulus) was an old camera, the drawn object which bore a close resemblance to the sofa was scored correct although the participant interpreted the object type differently. It was relatively easy to judge whether or not there was a good resemblance between the drawings and the actual object. There was no case where it was particularly difficult to make a judgment. Overall, mean scores were compared between stimuli.

As for the retrospective analysis of the interviews, each recorded video from the interview session was coded into strategies used by the participants. The types of strategies were compared between the participants across the stimuli.

## 5.4 Results

The results will be explained at an aggregated level collected from all the participants' measures discussed in Section 5.2: Hypothesis. Each of the following subsections corresponds to the discussed hypothesis in the order of: (1) number of objects, (2) number of divisions usage, (3) pause levels, (4) error rate, (5) divisions transitions, (6) division preferences and (7) verbal reports.

The motivation behind using the ANOVA statistics parameters (e.g. contrast tests, pairwise comparison) are the same as that explained in Section 4.4: Results. The results were analysed and presented for all drawn objects, whether or not they were correctly drawn, for a particular type of stimulus. The incorrectly drawn objects (also referred to as commission objects) are types of objects other than those defined in the actual stimuli. These objects were mistakenly interpreted and drawn as correct, due to confusion that occurred during learning. All drawn objects, however, were considered for all measures with the exception of the error rate, as participants believed them to be correct.

### 5.4.1 Number of objects

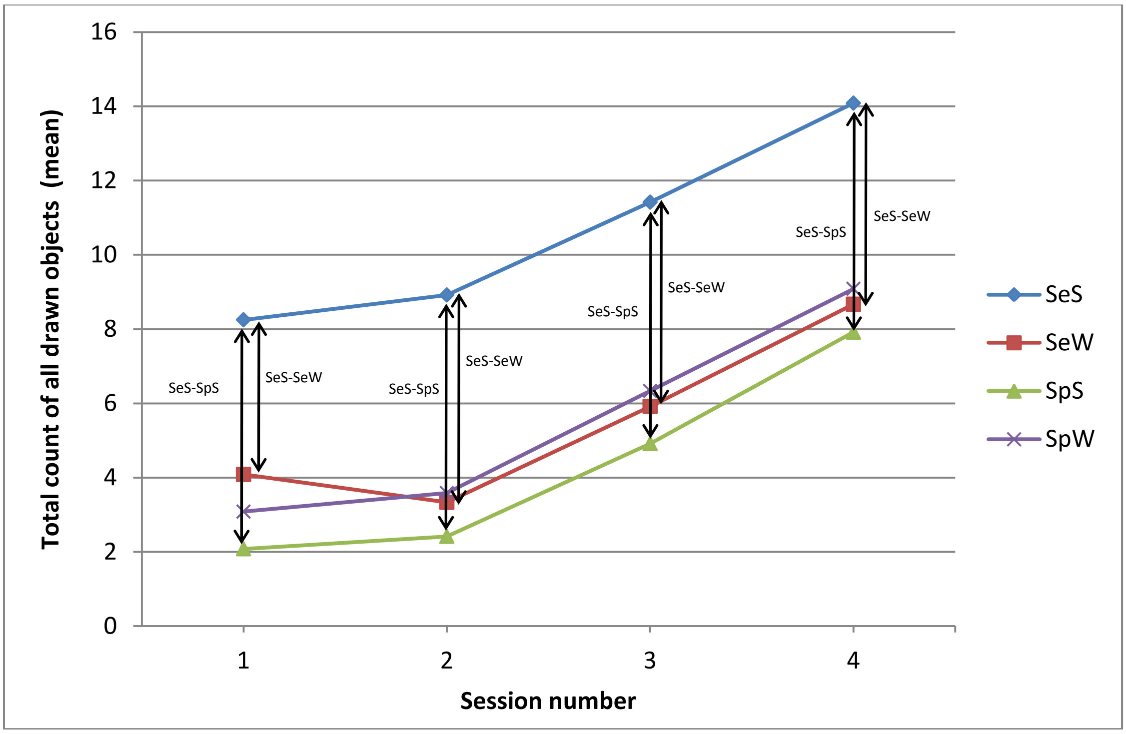


Figure 5.6: Number of objects drawn for all stimuli across four sessions. Arrows indicate significant effects between the stimuli at each session, all at $p<.001$.

The number of objects is defined as the total number of objects drawn, including commission objects as described above. We analysed the number of objects with and without the commissions. The graph, however, plots only correct objects for each type of stimulus structure. The overall analysis results showed little difference to those reported here due to the very small number of incorrect objects or commission errors (see Section 5.4.4: Error rates). Hence, considering all drawn objects does not affect the overall analysis and interpretation of the results.

Figure 5.6 shows the number of objects for all stimuli across four sessions. Generally, the number of drawn objects increases in the order of SpS < SeW < SpW < SeS stimuli with an exception for the SeW at session 1. Although it was predicted that the strong stimuli would produce the highest object count, the results showed that this prediction is only consistent for the SeS stimulus. Surprisingly, the SpS stimulus contradicts the prediction, as it showed the lowest object count throughout the sessions. For sessions 2 to 4, however, the SpW stimulus records more objects than the SeW.

The ANOVA results for all factors revealed significant main effects, all at $p<.001$ for (1) stimulus type, $F(1,11)=33.05$; (2) stimulus strength, $F(1,11)=37.96$; (3) session, $F(3,33)=104.8$ [with no correction for the degrees of freedom, as the assumption of sphericity was met for all main effects using Sphericity Assumed ($\mathcal{E}=1.000$; Mauchly's test for: (1) stimulus type and (2) stimulus strength, both at $\chi^2(0)=0.00$, $p<.001$; and (3) session, $\chi^2(5)=0.00$, $p>.05$)]. The significant effect for the stimulus type may be driven by the SeS stimulus. Furthermore, the significant effect for the stimulus strength showed that the number of objects produced in the weak stimuli is substantially different than that in the strong stimuli. Finally, the significant session factor is an indication of differences in the number of objects recalled in successive sessions. Except for the non-significant comparison between sessions 1 and 2, where $p>.05$, all remaining comparisons between the sessions were significant, $p<.001$ based on the contrast and pairwise tests.

The ANOVA results further showed a significant interaction effect between the stimulus type x stimulus strength, $F(1,11)=42.11$, $p<.001$ [with no correction for the degrees of freedom as the assumption of sphericity was met using Sphericity Assumed ($\mathcal{E}=1.000$; Mauchly's test for stimulus type x stimulus strength, $\chi^2(0)=0.00$, $p<.001$)]. This result confirms the trends for all stimuli in Figure 5.6, where the number of objects differs between the stimuli across the sessions indicating that these stimuli have a role that determines the rate of learning.

Further tests, however, as indicated by the paired t-test comparison between the same sessions for (1) both weak stimuli (e.g. SeW session 1 and SpW session 1; SeW session 2 and SpW session 2; etc.) and (2) between spatial stimuli, were non-significant. On the contrary, as expected, paired t-test between all respective sessions for (1) both strong stimuli (i.e. SpS vs SeS) and (2) between semantic stimuli (i.e. SeS vs SeW) showed significant effects, $p<.001$ (see Figure 5.6).

### 5.4.2 Number of divisions usage

In Experiment 2, the L3b-return transition count was the total count of return transitions to the previously visited divisions, which was calculated to find if the divisions were treated like individual chunk categories, as indicated by the frequency of transitions to the last visited divisions. Fewer return transitions would suggest that objects within a category were more likely to be drawn together in their division, before objects from other divisions were drawn. In this experiment, however, as previously described in Section 5.2: Hypothesis, the L3b-return transition count could not be calculated. This was due to the small number of transitions produced by the participants throughout the drawing sessions across the stimuli.

Therefore, the count of divisions used to draw objects was employed as an alternative measure. In order to get an overview of whether there was a difference in the number of divisions used by the participants to draw objects, we counted the divisions that contained at least one object across the sessions for all types of stimuli. Thus, there should be a count of between 0 to 4 divisions used for drawing in each session for a stimulus structure. For example, if a participant drew objects in the 'Hot' category division followed by objects in the 'Soft' category division, the total count of divisions is two.

The divisions count used across the sessions for all stimuli revealed an increasing number of division usage across all participants, where, generally, more divisions were used in session 4 than session 1. The predictions were that (1) more divisions would be used for the strong stimuli than the weak and (2) that the divisions usage between each set of strong and weak stimuli would be comparable.

As for prediction (1), only part of the results were consistent with it, because it was just the SeS stimulus which showed more divisions usage than both weak stimuli and the SpS stimulus from the beginning of the experiment, as shown in Figure 5.7. On the contrary, the SpS stimulus not only showed less division usage in all sessions, but also the least division usage, even compared to the weak stimuli. Therefore, in view of prediction (2), the strong stimuli may not be comparable, unlike the weak stimuli. This will be verified by the results produced by the t-test.

Although the means of division usage generally increased over time for all stimuli, a few exceptions applied to the semantic stimuli, where (1) it appears that the SeS were close to or at ceiling level across all sessions and (2) there was a lower division usage count at session 2 for the SeW stimulus.

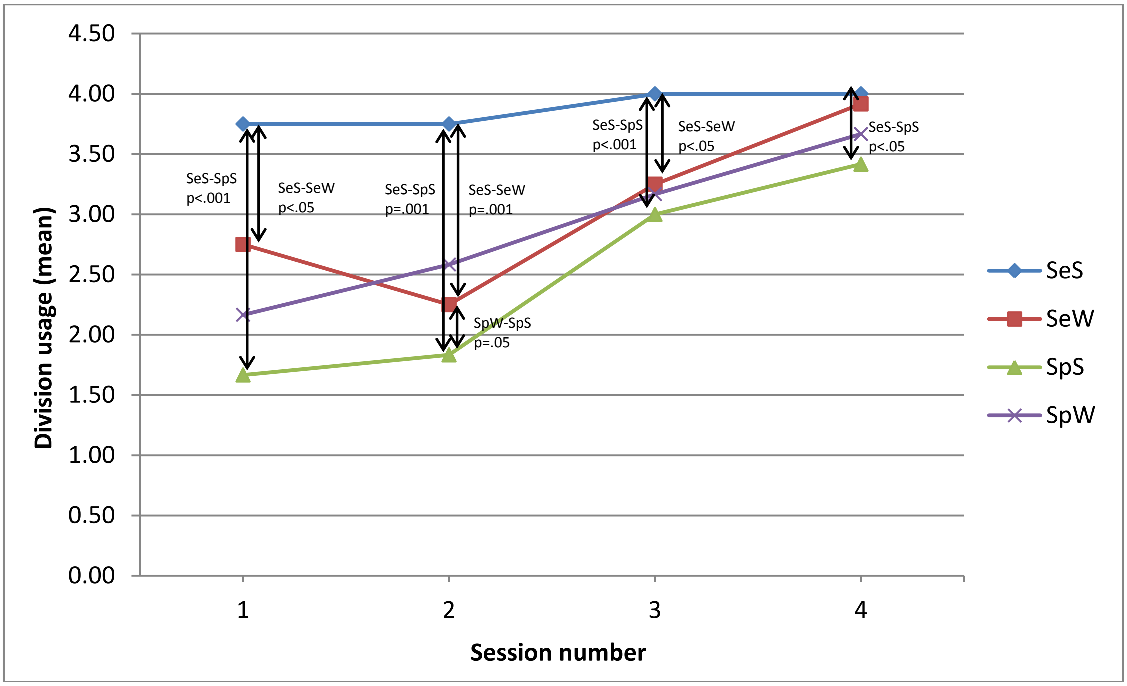



Figure 5.7: Average of division usage for all stimuli across four sessions. Arrows indicate significant effects between the stimuli at each session.

The repeated measures ANOVA revealed a significant main effect for (1) stimulus type, F(1,11)=13.58, p<.05; and (2) session, F(3,33)=29.21, p<.001 [with no correction for the degrees of freedom as the assumption of sphericity was met using Sphericity Assumed (Ɛ=1.000; Mauchly's test for (1) stimulus type, $\chi^2(0)$=0.00, p<.001; (2) session, $\chi^2(0)$=0.00, p>.05)]. The significant stimulus type may be due to the dominant division usage from the SeS stimulus. Furthermore, significant effects of the session mean that the number of divisions used not only differs between the sessions but increases across them, consistent with the graph shown in Figure 5.7.

The ANOVA further showed a significant interaction effect for (1) stimulus type x stimulus strength, F(1,11)=18.13, p=.001; and (2) stimulus type x stimulus strength x session, F(3,33)=4.07, p<.05 [with no correction for the degrees of freedom as the assumption of sphericity was met using Sphericity Assumed (Ɛ=1.000; Mauchly's test for (1) stimulus type x stimulus strength, $\chi^2(0)$=0.00, p<.001; and (2) stimulus type x stimulus strength x session, $\chi^2(0)$=0.00, p>.05)]. These results are consistent with the graph in Figure 5.7, as the division count is at different range for each stimulus structure, with the exception of the SpW stimulus at session 2.

Paired t-tests between the semantic stimuli across the sessions revealed a significant effect for the comparison between sessions 1, p<.05; 2, p=.001; and 3, p<.05, indicating that more divisions were used in SeS stimulus, which is in line with the prediction. Comparison between the spatial stimuli, however, was only significant in session 2, p=.05. This is in addition to the non-significant effect across the other sessions, which suggests that these types of stimuli may have been comparable. Moreover, a significant effect across all sessions (see Figure 5.7) between the strong stimuli supports the findings that the SeS stimulus is a better type of stimulus structure than the SpS. All comparisons across all sessions between the weak stimuli were non-significant.

### 5.4.3 Pause order L1 < L2 and generally L2 < L3a for all stimulus structure

L1, L2 and L3a pauses are analysed to reconfirm our hypothesis that pauses occur in a way similar to that found in the previous experiments. If this is the case, it is reasonable to assume that more internal processing is associated with longer pauses, as the longest pauses occurring during L3a-transition between divisions require mental processing involved at the line, object and divisions level, in contrast to the shortest pauses occurring during L1-within object level, which require processing only at line level (see Figure 5.3).

Table 5.4 shows the means for all pause levels for each stimulus. It is found that across all stimuli the L1-within object pauses are shorter (and fewer) than the L2-between objects pauses. This is consistent with the findings from the previous Experiments 1 and 2. The L2-between objects pauses are shorter than the L3a-objects between divisions pauses for the SeS and SpW stimuli, but this pattern is less obvious for the SeW and SpS, as shown in Figure 5.8. Also, across the stimuli, the L2 and L3a pauses decrease over time, with the exception of slightly higher L3a pauses in session 4 (6450ms) for the SeS stimulus. Nevertheless, the L2 pause at session 3 for the SpS stimulus is unusually low, which could be due to noise.

Table 5.4: Pauses across the stimuli

| **Task** | **Mean** | | | **Median** | | | **Standard deviation** | | |
|---|---|---|---|---|---|---|---|---|---|
| **type** | *L1* | *L2* | *L3a* | *L1* | *L2* | *L3a* | *L1* | *L2* | *L3a* |
| *SeS* | 467 | 5313 | 6402 | 469 | 5285 | 6760 | 26 | 1106 | 931 |
| *SeW* | 491 | 8939 | 8832 | 492 | 9039 | 8234 | 15 | 3166 | 3338 |
| *SpS* | 468 | 12430 | 10480 | 469 | 7725 | 7162 | 24 | 10753 | 8508 |
| *SpW* | 543 | 6078 | 7671 | 551 | 6494 | 7037 | 47 | 1208 | 2143 |

In sessions 1 and 2, as shown in Figure 5.8(a-d), the lowest to the highest L2 and L3a pauses are found in the following stimulus order: SeS < SpW < SeW < SpS. As participants completed sessions 3 and 4, the SeS stimulus showed almost constant L2 and L3a pauses, while a decreasing pattern for these pauses is more noticeable for the weak stimuli. The L2 pauses for the SpS stimulus, however, dropped lower in session 3.

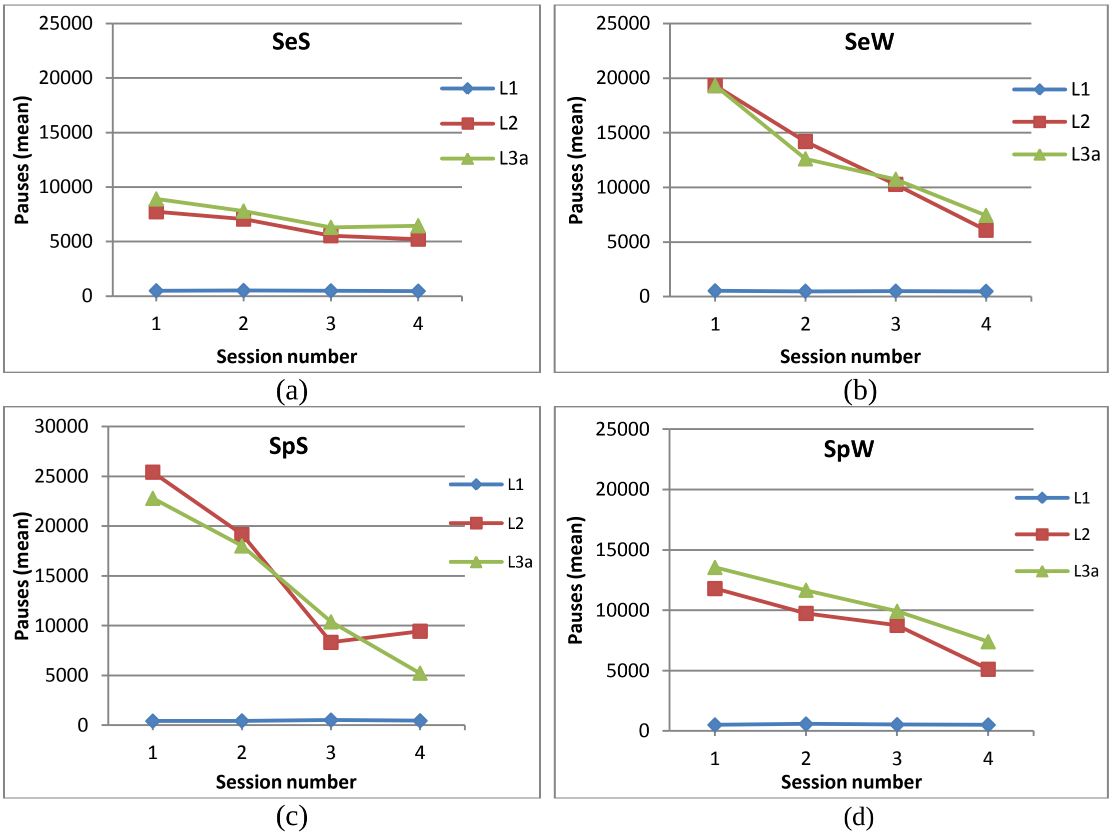



Figure 5.8: Means of all pause levels for each stimulus

The following section will discuss the results for each pause level in the order of L1, L2 and L3a.

### 5.4.3.1 L1 pauses

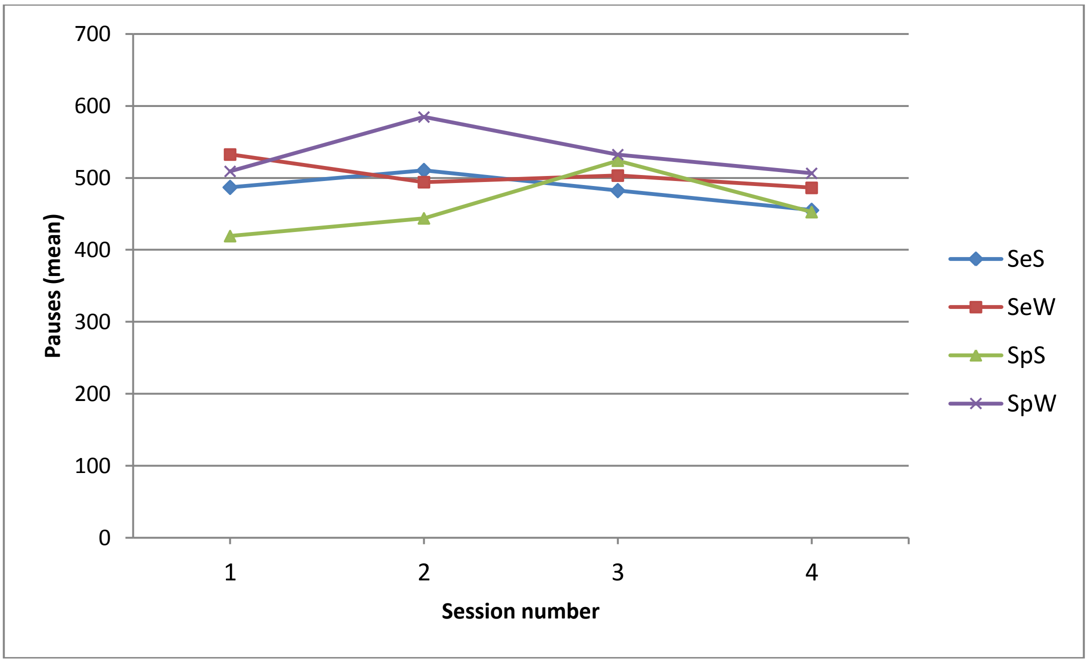



Figure 5.9: L1 pauses across all stimuli

The L1 pauses for all stimuli are within the range of 419ms-585ms, as shown in Figure 5.9. Although the pauses for all stimuli seem to converge in sessions 3 and 4, the L1 pause difference between these sessions is small indicating that pauses used to recall between the lines within an object are not considerably faster in session 4 than they were in session 3. Overall, the L1 pauses for drawing lines within objects may not be affected by the types of stimuli.

The repeated measures ANOVA for L1 pauses revealed a significant main effect for the stimulus strength, $F(1,11)=10.99$, $p<.05$ [with no correction of degrees of freedom as the assumption of sphericity was met using Sphericity Assumed, ($\mathcal{E}=1.000$; Mauchly's test for stimulus strength, $\chi^2(0)=0.00$, $p<.001$)]. This suggests that the internal mental processing differs between the weak and the strong stimuli. Figure 5.10 shows that the strong stimuli have lower L1 pause values than the weak. Therefore, the retrieval for the lines within an object is faster in the strong stimuli (419-524ms) with a mean of 472ms, than in the weak stimuli (486-585ms) with a mean of 519ms. As we will see in the following measures, however, this may be due to the dominant effect from the SeS stimulus and the fewest objects produced for the SpS stimulus, which affects the mean values of the lines for all drawn objects. An alternative explanation could be that once an object is recalled, all of its elements are activated. Thus, this reduces the amount of processing for these lines, resulting in shorter pauses occurring between the lines.

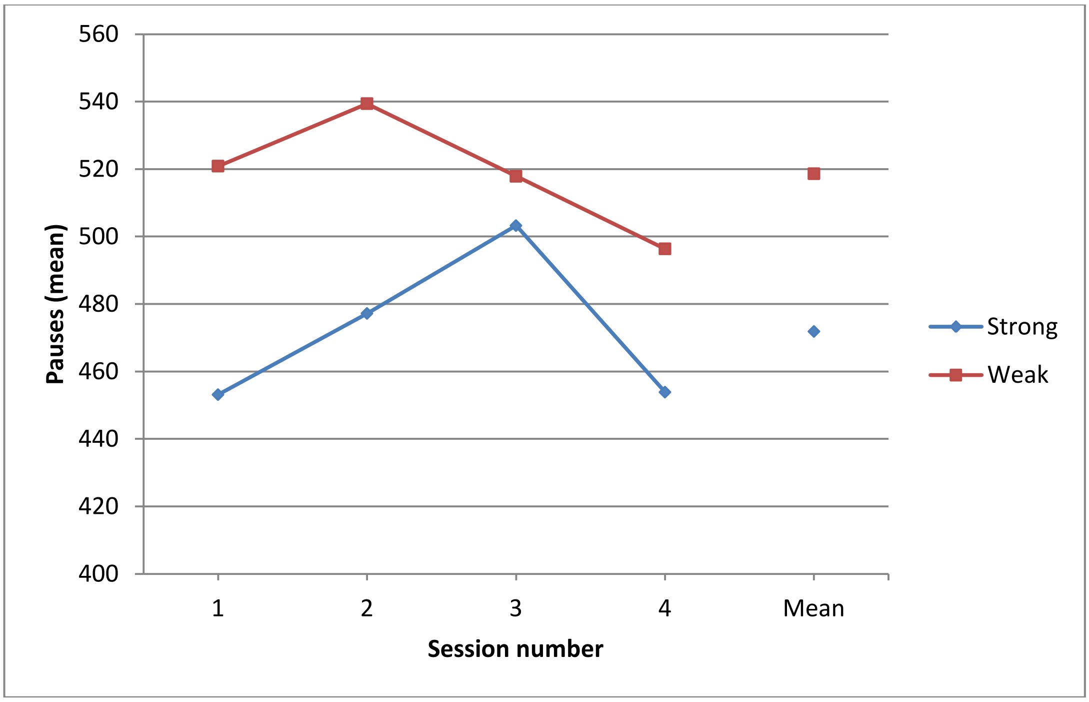


Figure 5.10: L1 pause levels between strong and weak stimuli (stimulus strength factor)

If the strong stimuli are comparable, the L1 pauses for sessions 1 and 2 would have been in the same range. As shown in Figure 5.9, the L1 pauses for the SpS stimulus, however, are shorter than the SeS stimulus in sessions 1 and 2. This effect may be due to the relatively small number of objects drawn in sessions 1 and 2 for the SpS stimulus (see Figure 5.6).

Further ANOVA comparison between the pairs of spatial stimuli in sessions 1 and 2 revealed only significant effects for the stimulus strength, $F(1,11)=10.86$, $p<.05$ [with no correction of degrees of freedom as the assumption of sphericity was met using Sphericity Assumed, ($\varepsilon=1.000$; Mauchly's test for stimulus strength, $\chi^2(0)=0.00$, $p<.001$)]. Although there was a significant effect found between the strength levels of the spatial stimuli when comparing both sessions 1 and 2, careful interpretation of this result is important because these are related to small numbers of objects. Therefore, interpreting this effect with regard to only a few objects may not be representative enough to explain the effects produced by the stimulus structure. Hence, this implies that L1 pauses may possibly be the same for all stimuli.

The ANOVA comparison between the semantic stimuli in sessions 1 and 2 showed no significant effect. This means that both the semantic stimuli have no obvious difference between them in these sessions.

The remaining main and interaction effects were non-significant.

#### 5.4.3.2 L2 pauses

Figure 5.11 shows the L2-between objects pauses for all stimuli across the sessions. Overall, there is a trend of decreasing pauses for all stimuli in successive sessions suggesting that the retrieval of objects becomes faster as learning improves. Furthermore, there seems to be an effect on the stimuli in session 1 where L2 pauses show different values. This could indicate that the participants were still unfamiliar with the materials to be learned and remembered different numbers of objects in each stimulus, demonstrating that the stimuli structures have an impact on learning even at the beginning of the experiment.

Apart from the SpS stimulus, all stimuli converged in session 4 where recall between objects was faster than in the previous sessions. This suggests that the stimuli (i.e. SeS, SeW and SpW) influence the rate of learning and drawing performance. The structure of the SpS stimulus, however, may provide less cues and, hence, less support for learning.

Although the SpS stimulus generally shows a decreasing trend, L2 pauses are unusually low in session 3, which could be caused by spurious data points. Closer inspection of the data, however, showed that this is unlikely. This effect may be more strongly related to the few objects recalled in session 3 (approximately 5 objects, which are less than half of the total number of objects - see Figure 5.6). Furthermore, the L2 pauses for the SpS stimulus, which exceed those of all the rest, may suggest that this type of stimulus structure is more difficult to learn.

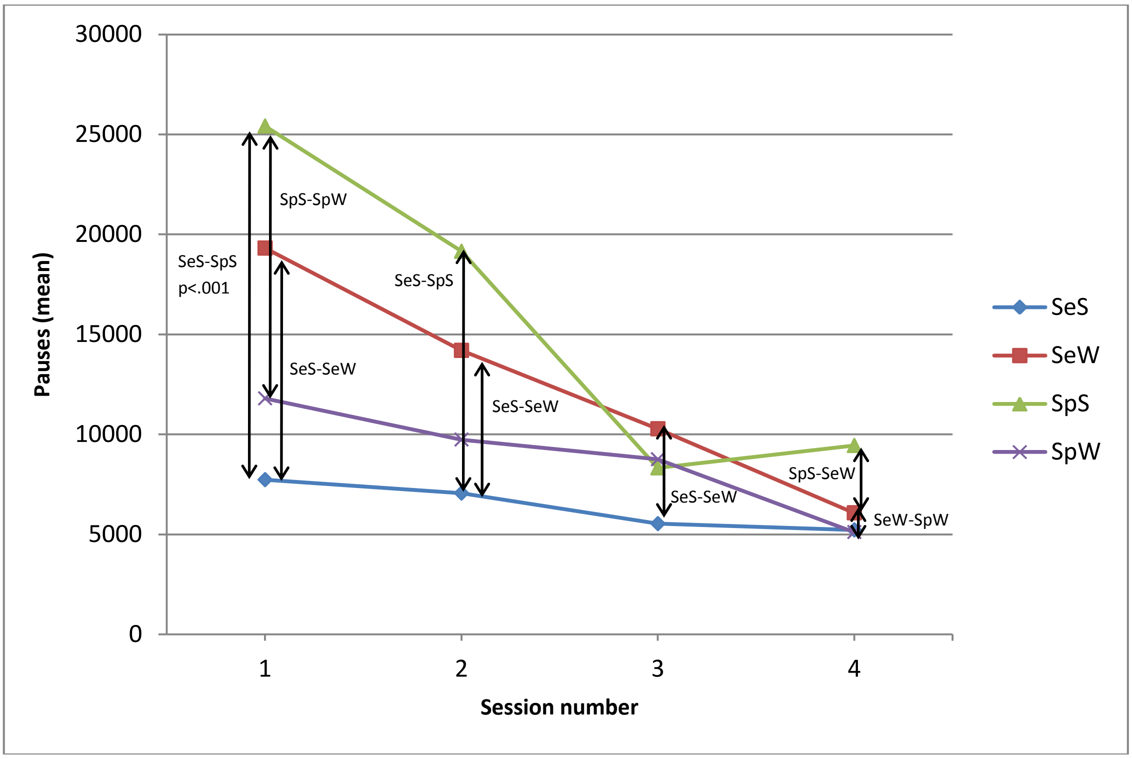


Figure 5.11: L2 pauses for all stimuli across four sessions. Arrows indicate significant effects (p<.05) between the stimuli across the sessions

The repeated measures ANOVA for the L2 pauses showed a significant main effect for the session, $F(2,22)=8.64$, $p<.05$ [with a correction of degrees of freedom using Greenhouse-Geisser as the assumption of sphericity was violated ($\mathcal{E}=0.67$; Mauchly's test for session, $\chi^2(5)=15.36$, $p<.05$)]. Contrast tests further showed a significant effect, $p<.05$ between (1) sessions 1 and 4, $F(1,11)=17.34$, $r=0.78$; (2) sessions 2 and 3, $F(1,11)=6.82$, $r=0.62$; and (3) sessions 2 and 4, $F(1,11)=7.79$, $r=0.64$. The pairwise comparison also showed a significant effect, $p<.05$ between (1) sessions 1 and 3; and (2) sessions 1 and 4. There was no significant effect, however, between (1) sessions 1 and 2; and (2) sessions 3 and 4. This means that in the first and last two sessions, the learning rate was somewhat of an equal level. Learning, however, improved at the end of the experiment, compared to session 1, where pauses between objects became shorter; hence, recall was faster.

The ANOVA further revealed a significant interaction effect between stimulus types x stimulus strength, $F(1,11)=23.21$, $p=.001$ [with no correction of degrees of freedom as the assumption of sphericity was met using Sphericity Assumed ($\mathcal{E}=1.000$; Mauchly's test for stimulus types x stimulus strength, $x^2(0)=0.00$, $p<.001$)]. This is consistent with the trend presented by L2 pauses in Figure 5.11, where in each stimulus pauses generally occur at different values across the sessions, including session 4, where the mean value is 5117ms for the SpW stimulus and 5222ms for the SeS stimulus.

The remaining main and interaction effects were non-significant.

As shown in Figure 5.11, a paired t-test between the stimuli in session 1 showed significant effects between the following stimuli, confirming the effects of the stimulus structure in the early experimental session: (1) SeS and SeW, p=.012; (2) SeS and SpS, p=.001; (3) SpS and SpW, p=.027, but no significant effect between (1) SeS and SpW, p=.434; (2) SeW and SpS, p=.379; (3) SeW and SpW, p=.267. Figure 5.11 also shows the t-test comparison between the rest of the sessions for the remaining stimuli.

#### 5.4.3.3 L3a pauses

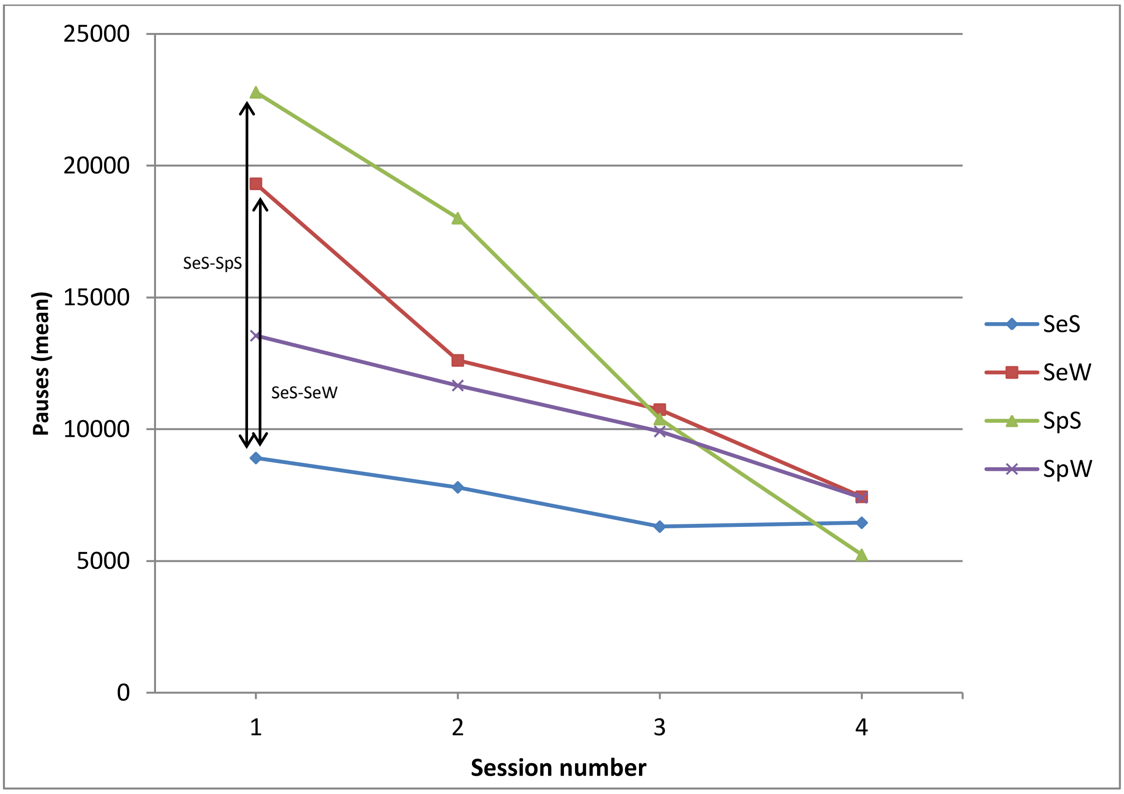



Figure 5.12: L3a pauses for all stimuli across four sessions. Arrows indicate significant effects (p<.05) between the stimuli in session 1.

Figure 5.12 shows the L3a-first transition between divisions' pauses for all stimuli across four sessions. Consistent with the patterns found in the L1-within object and L2-between objects pauses, the L3a pauses also decreased over successive sessions, where they diverged in session 1 and converged for all stimuli in session 4. This suggests that the first transition between different divisions becomes faster over time regardless of the type of stimulus.

In sessions 1 and 2, the pause pattern from the longest to the shortest is in the order of SpS < SeW < SpW < SeS. Except for the SeS stimulus that retained the lowest L3a pauses, the remaining stimuli almost converged at higher pauses in session 3. Both weak stimuli converged in session 4 at higher L3a pause values than the SeS stimulus, while the SpS showed the lowest first transition between divisions pauses in this session.

The repeated measures ANOVA showed a significant main effect for session, $F(3,33)=7.36$, $p=.001$ [with no correction of degrees of freedom as the assumption of sphericity was met using Sphericity Assumed ($\mathcal{E}=0.73$; Mauchly's test for session, $\chi^2(5)=9.82$, $p>.05$)]. Contrast tests further found a significant effect at $p<.05$ between (1) sessions 1 and 4, $F(1,11)=16.01$, $r=0.77$; and (2) sessions 2 and 4, $F(1,11)=6.68$, $r=0.61$ indicating that the first two sessions have longer L3a pauses than session 4, when the rate of learning had improved along with knowledge of the stimuli.

The ANOVA further revealed a significant interaction effect between stimulus type x stimulus strength, $F(1,11)=8.37$, $p<.05$ [with no degrees of freedom correction as the sphericity was met using Sphericity Assumed ($\mathcal{E}=1.000$; Mauchly's test for stimulus type x stimulus strength, $\chi^2(0)=0.00$, $p<.001$)]. This is consistent with the graph in Figure 5.12 where L3a pauses are different between all stimuli.

Finally, the ANOVA revealed that comparison between stimuli at all strengths for all sessions as indicated by the interaction effect between stimulus type x stimulus strength x session generally showed almost marginal significant effects, $F(1.86,20.43)=3.06$, $p=.07$ [with a correction for the degrees of freedom using the Greenhouse-Geisser as the assumption of sphericity was violated ($\mathcal{E}=0.62$; Mauchly's test for stimulus type x stimulus strength x session, $\chi^2(5)=13.98$, $p<.05$)]. A contrast test between sessions 1 and 4, however, showed a significant effect, $F(1,11)=13.11$, $r=0.73$, $p=.004$. Consistent with the graph in Figure 5.12, pauses for the first transition between different divisions for each stimulus structure in session 1 are longer than those in session 4, which suggests improvement in learning.

There is the possibility of a substantial difference between each of these stimuli for L3a pause values in session 1. As shown in figure 5.12, however, a paired t-test between the stimuli in session 1 only revealed a significant effect, $p<.05$ between (1) SeS and SeW; and (2) SeS and SpS. This indicates that the time spent to draw objects between an existing and newly visited divisions at the beginning of the experiment was less for the SeS stimulus than the SpS and the SeW stimuli.

### 5.4.4 Error rates

Do the stimuli produce an effect for different amounts of error? The errors were coded in five categories:

1) *drawing* errors – unintentional mistakes, such as marks, dots and strokes

2) *other objects* – any drawn objects, which are not among the 64 objects defined in the stimuli (e.g. a train in the 'Large' category of the SeS stimulus)

3) *objects from other stimuli* – objects mistakenly drawn in the wrong stimulus category (e.g. a submarine from the SpS stimulus in the 'Cyan' category of the SeW stimulus)

4) *objects in wrong divisions* – objects mistakenly drawn in the wrong division of a stimulus structure (e.g. a ghost from the 'Emerald' category in the 'Cyan' category of the SeW stimulus)

5) *objects in wrong cell* – objects mistakenly drawn in the wrong cell only applies to the SpS stimulus (e.g. a fork in a different cell of the SpS stimulus)

There were very few *drawing* and *other objects* errors (8 and 10 out of 192 drawings respectively) produced across the sessions for all types of stimuli. Therefore, these types of error were not discussed further. Our analysis focused instead on the *objects from other stimuli* and *objects in wrong divisions* errors for all stimuli and the *objects in wrong cell* error for the SpS stimulus, as shown in Figure 5.13.

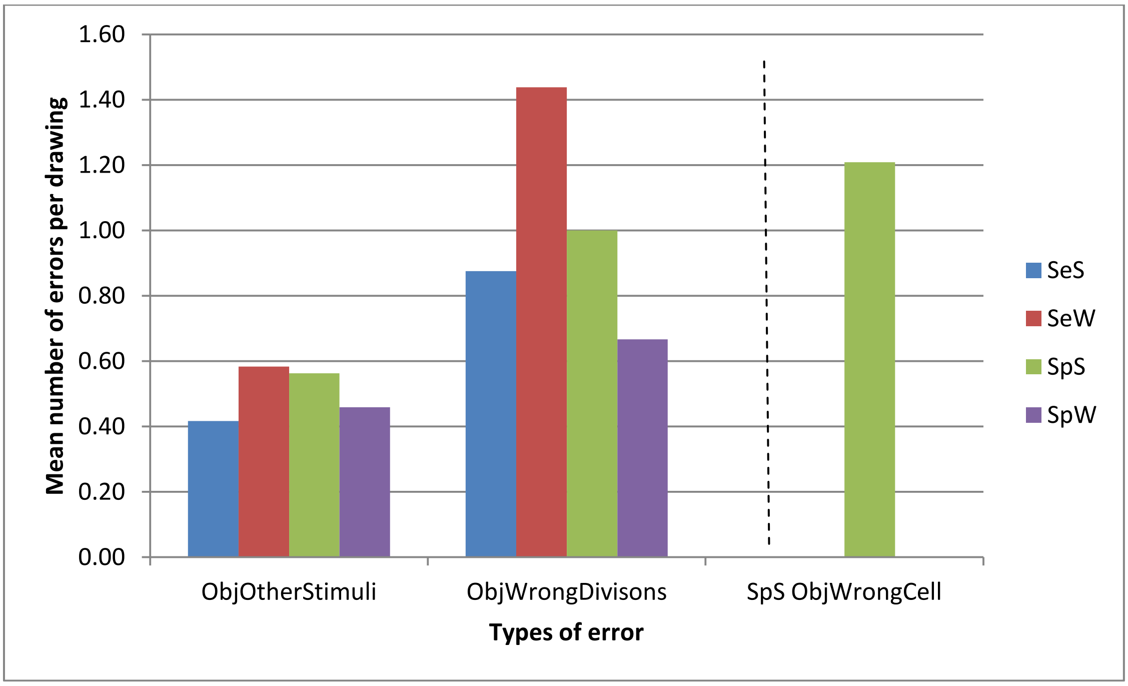
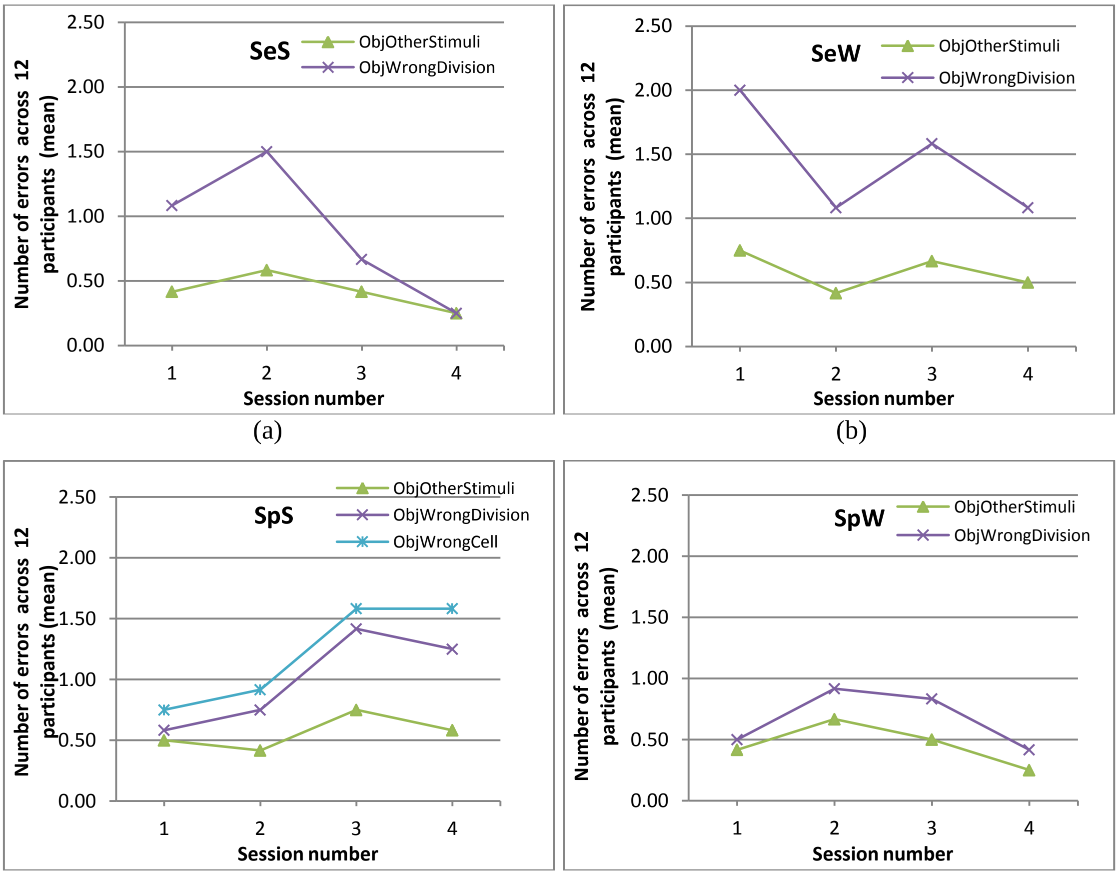



Figure 5.13: Error distribution across stimuli

Generally, as shown in Figure 5.13 all stimuli produced more errors for the *objects in wrong divisions* than for the *objects from other stimuli*. Therefore, confusion errors (i.e. *objects in wrong divisions*) were more common than commission errors (i.e. *objects from other stimuli*) for all stimuli. In Figure 5.13, both types of errors showed a decreasing rate in the following stimulus order: (1) SeW > SpS > SpW > SeS for the *objects from other stimuli* error; and (2) SeW > SpS > SeS > SpW for the *objects in wrong divisions* error.

The ANOVA test for the comparison between all stimuli for the *objects in wrong divisions* and the *objects from other stimuli* errors revealed a non-significant effect. A paired t-test performed for the *objects in wrong cell* errors also showed a non-significant effect between sessions for the SpS stimulus.

Further error types comparisons were made between the stimuli, as shown in Figure 5.14.




(a) (b) (c) (d)

Figure 5.14: Mean of errors for all stimuli

In general, the errors were few for all types of stimuli. As shown in Figure 5.14(a) and (b), however, errors for the SeW stimulus show means at a greater range than the errors for the SeS stimulus. This finding is consistent with the prediction. Although there is a pattern of decreasing errors for both types of stimuli, the SeS stimulus shows greater decrease in session 4 for the *objects in wrong divisions* error than the SeW stimulus. A paired t-test comparison between sessions 1 and 4 for each type of error from both stimuli, however, was non-significant.

The SpS stimulus in Figure 5.14(c) shows an inconsistent trend with the other stimuli errors. In this type of stimulus, errors increase over time with more occurring in session 4 than in 1, which contradicts the prediction. In session 1, errors decrease in the SpW stimulus shown in Figure 5.14(d) giving the least errors produced across the sessions compared to other stimuli.

A further ANOVA test performed between the semantic and the spatial stimuli respectively for each type of error showed largely non-significant effects. This implies that the strong stimuli are comparable, as are the weak stimuli. This is consistent with the prediction.

### 5.4.5 Division transitions

The division transitions measure is used to determine whether the participants treated each division as a chunk by drawing all objects in a slot before moving on to the next. Fewer transitions indicate that the divisions may have been treated as chunks, which is probable for the strong stimuli, while more transitions suggest that participants were less likely to consider the divisions as chunks. More transitions may indicate the not so strong probability that the participants had an organized schema in memory for these stimuli.

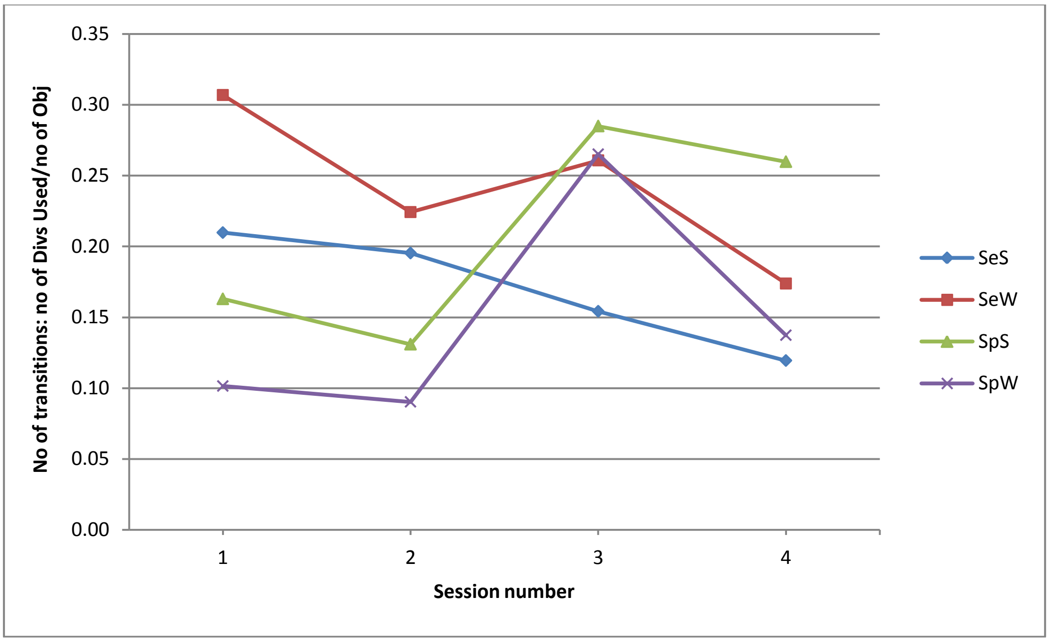


Figure 5.15: Number of division transitions for all stimuli

Figure 5.15 shows the number of division transitions produced for each stimulus taking into consideration the number of divisions used and the number of objects produced across sessions. It is only reasonable to discuss the findings from the division transitions measure by relating them to the previously discussed number of divisions and number of objects measures. This is because discussion of the division transitions is more meaningful and reliable when there are more objects and divisions used during drawings. This enables a greater potential for drawing between divisions that may indicate the use of chunks. On the contrary, fewer objects with more transitions may reduce the pattern of chunks.

Figure 5.6, presenting the number of objects in sessions 1 and 2, showed very few divisions' usage and very few objects were drawn in all stimuli with an exception for the SeS. Therefore, we need to be careful when interpreting the results from the division transitions. A general inspection in Figure 5.15 showed that the smoothest changing transition trend occurs in the SeS stimulus. There were fewer transitions given that the total number of objects drawn and the divisions used for this type of stimulus were the highest, compared to the rest of the stimuli (i.e. SeW, SpW, SpS). The transitions for the SeS stimulus gradually decreased over time, consistent with the effect of stable learning. More transitions occur for the SeW, SpW and SpS stimuli in sessions 3 and 4 than the SeS, although these correspond to the use of more divisions and more objects.

The effect of improved learning, however, is mostly supported in sessions 3 and 4. This is also evident from the decreasing number of transitions between sessions 3 and 4 for all stimuli. Therefore, further inspection of Figure 5.15 between the strong stimuli showed that the SeS stimulus produced the fewest transitions, compared to the greatest number of transitions for the SpS. This finding complements the view that learning is easiest for the SeS stimulus and most difficult for the SpS. The lower transition count for the SpW stimulus than the SeW, indicates that the former is an easier type of stimulus for learning. This is also consistent with the findings from the other measures.

### 5.4.6 Division preferences

As previously described in Section 5.1: Introduction, this experiment aims to investigate the effects of stimulus structure on mental schema structure. Therefore, the stimulus structure which has four divisions may correspond to the internal mental hierarchical structure, according to that proposed in Figure 5.3, where each division may be regarded as a chunk. Each type of stimulus, which was designed to have four divisions, may be mapped as four chunks on the same hierarchical level.

If it was purely the division structure that produced the mental schema as argued, the divisions' preferences would be spread out equally, as different participants would use any arbitrary divisions. Taking the SpS as an example, a participant may prefer to use the bottom right division, while another may prefer the top left. This was not quite the case, however, as some division preferences picked by the majority of the participants indicate that certain branches of the hierarchy were preferred to others to some extent. Otherwise, if there was no consistent pattern of division preference, the underlying mental representation may not appear purely in a tree-like format, but may represent a formation akin to a lattice with possibly overlapping branches. Therefore, this analysis aims to find whether the participants have a tendency to choose certain preferred divisions over others in each stimulus. This may indicate the potential form of the underlying structure of the mental schema.

An example of the preferred division choice is that a participant may prefer to start the drawings with the ‘Soft’ category as the first point at each session when given the SeW stimulus. As the analysis of the preferred divisions in all sessions increases the complexity of interpretation of the results, however, we are only considering the use of the first preferred divisions at the beginning of drawing in each session. This measure will reveal if the participants exhibit a general pattern for the selection of the first preferred division in each stimulus structure across the drawings.

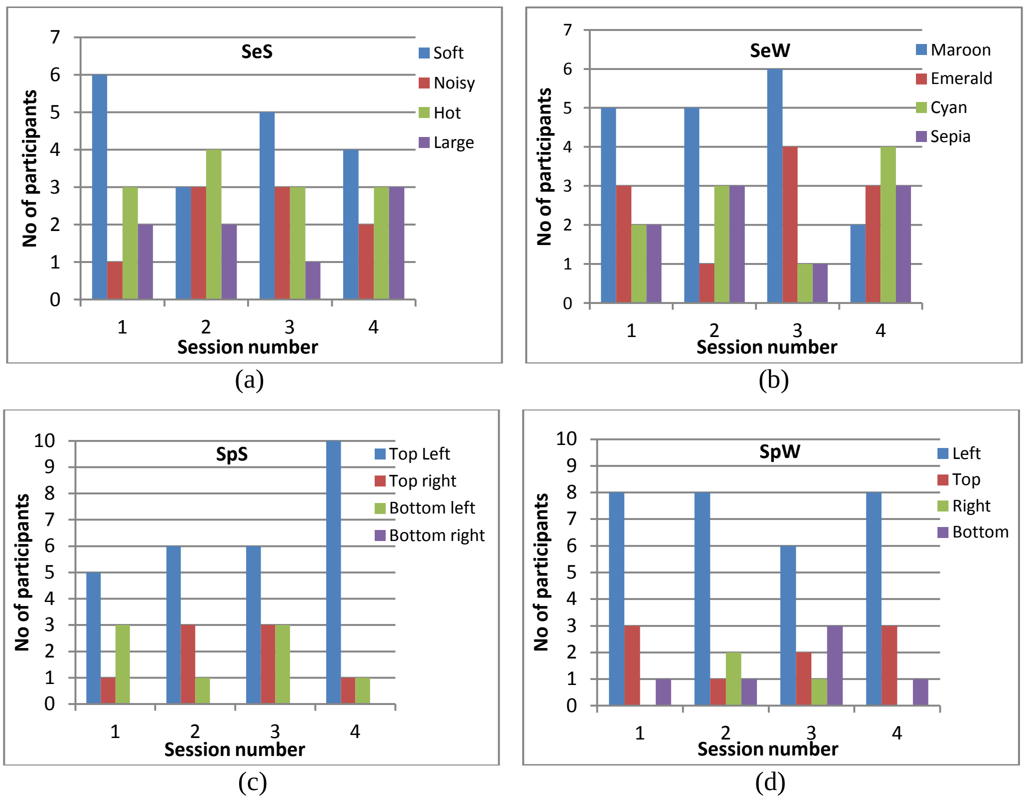



Figure 5.16: Participants’ preference of recall in the first division choice

Figure 5.16 shows the frequency of the participants’ choice of divisions across the sessions for all stimuli. It was found that they were using the structure as presented on the stimulus even when these divisions were counterbalanced and presented in a different order in each drawing task. They also showed preferences for some divisions over others at the beginning of each drawing. As shown in Figure 5.16, generally, the preferred choice among the participants at the beginning of the drawings (i.e. first division) across the sessions was (1) the 'Soft' category for the SeS stimulus (except for session 2); (2) the 'Maroon' category for the SeW stimulus (except for session 4); (3) the top left (out of four symmetrical boxes) for the SpS stimulus; and (4) the left side for the SpW stimulus.

As for the spatial stimuli, the preference for starting at the left and top left may have some relation to the motor actions involved in drawing and the common strategy of drawing processes among right-hand drawers. These come in addition to the common left-to-right writing convention in most languages, including English. It is difficult, however, to explain further why the 'Soft' category for the SeS stimulus and 'Maroon' category for the SeW stimulus were more favourable at the beginning (first division choice) of the drawings than other divisions. It may have been that the objects in the 'Soft' and 'Maroon' categories were more salient and familiar than the objects in the other categories, thus, increasing the activation in memory for their retrieval. Nevertheless, it is impossible to measure the degree of object familiarity and the difficulty in remembering objects from this set of data.

### 5.4.7 Verbal reports

The retrospective interviews were performed to verify whether the participants made use of the stimulus properties, such as semantic associations between the objects and spatial cues given in the stimuli, rather than other strategies unrelated to the experiment design. They also aimed at checking whether the 15 seconds of study time was a successful design. Further, the participants were asked to rate the level of difficulty for each stimulus at the end of the experiment. In an ascending order from the easiest to the most difficult type of stimulus structure, as shown in Figure 5.17, the stimuli were rated thus: SeS > SeW > SpW > SpS.

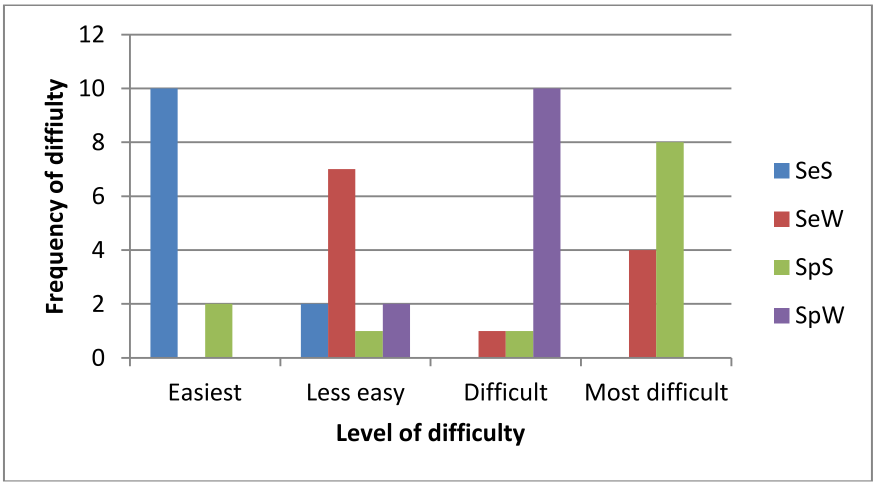



Figure 5.17: Rating of stimuli according to level of difficulty

Further, verbal report analysis investigates the types of learning strategies generally adopted by the participants. The reported strategies were categorized in three sets related to: (1) *semantic* (meaning); (2) *spatial* (space and location); and (3) *other strategies*. It was relatively easy to code the verbal reports, as the majority were quite straightforward. Hence, inter-rater reliability, or second-rater judgement, was not used.

The *semantic* category consists of strategies that are further divided into two categories called *label* and *other semantic-related* strategies. The *label semantic* category consists of strategies related to the labels shown on the semantic stimuli. Examples are associating the first object to the given label for the category and the following to the first object of that category (e.g. associating the bicycle with the 'Sepia' category label followed by an association of the swimming pool with the bicycle) and using the labels shown on the stimuli (e.g. associating the candle to the 'Hot' category label). The *other semantic-related strategies* category consists of strategies based on meaningful associations, such as performing the generate and test method, using mnemonics (e.g. assigning the first letter of the name of an object to the first letter of the named category, such as 'C' for car to 'C' for 'Cyan'), remembering the relations of the objects by composing stories or narratives and producing a different (idiosyncratic), yet meaningful, categorization of the objects other than that presented in the stimulus.

The *spatial* category consists of those reported strategies, which were associated with the use of space and location, such as partitioning areas in the spatial stimulus into regions, remembering the objects according to proximities, pairing objects according to where they were located on the stimulus and appreciating location in a tabular grid format of rows and columns for the SpS stimulus.

The *other strategies* category consists of strategies such as remembering objects because of their uniqueness and complexity or simply because they were the most recognizable objects in a particular stimulus.

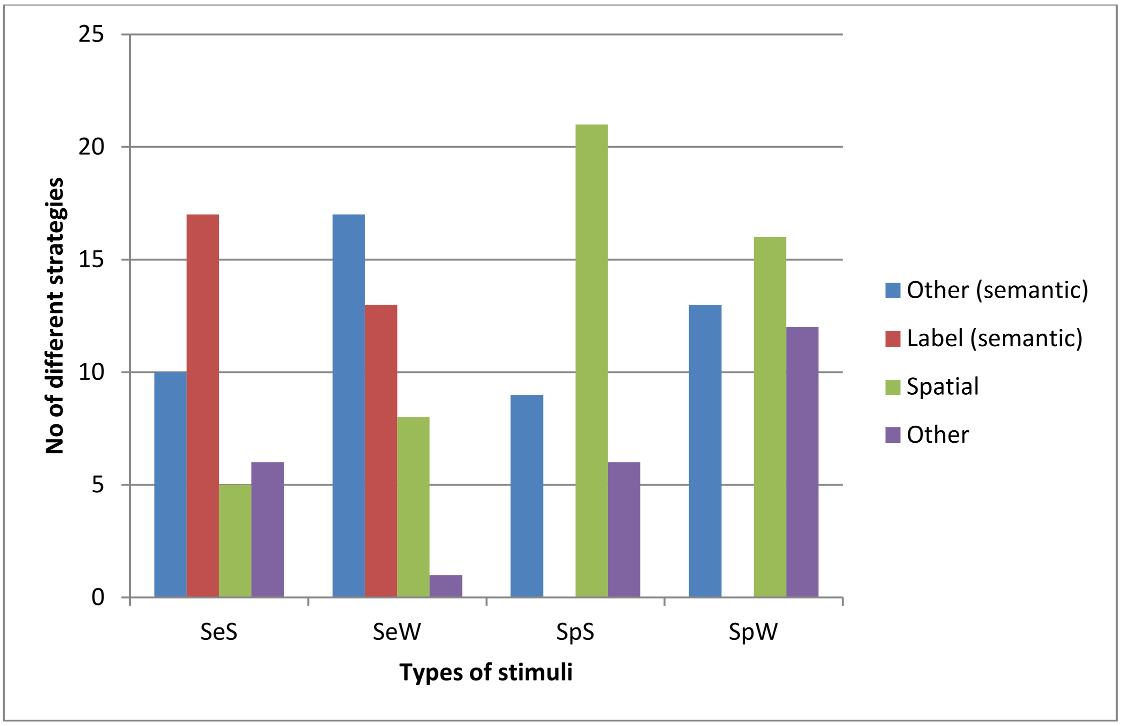



Figure 5.18: Verbal report strategies

Figure 5.18 shows the total count of strategies according to the defined categories for each type of stimulus. Generally, a greater number of semantic related strategies were reported for the SeS and SeW stimuli. A closer inspection showed that the category *label* (i.e. hot, noisy, soft, large) was used more often as an aid for recall than the *other semantic-related* strategies category for the SeS stimulus. In contrast, the participants preferred to use *other semantic-related* strategies than the colour *labels* (i.e. cyan, magenta, sepia, emerald) for the SeW stimulus.

As for the spatial stimuli, the participants reported that, generally, the *spatial* related categories were more helpful during the learning process. This is demonstrated by the greatest count for the *spatial* category reported for the SpS stimulus. Although this finding mirrors that for the SpW stimulus, the *other semantic-related* category and *other* category were also reported by the participants as strategies that influenced their learning. This could mean that participants used different combinations of strategies, such as selecting the easiest or most unique object, using mnemonics or narrative associations to remember the objects for the SpW stimulus. No measures for the *label* category exist for the spatial stimuli, as these types did not have any labels.

## 5.5 Discussion

The main aim of this experiment was to determine whether participants used the stimulus structure to induce the underlying mental schema structure. This was achieved by investigating the effects of weak and strong stimulus strengths applied to the semantic and spatial stimuli for learning. It was predicted that the strong stimuli would be easier to learn than the weak. Thus, the SeS stimulus was predicted to be easier than the SeW stimulus, and the same would apply for the spatial stimuli. Furthermore, the SeS stimulus was predicted to be comparable to the SpS, as the SeW would be to the SpW.

It was found that, in ascending order from easiest to most difficult, the stimulus type more conducive to learning was: SeS < SpW < SeW < SpS. The measures (i.e. number of objects, number of divisions usage, pause levels, error rates, division transitions, division preferences and verbal reports) used in this experiment, summarized in Table 5.5, all contribute to explanations for the differences in learning outcomes detected across the stimuli. Discussion will be based on the converging collective evidence from these measures with regard to the hypothesis and the findings. The results from this experiment provide a coherent picture of the mental representation of knowledge acquired from the drawings data.

Although the participants in this experiment had been expected to learn more easily using both of the strong stimuli, the experiment has concluded that learning was the easiest only under the SeS stimulus. Surprisingly, the SpS stimulus was found to be the most difficult of all stimuli for learning. Between the weak stimuli, evidence showed that learning was easier for the SpW stimulus and more difficult for the SeW.

Discussion will centre on the collective measures insofar as they can provide an explanation for the underlying mental structures. Previous investigators (Palmer, 1977; Cheng & Rojas-Anaya, 2008) suggested that mental representations are not only hierarchically organized, but also that information that constitutes the mental schemas is structured in the form of chunks. Little is presently known, however, about the organization of mental schema structures for graphical information, especially when learning involves semantic and spatial information of different strength levels. How will the findings from this experiment provide evidence for the claims on the underlying schema structures? Owens, Bower, and Black (1979), for example, indicated that learning materials, including verbal, textual and pictorial, that provide strong associations are a better source of cues (e.g. semantic relevance between categorical memberships) for the learner. They induce a strong activation (i.e. one that primes the memory trace more actively) of the most relevant concept(s) of the target information for its encoding, easier retrieval and longer preservation, thus facilitating learning. This effect, which produces better memory performance, is a coherent process that promotes organized information and has been claimed to adopt a hierarchical representation.

Table 5.5: Summarized results from Experiment 3

<table>
<tr><th></th><th>SeS</th><th>SeW</th><th>SpS</th><th>SpW</th></tr>
<tr><td>Number of objects</td><td colspan="4">SpS < SeW < SpW < SeS</td></tr>
<tr><td>Number of divisions usage</td><td colspan="4">SpS < SpW < SeW < SeS</td></tr>
<tr><td rowspan="2">Pauses</td><td colspan="4">L1 < L2</td></tr>
<tr><td>L2 < L3a</td><td colspan="2">pattern not obvious (L2 ≈ L3a)</td><td>L2 < L3a</td></tr>
<tr><td>L1 pauses</td><td colspan="4">Over time: constant; Session 4: converged</td></tr>
<tr><td rowspan="2">L2 & L3a pauses</td><td colspan="4">Over time: decrease</td></tr>
<tr><td colspan="4">SeS < SpW < SeW < SpS</td></tr>
<tr><td rowspan="3">Error types</td><td colspan="4">Objects wrong slots > Objects other stimuli</td></tr>
<tr><td colspan="4">Objects wrong slot: SeW > SpS > SeS > SpW</td></tr>
<tr><td colspan="4">Objects other stimuli: SeW > SpS > SpW > SeS</td></tr>
<tr><td>Verbal reports</td><td colspan="4" rowspan="2">Easiest to most difficult: SeS > SeW > SpW > SpS</td></tr>
<tr><td>Stimulus rating</td></tr>
<tr><td rowspan="2">Strategy use</td><td colspan="2">Semantic-related</td><td colspan="2">Spatial-related</td></tr>
<tr><td>Label</td><td>Other-semantic</td><td>Spatial</td><td>Spatial, Other-semantic, Other</td></tr>
<tr><td>Division transitions</td><td colspan="4">Session 4: SpS > SeW > SpW> SeS</td></tr>
<tr><td>Division preferences</td><td>Soft</td><td>Maroon</td><td>Top-left</td><td>Left-side</td></tr>
</table>

### 5.5.1 Effects of stimuli

A summary of the results that support this pattern will be discussed first, followed by an interpretation of these findings, which are either consistent or inconsistent with the findings of previous research.

#### 5.5.1.1 SeS: the easiest type of stimulus

Consistent with our prediction and the rate of stimulus difficulty as reported by the participants, the SeS stimulus was found to be the easiest to learn. This is supported by the following measures, which determined that the SeS contains: (1) the highest number of objects drawn, (2) the highest division usage count, (3) the shortest L2 and L3a pauses, (4) the fewest transitions between divisions and (5) the least errors across all sessions. Furthermore, as the participants did more sessions, the number of drawn objects increased, more divisions were used, error rates decreased, the number of division transitions decreased and pauses between objects and between divisions (first transition) decreased.

In line with the prediction, further results from the comparison between the semantic stimuli showed that the SeS stimulus was more easily learned than the SeW. The following measures support this finding: (1) higher object count, (2) more divisions were used, not just during the early sessions but, across all sessions, (3) lower L2 and L3a pauses and (4) fewer errors in the SeS stimulus than the SeW.

A few findings from the SeS stimulus, however, contradicted the prediction. A comparison between the strong stimuli showed that the SeS was better learned than the SpS. Therefore, these stimuli are not comparable. This is evident by: (1) more objects drawn, (2) greater division usage count, (3) lower L2 and L3a pause values and (4) lower error rates across most sessions in the SeS stimulus than in the SpS.

It is possible that the SeS stimulus was the easiest to learn due to the strong semantic associations between the category labels and their members, which share the same attributes. This may provide effective retrieval cues that facilitate learning. In support of this, Underwood (1969) had suggested that category names are an important associative attribute. Also, Tulving and Pearlstone (1966) empirically demonstrated that category names are an effective retrieval cue. Our findings from the SeS stimulus that showed the greatest number of divisions usage across all sessions, also supports this notion, whereby strong associations between category names and objects are likely to enhance learning performance, even at the first attempt of recall during learning.

Therefore, strong and meaningful associations between objects and category labels may correspond to a more organised mental hierarchical structure, as discussed in the hypothesis (Figure 5.3). Furthermore, it could be that the strong association between labels and the types of objects belonging to the 'Soft' category, for instance, such as feather, toilet rolls, shirt and socks activate stronger cues during the recall process. The 'Soft' category name may prime and spread activation to the most relevant objects that are more strongly associated with the 'soft' context, such as feather and toilet rolls. This finding extends the claim made by Goldstein (1958) that class-membership identification is influential in the recognition of familiar objects. Therefore, a member of a class is more easily recognized and retrieved from memory if the class has common properties that represent the member. This notion is consistent with that proposed by Broadbent (1971), where properties of a class are accessible prior to item retrieval. In addition, the easier learning characterising the SeS stimulus supports the view of Cutting and Schatz (1976) that closely related items from a category involve faster processing than inter-category items. Thus, it is reasonable to claim that this effect may facilitate the formation of mental schemas into an organized structure. Given that retrieval is a top-down process, the categorical attributes will be higher than the objects for each category, while the whole stimulus would be at the highest level. These findings have also confirmed that objects are not remembered individually. Instead, a more sophisticated strategy is employed by using more general rubrics, such as category names, to facilitate encoding and retrieval.

We now have a general idea of the potential organization of the mental schema for the SeS stimulus, but how does pause data provide an explanation for the retrieval process from this kind of structure? The significant L1 pauses between the third and fourth sessions showed that pauses used to draw between the elements of an object become shorter towards the end of the experiment. This is due to the improvement of motor processes over time and through practice, as indicated by the Power Law. In addition, fastest recall between objects within and between different categories, as indicated by the shortest L2 and L3a pauses, may be an effect of the successful use of adjective attributes as cues that prime strong activation for the relevant objects; hence, facilitating retrieval. A similar effect was reported by Pollio et al. (1968, 1969), whereby the structured material, such as the SeS stimulus, is organized hierarchically making the search process easier and faster in this multi-level type of organization, using either a depth-first search or a breadth-first search strategy. In addition, retrieving members of a category for a particular attribute may effectively limit the search process to that category alone, thus reducing the amount of time spent searching.

Furthermore, there is a good chance that objects within the same category are entirely drawn in divisions before those in other categories, indicating that participants used the given division structure as anticipated. This effect can be seen by the distinct L2 and L3a pauses separation as shown in Figure 5.8, which further indicates that the divisions are organized as *chunks* forming a hierarchical structure. This is in line with the notion of *response bursting*, where elements of these bursts comprise meaningful units defined by a pattern of associative and semantic relations that is common to all items (Bousfield, Sedgewick, & Cohen, 1954; Pollio et al., 1968). The lower L2 than L3a pauses across all sessions support the claim that less time is required to recall between objects within a division than to traverse the hierarchy to retrieve objects from different divisions (or categories). This finding is also consistent with that reported by Eysenck (1974) in an experiment of word list recall of different categories, where a significant positive correlation (.55) was found indicating that retrieval was organized or clustered in categories. The lowest number of transitions between divisions found towards the last two sessions for the SeS stimulus has also strengthened the explanation that these divisions are treated as chunks, thus increasing the likelihood of hierarchical organization for this type of stimulus.

A greater decrease of errors in the SeS stimulus than the SeW supports the claim that confusion and commission errors were corrected more quickly in the SeS stimulus, due to the stronger association between the labels of category names and the constituent types of objects. The use of category labels over the semantic related strategies present in the verbal reports strengthens the justification that category labels could be used at a higher level of the mental hierarchical structure that cues recall. Furthermore, the preference for beginning the drawings from the 'Soft' category may be an indication that the most familiar category is first primed from memory.

#### 5.5.1.2 SpS: the most difficult type of stimulus

It is surprising that the SpS stimulus was found to be the most difficult type of stimulus for learning. The converging evidence that supports this finding includes (1) the fewest number of objects, (2) the least division usage count, (3) generally the longest L2 and L3a pauses, but the lowest L1 pauses in sessions 1 and 2, (4) more errors than the SpW and SeS stimuli, (5) the greatest divisions transition and (6) the reports that it was the most difficult stimulus across all sessions. This is consistent, however, with the prediction that more objects would be drawn and more divisions would be used in successive sessions. On the contrary, more errors were produced over time.

Therefore, the SpS stimulus was not comparable with the SeS stimulus and that was inconsistent with the prediction. The comparison between these two stimuli is supported by the following results: (1) fewer number of objects, (2) fewer divisions usage count, (3) greater L2 and L3a pause values and (4) more errors produced in the SpS stimulus than the SeS.

A further comparison between the spatial stimuli also revealed findings that were inconsistent with the prediction. This is because the SpS stimulus was found to be more difficult than the SpW, as supported by the following evidence: (1) fewer objects (except in session 1) (2) less divisions usage count, 3) greater L2 and L3a pause values and (4) more errors produced in the SpS stimulus than the SpW.

Why was the SpS the most difficult type of stimulus for learning? A possible explanation could be the symmetrical grid-like structure of the SpS stimulus akin to a tabular format, which is less unique than the asymmetric structure of the SpW stimulus. This finding is inconsistent with Gattis (2001) and Tversky (2001), who argued that learning is facilitated by the use of a tabular format. The symmetric design could have induced weaker episodic memory, as tabular formats are more common and are seen more frequently in everyday activities, thus, weakening the process of memorising the SpS stimulus due to interference, which may cause the faster decay of remembering the related information in this type of stimulus. As a result, this effect could have shadowed the learned tabular material from the SpS stimulus. This finding has some similarities with Goldstein and Chance (1971) who reported that accuracy of recall is poor for a symmetrical stimulus configuration, as compared to an asymmetrical stimulus (e.g. snowflakes vs people's faces). Cherry, Park, and Donaldson (1993) also found that an array of items arranged in a matrix is less visually distinctive.

The lack of effective retrieval cues, as the cells were all of the same size, may be an additional factor for the difficulty the participants experienced during retrieval, where they could have ignored the structure given in the stimulus to facilitate their learning. The SpS stimulus may have provided more cues, instead of better cues. At least with this particular type of stimulus, however, more spatial cues, such as the location of the cells, does not necessarily coincide with more effective cues for encoding and retrieval. This may have, hence, resulted to poorer recall. This may be further supported by the greatest number of L2 and L3a pauses, which may indicate that more processing occurred for this type of stimulus. Therefore, it may be that the SpS stimulus is, in actual fact, a weak type of stimulus unlike that predicted. As a result, the mental schema structure for the SpS stimulus may not be represented in the form of a hierarchical structure, but may even possibly represent a less structured mental schema. This is evident by the lack of consistent L2 and L3a pause patterns, as shown in Figure 5.8, where the processing used to recall between objects from the same division is no different than that between objects in different divisions. In other words, there is the possibility that the participants were drawing objects arbitrarily across the areas without much consideration for the four areas separated by bold lines, which may have not appeared salient to the participants. This can be observed in the greatest number of transitions occurring between the divisions when participants had learned more objects from that stimulus, as shown in sessions 3 and 4 in Figure 5.15. This strengthens the likelihood for a less structured mental organization for the SpS stimulus. Furthermore, the lower L1 pause values in sessions 1 and 2 could be due to two reasons: (1) lower number of objects recalled in these two sessions and (2) the SpS stimulus having an effect on the recall of between the lines of correct objects, which is influenced by the grid-like stimulus layout.

If the information from the SpS stimulus is not encoded in a hierarchical structure, what may be the alternative representation? McNamara (1992) proposed that another type of mental representation for learning spatial layouts is the *metric structure*, where the absolute position of the objects is stored in the spatial memory based on a coordinate system. This type of representation allows for asymmetric attention on the stimulus. This claim was speculative, however, and needed more verification in order to be confirmed. If this possibility is true, it may be that participants tend to focus, or *anchor*, their first object drawing on a certain position on the stimulus, which then primes other objects. As observed on the division preference measure, shown in Figure 5.16(c), an increasing number of participants selected the cell located at the top left of the grid layout in successive sessions as the first anchored object. The top-left area selection as the first division preference in each session indicates that drawing occurs from left to right in the stimulus. This type of strategy is consistent with the left-to-right writing convention in various languages, including English.

If the information is organized in a weak hierarchical structure, however, it may well be that this type of stimulus has a greater depth of hierarchy compared to other stimuli. This is because the stimulus presentation of the SpS had dotted lines within the four major divisions; hence, producing sub-divisions in each of the four larger grids. This may imply that there were more than four divisions, which could potentially introduce another level of difficulty for learning. It may be that the dotted lines were unnecessary or the tabular format could be redesigned to represent a stronger appearance of the SpS stimulus, thus, potentially producing different results than the ones presently found.

Due to the fact that objects were each positioned in smaller boxes within the larger box, a context priming effect could have taken place, where the association between objects and cells could be reconsidered, an example being the assigning of the top-left objects within a single grid of the cells. Furthermore, recall of certain lines of an object may be faster due to the specific position of the object. For example, objects positioned in the sides or corners of the cell could contain stronger cues, rather than being recalled in larger areas without any obvious boundaries. The stronger association between successive objects that could potentially facilitate the recall for each element may have been another reason for the lower L1 pauses for the SpS stimulus. Therefore, the grid layout of the SpS stimulus provided more contexts to prime. As recall for the correct objects was relatively difficult, it is reasonable that the least divisions usage across all sessions would be observed. An increasing division usage, however, means that learning improved over time although the SpS stimulus was difficult. Although the error rate for the SpS stimulus is lower than the SeW, it is somewhat surprising that more errors were produced as sessions progressed (see Figure 5.14). As the grids were of the same size, confusion over the exact positioning of the objects was likely to occur. Therefore, the fact that more objects were placed in the wrong cells indicates that confusion errors were regular, which may further suggest the less organized mental hierarchical structure for this type of stimulus. In the verbal reports for the SpS stimulus, spatial related strategies, such as remembering objects according to spatial proximities and partitioning areas of the spatial stimulus in regions, were most commonly used. This is confirmed by the participants' preference for starting their drawings from the top left of the drawing area in each session.

#### 5.5.1.3 SpW easier than SeW

It was predicted that the weak stimuli were (1) comparable and (2) more difficult to learn than the strong. Therefore, the SeW and SpW stimuli were predicted to produce similar findings based on the measures.

It was found, however, that these weak stimuli were only more difficult than the SeS stimulus and not the SpS. Thus, consistent with the prediction, the SeW stimulus is more difficult than the SeS. Nevertheless, the SpW stimulus is easier than the SpS, which is inconsistent with the prediction. Results from the investigation of the weak vs the strong conditions (excluding the SpS stimulus) have extended the findings reported by previous investigators that strong stimuli, which provide more effective cues, enhance memory performance more than weak stimuli (Thomson & Tulving, 1970; Bäuml, 1998).

As findings for the weak stimuli were the opposite of the strong, as previously discussed, it is interesting to interpret the findings between the weak stimuli themselves. To begin with, however, it is difficult to decide whether one type of weak stimulus facilitates learning better than the other, as not all of the findings from the measures converged.

Although the findings from the anecdotal verbal reports showed that the SeW stimulus was easier than the SpW, the majority of the other findings were not consistent with this report, with the exception of the more divisions used in the SeW than the SpW stimulus. Instead, the following measures may suggest that the SpW stimulus is potentially easier than the SeW (see Table 5.5): (1) more objects drawn, (2) shorter L2 and L3a pauses, (3) more consistent pause patterns between L2 and L3a pauses and (4) fewer errors. The ANOVA showed that these measures were significant between the weak stimuli with the exception of the error rates measure (i.e. errors were not significantly different between the weak stimuli). Across the sessions, the following measures were consistent with the prediction: (1) more objects were drawn, (2) more divisions were used (except in session 2 for the SeW stimulus), (3) the L2 and L3a pauses generally decreased and (4) error rates decreased over time for both types of weak stimuli. More errors, however, (also calculated as the greatest number of errors over all stimuli) were produced in the SeW stimulus than the SpW.

A plausible explanation as to why the SpW stimulus seems to be easier could be the unconventional divisions presentation in the stimulus. This finding echoes Cherry and Jones (1999), who argued that the use of spatial layout (i.e. landmarks, barriers, paths), referred to as the *structural context*, is more effective as a mnemonic aid when there is a less meaningful association between items of the learned material, referred to as the *organization context*. How does the unconventional divisions presentation improve encoding? The distinct division structure may have caused this type of stimulus to be remembered better due to less interference from other external and internal presentations. This type of stimulus structure may have provided better cues during retrieval, thus enabling strong activation, which in effect improves learning. Therefore, unlike the prediction, the SpW stimulus may have actually been considered as a SpS stimulus.

Other measures may collectively suggest that the SpW stimulus is mentally represented in an organized hierarchical structure. For example, the distinct pause separation between the L2 and L3a pauses, as shown in Figure 5.8, which is similar to that found from the SeS stimulus, may indicate that each division is considered as a chunk. Therefore, the participants could have employed a drawing strategy where objects were entirely drawn in each individual division successively. If this is the case, the highest level of the hierarchical structure will employ the whole-stimulus with each division (i.e. left, top, right, bottom) at the level below. Thus, it is reasonable that retrieval time is faster with this kind of stimulus presentation, as shown by the lower ranges for the L2 and L3a pauses than those for the SeW stimulus. This may be related to the *fan effect* (Anderson, 1974), where activation spreads to the related links in the network as a result of connections occurring between the concepts. The notion of the divisions considered as chunks, based on objects drawn together in each division, is also supported by the fact that more objects were drawn with less divisions usage. In addition, it is less likely for errors to be produced if there is an organized mental schema present and the SpW did display the least amount of confusion errors (*objects in wrong divisions*) over all.

It may have been, however, that the spatial location was not the major strategy used as a cue by the participants in order to facilitate learning. The anecdotal verbal reports, which indicated the use of not only spatial, but also semantic and other strategies, have suggested that semantic interpretations could also have been used to remember the objects within and potentially between the divisions. This indicates that apart from using the divisions as a cue to encode and retrieve the constituent objects, semantically related strategies, such as categorization according to the participants' own defined semantic associations drawn between the objects, could influence the structuring of the mental schema. Hence, a more focused experimental design is necessary to confirm these possibilities.

Across the sessions, at least half of the participants preferred to begin their drawings on the SpW stimulus from the left division. Again, this drawing strategy is consistent with the common writing convention in many languages, which begin writing from the left. This division preference measure suggests that some principles of Gestalt theory may not be employed at all levels during drawing. For example, this means the participants could have used the closure principle to distinguish between divisions, but may not rely on symmetry to construct their drawings. Therefore, the order of the divisions may not matter, as they could have drawn the objects in any division.

It is, however, interesting that although the SpW has a more unconventional stimulus layout, the learning outcome superseded that from the SpS stimulus. A possible explanation for this can be found in the more random positioning of the objects in the four divisions partitioned by the horizontal, the vertical and the diagonal lines. Thus, there is no restriction in having to remember the objects in any specified location or position, as required for the SpS stimulus. This constraint could have reduced the cues during encoding and recall, making the objects on the SpS stimulus difficult to remember. It could also have been that the participants were better at remembering objects randomly located in an area, as presented on the SpW stimulus, than objects positioned at specific locations in grids, as in the SpS stimulus. This experiment has replicated the results reported by Stevens and Coupe (1978), where participants encoded spatial relations across regional boundaries.

We have discussed the probable explanations for the easier learning attributed to the SpW stimulus. The next question worth addressing is what makes the SeW stimulus more difficult than the SpW? The poorer recall of inconsistent items for a category observed in this experiment extends the results reported by other investigators, such as Tulving and Pearlstone (1966), Collins and Quillian (1969, 1970), and Thomson and Tulving (1970). The weak association between the colour label and its objects may have produced less effective cues, hence weaker activation that resulted in poorer and more difficult retrieval. This may be an effect of a less organized mental schema. It may take longer to search for the related information as more connections are present to link the various concepts that belong to each type of object, which is consistent with the greater L2 and L3a pauses observed in the SeW stimulus. Therefore, there is a high probability of interference and confusion occurring for the retrieval of the correct objects for the respective type of colour label. This explanation is supported by the confusion (*objects in wrong division*) and commission (*objects from other stimuli*) errors that were greatest for the SeW stimulus.

Similar to the SpS stimulus, the inconsistent pauses pattern between L2 and L3a pauses, shown on SeW, may also indicate that this type of stimulus may either have a less organized hierarchical structure or not be mentally represented under a hierarchical organization. This means that there was no time difference between drawing objects within and between divisions, indicating that each division is not considered as a chunk. Thus, it may not have such a structure in the mental schema. Fewer objects drawn but more divisions usage than the SpW stimulus further suggests that object drawings are more random across the divisions, thus, limiting the chances of each division being represented as a chunk. An alternative explanation would be that the drawings of these random objects are meaningfully grouped according to idiosyncratic categories depending on the existing knowledge and experience of each participant.

Findings from the SeW stimulus imply that semantic cues do not necessarily facilitate encoding and retrieval, but more importantly they are highly relevant to their constituent items. This has also been reported by Collins and Quillian (1969), Smith, Shoben and Rips (1974), Rosch and Mervis (1975), McKoon, Ratcliff, and Dell (1985). If the presented cues are not effective, participants can adopt other potentially more effective learning strategies, as was verbally reported and demonstrated by the use of *other semantic* strategies more often than the presented colour *labels* category. For example, the general use of mnemonic strategies by associating the first letter of the colour label with the first letter of the constituent objects is similar to that reported by McKeithen et al. (1981).

Between the participants, the preference of using the 'Maroon' category at the beginning of the drawings in each session (except session 4) may indicate that its constituent objects were the most salient to memorise. The present data, however, is not sufficient to explain why the 'Maroon' category was preferred to the other colour labels. It may have been that objects within this particular category had stronger associations, which may have rendered them semantically more relevant with each other. This explanation, however, is speculative and more investigation is needed.

### 5.5.2 Effects of pauses: In the order of L1 < L2 and generally L2 < L3a

Across all stimuli, the pause levels were generally found to be in an ascending order of L1-within object pause, L2-between objects pause and L3a-first transition between divisions pause. More specifically, this effect is clearly present for the SeS and SpW stimuli, but is less obvious for the SeW and SpS stimuli. In line with the previous discussion, the mental schema for the SeS and SpW stimuli is likely organized in a more structured manner composed of chunks that correspond to a division from these stimuli, as opposed to the less structured organization of the SeW and SpS stimuli, where divisions may not be considered as chunks. This is supported by the distinct separation between the L2 and L3a pauses for the structured stimuli, while these pause patterns were less obvious for the less structured stimuli. Therefore, it is reasonable that these structured stimuli provide facilitating cues more effectively than the less structured stimuli, thus, producing easier and faster retrieval due to the greater activation spreading among the related concepts. As a result, if chunks form the mental schemas for the more structured stimuli, traversing between the divisions in the hierarchical structure (L3 pauses) takes longer than the time used to retrieve between two objects (L2 pauses). On the contrary, divisions from the less structured stimuli may not correspond to chunks forming the mental schemas, if the pauses used to recall objects within and between divisions are comparable. This effect was demonstrated in this experiment.

One might think that the effects from these pauses may be due to the shorter distance between the objects as located in the stimuli, where they are closer in space rather than in the hierarchical mental representation. Previous investigators, however, have demonstrated that spatial information (Stevens & Coupe, 1978; Mandler & Ritchey, 1988; McNamara, 1992; Cherry & Jones, 1999) is organized. Thus, the pauses are an effect of the searching for the relevant objects during retrieval. This involves traversing the organized schema, rather than the physical distance between the objects as presented on the stimuli or the actual environment (Ratcliff & McKoon, 1981, Hirtle & Jonides, 1985; Merill & Baird, 1987; McNamara et al., 1989; Holding, 1992, 1994). The faster priming for L2-between objects within the same region, compared to the slower for L3a-between objects in a different region, is consistent with McNamara (1986). This result indicates that objects in the same division are more readily available in the participants' memory than objects in different divisions, regardless of the distance between them. This interpretation is consistent with the partially hierarchical theory, as proposed by McNamara, where information from different regions is stored in different branches of the partially hierarchical mental representation.

The lower L1-within object pause than the L2-between objects pause for all stimuli is consistent with the findings from Experiments 1 (Obaidellah & Cheng, 2009) and 2, as well as previous similar work (Cheng et al., 2001). The L1 pause results confirmed that the participants were treating all lines within the object as an object itself. This indicates that all lines within an object were likely more activated to enable faster processing; hence, they were retrieved more easily and rapidly to facilitate drawing performance. Explaining this in terms of the hierarchy, it may be possible that the lines within an object were recognized faster because the line levels for the relevant portion of the structure were activated due to an effect from the object level above. The L2 and L3a pauses that decreased over time, as confirmed by the ANOVA and is also consistent with the findings from Experiment 2, strongly suggests that learning improves as the participants performed more sessions. This is consistent with Cherry and Jones (1999) and also supports the power law of learning theory (Newell and Rosenbloom, 1981; Anderson, 1995).

As confirmed by the ANOVA, the pattern of L2 pauses that occur at different places across the stimuli structures indicates that the retrieval of objects not only became faster over time, suggesting an effect of faster processing, which may be associated with stronger activation as learning improves, but also the rate of retrieval between objects was different between the stimuli. This was demonstrated by the decreasing L2 pauses indicated by the significant sessions from ANOVA, which converged in session 4 suggesting that learning progressively became more stable. Taken together, these results imply that, in general, the learned objects from the respective stimuli become organized in a more structured manner as the participants performed more sessions.

In general, therefore, it seems that the structure of each type of stimulus influences the level of pauses between the objects. In other words, the SeS stimulus, which has the shortest L2 pauses over time, is the type of stimulus structure that facilitates learning the best, as pauses used to recall between objects are reasonably rapid. The semantic priming effect that facilitates the retrieval of subsequent objects from the processing of a related object is consistent with Meyer et al. (1975). A similar effect is demonstrated by the SpW stimulus over the SeW indicating that faster retrieval may occur between the random objects within an unconventional division area, as opposed to the random objects within a division that has weak categorical cues. The findings of the L2 pauses for the SpS stimulus, which contradict the prediction, however, indicate that more time was used to recall between two different objects. This also strengthens the evidence that the SpS stimulus is a difficult type of stimulus with a weaker mental schema structure and, thus, weaker support for learning.

Across the stimuli structure, the L3a pauses show a similar pattern to the L2 pauses in an ascending order of SeS < SpW < SeW < SpS (except for sessions 3 and 4). This finding is consistent with other measures. The ANOVA also confirmed that the time used to traverse the divisions was different across the stimuli and became faster over time with practice. This provides further suggestions that each type of stimulus has a distinct information organization, which means that the level of detail of the mental schema structure may differ from that presented on the stimuli. Furthermore, improved learning over time, as confirmed by the significant session from ANOVA, provides additional evidence for the effectiveness of the structured information organization. This is demonstrated by the decreasing L3a pauses, which indicate the faster processing of traversing between the divisions due to practice.

## 5.6 Conclusion

Findings from this experiment have revealed that the four stimuli examined produced different learning effects. The semantic and spatial stimuli differed in terms of the manipulation of stimulus strength (i.e. weak vs strong). This section will discuss the overall implications of these stimuli on learning.

Consistent with the findings from previous literature (Collins & Quillian, 1969; Smith et al., 1974; Rosch & Mervis, 1975; Whitney & Kunen, 1983; McKoon et al., 1985; Howard & Kahana, 2002), it is reasonable to conclude that meaning is important to facilitate learning. This is also shown by the results found from the SeS stimulus. The category labels of the SeS stimulus seem to provide an effective cue for the recall of objects. The category could possibly exist at a higher level of the mental hierarchical structure, whereas at a lower level each category label has a set of objects that share similar characteristics. It is important, however, to emphasize that meaning is fully effective only if the category has a strong association with the materials to be learned, such as the objects for the SeS stimulus. Meaning is less effective when weak or more arbitrary associations exist between objects and labels, as demonstrated by the SeW stimulus. It is also possible that it is difficult to redefine an existing mental schema that already has strong associations between the objects and their corresponding type of category, as specified by the *encoding of specificity* theory (Tulving & Thomson, 1973).

Participants have a concrete conceptual mental schema of an object that relates to a certain category. Therefore, when they are deliberately required to assign an object to a category that may not be consistent with their existing mental schema of the object, they might find it difficult to reassign it in order to either redefine the existing schema or form a new one that has an equal level of strength between the label and the object as that of the existing schema. For example, a swimming pool could have a strong association with the colour cyan. In the SeW stimulus, however, the swimming pool was deliberately assigned to the 'sepia' category. Therefore, reassigning the swimming pool to a yellow-like category, may not produce a similar effect to the existing 'swimming pool-blue' association from the participants' own mental hierarchy.

A question worth raising is: Does the use of spatial information provide a similar learning effect as the use of semantic information?

It was predicted that the SpS stimulus corresponds to a hierarchical structure, which could be broken down to further lower levels in the order of divisions, objects and elements of the objects. Previous literature (Gattis, 2001; Tversky, 2001) have emphasized that learning spatial-related information can be facilitated by the use of the tabular format consisting of rows and columns. This structure, however, did not fit well, at least with the learning of 2D graphical objects. The reason may be that the tabular format is more effective for other types of material, such as lists of words. The dotted lines in the SpS stimulus may have introduced greater complexity, as opposed to presenting a simpler form of only four main divisions without dotted lines.

The SpW stimulus seems to have a greater learning effect than the SpS. This may be due to the uniqueness of the divisions presentation in the SpW, which could be a stronger cue for learning. Distinct areas contained the objects, separated by horizontal, vertical and diagonal lines. Each of the distinct areas may correspond to a category, such as left, top right, right and bottom. This may further correspond to an organized mental hierarchical structure, which places these categories at higher levels in the hierarchy. This may well be the reason behind the easier learning experience, compared to the structure of the SpS stimulus.

It was predicted in Experiment 2 that the effects of learning could be measured in fewer sessions. Although the evidence from the collective measures indicates that learning reached the ceiling level quite rapidly in this experiment as well, the effects of learning by the different stimuli would be more obvious if the experiment was performed in more sessions. This is because in the present study, we did not get sufficient L3b-return transition pauses and transition counts data over four sessions than from Experiment 2, as a few of the participants may not have learnt the stimuli adequately. Therefore, performing this experiment with the addition of two or three sessions may result in more informative findings.

In addition, during this experiment the participants were given 15 seconds to recognize the objects on the stimulus after each Copying task. This duration proved exactly right, as the participants displayed a remarkable learning performance across the six sessions.

# Chapter 6 Discussion and Conclusions

*It is only by drawing often, drawing everything, drawing incessantly,*
*that one fine day you discover to your surprise that you have rendered something in its true character*
*(Camille Pissarro)*

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## 6.1 Introduction

The primary aim of the research presented in this thesis was to investigate the factors that facilitate learning when different graphical material is presented to the learner in order to identify the strengths and limitations of these types of material. A series of experiments was conducted to investigate the effects of chunking and schemas in learning by drawing with the aim of developing a theory to inform graphical material design. More specifically, the experiments investigated the effects of stimulus presentation that manipulates semantic and spatial information in order to determine how they affected the participants' learning performance over a specified period. The findings from these experiments were explained in relation to how chunks formed the underlying mental schema in a hierarchical format.

This chapter will outline the key findings from this research and the implications they bring for learning with graphical materials, along with suggestions for the design of these materials. The first section will emphasize the results of each experiment considering chunking, which affects the organization of mental schemas, in relation to pause analysis and the use of semantic and spatial information to facilitate learning. The following section will discuss the effects of spatial and semantic coding in learning with drawings. The discussion will be based on strategies of learning. This includes an examination of whether pause analysis provides an appropriate method for the assessment of learning from graphical materials and which are its potential benefits. We will also review the scope and limitations of the present study and consider how the research findings could be developed in future research. Finally, the results from this research are used to make recommendations for graphical material design, particularly for the scientific and technical domains.

## 6.2 Summary of research and key findings

This section summarises the findings from the three experiments conducted in this thesis and relates them to the existing literature on the subject.

### 6.2.1 Experiment 1: Role of chunking and schemas in drawing a complex abstract diagram

Our first experiment, which served as an exploratory study, investigated the effects of chunking with various modes of drawing (i.e. Tracing, Copying, Immediate and Delayed Recall) using the Rey figure as a single stimulus. The Rey Figure was chosen for different reasons. Firstly, it consists of straight lines, which yields less complicated drawings allowing the use of the GPA method. This figure is complex enough, however, to allow for an evaluation of whether chunks of graphical information are organized in a structured manner in a mental schema structure and for an investigation of the kinds of chunks and schemas present in memory. Secondly, the elements of this figure are considered to be spatially organized, as demonstrated by the relations between them, which make up putative patterns that are arranged in certain positions in order to make the figure recognizable.

The Rey figure has been used mainly in psychological experiments to assess cognitive abilities, such as memory, attention and visuospatial processing in the ability to plan, organize and assemble complex information (Binder, 1982; Waber & Holmes, 1985; Shin et al., 2006). The assessments in these studies employed various criteria, including scores related to location, accuracy and organization. For example, the standard Osterrieth's scoring criteria proposed by Lezak (1983), reported that Osterrieth defined 18 units of drawing from the figure, each of which corresponded to perceptual chunks, which may have been selected on the basis of the Gestalt principles. This approach in scoring is consistent with that used in our experiment. The scoring may reveal that people, in general, do tend to chunk or group elements based on perceptual similarities, which further implies that these chunks are organized. The scoring criterion, however, does not describe how these chunks are structured mentally. Thus, these scores answer to the question of *what* elements and chunks are produced, rather than *how* the component parts of the Rey figure are organized. We argue, hence, that the existing Rey Figure scoring criterion has not considered how chunks of elements in the figure are organized in the drawings, which would help us uncover the underlying mental structure of this type of figure.

In other words, the scoring is focused on evaluating the *product*, rather than the *process* involved during abstract-figure drawing. Accordingly, the majority of previous studies have investigated the outcome of the drawings, such as the accuracy of production, error rates and production style (Rosselli & Ardila, 1991; Shorr, Delis & Massman, 1992; Kirkwood et al., 2001). Recognizing this limitation, the Rey figure experiment reported in this thesis contributes to research from the *process* perspective. This point of view is useful in formulating questions regarding the underlying structure of perceptual chunk organization, the order of the graphical production and the strategies applied when learning involves the drawing of structured diagrams.

Our study empirically confirms that parts of the Rey Figure are commonly chunked on the basis of shared characteristics consistent with the Gestalt principles of perception, such as proximity, symmetry, continuity and similarity. This effect was more evident from the shorter L1-within pauses, than the L2-between pauses, as elements within a pattern are more commonly drawn together, before those from other patterns. Along with the consideration of the pause data and the tendency of participants to produce the patterns in the order of *frame*, *inner* and *outer* groups, this finding empirically supports the theoretical prediction of van Sommers (1984), who claimed that the Rey figure is structured in a hierarchical manner. Drawing in this manner is also consistent with the argument of Bouaziz and Magnan (2007) that figures are drawn from the outside shape to the inside, according to their proposed theory of "Centripetal Execution Principle."

To the author's knowledge, however, no research so far has demonstrated how the components from the Rey Figure are structured and in what (and how many) levels are its chunks organized. The Rey figure could be hierarchically structured in a manner where the highest level encompasses the whole-figure, followed by all putative patterns at the level below and the lines for each pattern at the lowest level leaving the hierarchy with three levels, as shown in Figure 6.1(f). Findings from this experiment, however, enable us to specify that the chunk organization of the Rey Figure may be represented in four levels in the order of: whole Rey Figure → three group patterns (i.e. frame, inner, outer) → chunks for each group pattern → individual lines for each pattern, as shown in Figure 3.22. This representation is consistent with Palmer's (1977) notion of a multilevel perceptual organization of elements.

At the level of drawing sequence (i.e. the order in which each line was produced), the participants started with the largest rectangle pattern, which afterwards restricted the drawers' choice to those inner patterns within the large rectangle, before continuing with the outer parts of the Rey Figure. This implies that the pattern of drawing involves a technique of producing an outline that stems from a larger overview of the entire figure before smaller and more focused patterns are drawn. Bouaziz and Magnan (2007) reported similar findings with the drawings of simpler patterns. Although Bouaziz and Magnan demonstrated that this was notable in a Copying task, our experiment further suggests that this method of drawing, which proceeds from the outer to the inner patterns, is potentially applicable to other modes of drawing, including Tracing and Recall from memory. The process of drawing in this specified order may have some relation to the use of spatial schemas, such as location, orientation and the relation between the elements based on their position. For example, beginning the drawing by outlining the pattern, which constitutes the frame group, may in part provide spatial cues for the drawer to draw the related patterns that form the inner and outer groups.

This is consistent with the notion of a schema structure that is composed of *slots* and *fillers*. At a higher level, we may predict that the spatial schema for the Rey Figure consists of 3 *divisions* derived from the frame, the inner and the outer groups. The contents of each division are occupied with the corresponding patterns (known as the *fillers*). The majority of the participants executed their drawings in the division order of: outline, moving to the inner, followed by the outer group of elements. This may further indicate that there is a dependency factor between the divisions. Therefore, based on this pattern of drawing, it is necessary to begin from the frame group before continuing with the inner and the outer groups. The dominant strategy applied in this approach to drawing was the depth-first search strategy. The participants, however, may employ the breadth-first search when a pattern from any of the already drawn groups was forgotten. In our data, none of the participants picked as their starting point of pattern drawing either the outer or the inner group. Thus, this emphasizes that this approach is different to what it would be if semantic interpretation were used as a recall method and access to meaningful categories was more independent. In this case, categories could be accessed in any order. Hence, if a semantic schema was largely used in the drawings of the Rey Figure, a participant would not follow such a rigid drawing sequence. Therefore, at least in the case of the drawing of an abstract shape, such as the Rey Figure, there is an indication that spatial schemas may have a larger role to play than semantic information. We may not rule out, however, the possibility that a semantic interpretation may have been used at a lower level, in order to facilitate memory for the learned patterns. This claim is made on the basis of the informal verbal reports, where a few of the participants described using mnemonic methods, such as associating certain patterns of the abstract figure to other meaningful shapes (e.g. fish, a warehouse, the logo of a bank).

Another point worth noting from this experiment is the effect chunks had on the four drawing modes, namely Tracing, Copying, Immediate and Delayed Recall. The participants appeared to be using chunking in all tasks, even though this is present to a lesser extent in the Tracing tasks. If chunks were not being used at all in the tasks, then elements would be produced rather haphazardly. As a result, the L1 and L2 pause values would be indistinguishable. The consistent pattern (L2 > L1), however, which was significantly different for all tasks, including Tracing, strengthens the claim that chunks have a causal role in the drawings, where selection of the elements that form a chunk pattern is consistent with Gestalt patterns. Across the tasks, the L1 pause patterns were similar for all sessions, indicating that in all tasks the same selection of elements constituted a chunk. The L2 pauses, however, were found in an ascending order in: Tracing < Immediate Recall < Copying = Delayed Recall. This suggests that pauses for recall between the patterns for these tasks were substantially different, with the exception of the Copying and Delayed Recall tasks, as comparison between these two was non-significant.

As the effect of chunking is not so apparent in the Tracing task, L2 pauses are expected to be the shortest. This happens because tracing the Rey figure may not necessitate elaborate retrieval from the long-term memory. Furthermore, the nature of the Tracing task itself and the experiment, which did not include any study time, imply that recall must have taken place from the short-term memory. Thus, even when relying on their initial impression of the figure, the participants quickly recognised the patterns of elements in the complex figure. The Immediate Recall task, which yielded intermediate L2 pauses across all tasks, suggests that there may be a *recency* effect from the previous tasks at play, as Immediate Recall was always the last drawing task in each session. Therefore, the chunks may already have been strongly activated in the memory, which enables easier and faster retrieval, despite the absence of reference to the target diagram in this task. The longer time required to recall patterns in the Delayed Recall task than in the Immediate, may further support this reasoning, as information decay causes forgetting thus, weakening activation for these patterns. Furthermore, the Copying task was not significantly different to the Delayed Recall task, as by its nature the former necessitates the participants to keep glancing at the target diagram during reproduction. This results in longer sessions. It also requires more involved cognitive processing in terms of recognizing patterns in the stimulus, searching for them in the mental schema, and planning and executing them. In addition, over time the participants had learnt the diagrams well, as by the sixth session L2 pauses for both the Copying and Delayed Recall tasks had converged. This suggests that the Copying task had become effectively a Recall task, as there was no longer a need for the participants to shift their attention to the target diagram when retrieval of patterns from memory was possible.

It is surprising how well the participants learned the Rey figure, which consists of 64 lines that make up 13 patterns, given that it is relatively complex. We expected that learning would occur over many repetitive sessions. The participants, however, achieved a ceiling level of learning, where production of the figure was accurate, as early as the fourth session. This effect further strengthens our claim that chunks have a large role in drawing complex figures. If elements were learned individually, rapid learning would not have occurred at such an early stage. Hence, the effect of a hierarchical structure is quite powerful in drawings of structured diagrams like the Rey Figure. As shown in Figure 3.22, the use of the three divisions, which are broken down into individual chunks followed by specific lines for each chunk, specifies that each large chunk (i.e. group pattern) consisting of smaller chunks (i.e. individual patterns) enables the mind to process information efficiently. This is consistent with the notion proposed by Miller (1956), where the capacity of the mind to process information at any one time spans in the range of 7±2 units. If this idea is taken on board, retrieval ought to be processed quickly in between the short- and long-term memory, 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.

An alternative explanation for the specified order of drawing could be the natural innate abilities of participants that underpin the strategies used for drawing, such as preferences and starting points of drawing. Van Sommers (1984) termed these principles *anchoring*, where drawers in general conform to a systematic technique, such as a clockwise direction when producing a circle. Such conformity to production routines may contribute to the patterns observed in this experiment. Furthermore, we cannot rule out the possibility that these effects are also related to the mechanical properties of the hand, which involve the control of the hand and finger movements. Nonetheless, Koch and Hoffmann (2000), Sakai et al. (2004) and Miyapuram et al. (2006) demonstrated that motor action processes are also chunked to enable efficient performance and to reduce cognitive demand in controlling the performance of a specified task. The preference to draw in a particular order is expected due to kinaesthetic efficiency reasons. For example, it is easier to draw successive patterns within close proximity, which reduces hand and finger movement, rather than subsequent patterns at a greater distance.

As already discussed, it is likely that participants may not only rely on the use of spatial information to facilitate the retrieval of chunks, and learning. In informal verbal reports, the participants associated certain patterns with specified labels, which may suggest the use of some semantic information assisting in the memorisation of patterns. This served as the foundation of the following experiment.

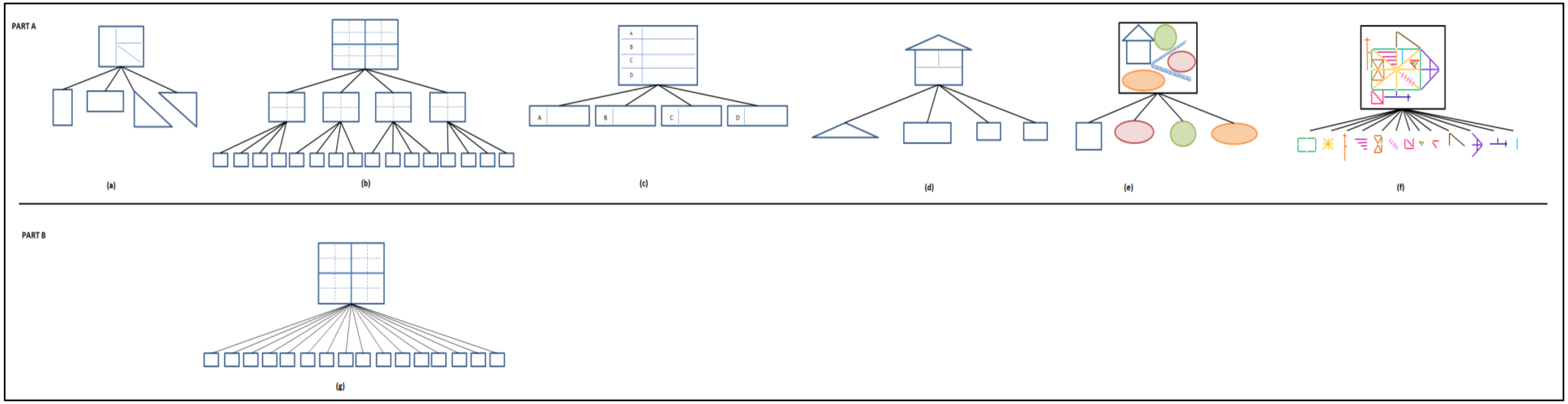


Figure 6.1: Divisions presentation from the stimuli used in this study. Part A presents the predicted mental hierarchical structure for each type of stimulus. Part B presents the possible type of structure in the mental schema used by the participants during retrieval. (a) Sp (exp2) and SpW (exp3), (b) SpS (exp3), (c) Se (exp2), SeS and SeW (exp3), (d) SS-house scene (exp2), (e) SS-garden scene (exp2), (f) Rey figure (exp1), (g) SpS (exp3).

### 6.2.2 Experiment 2: The effects of semantic and spatial schemas in learning

The main aim of this experiment was to investigate the effects produced by the stimuli when presented with semantic and spatial information and to evaluate their effectiveness in learning. More specifically, the experiment sought to induce the mental schema based on the given stimulus structure to examine the effects of chunks in relation to the given information. The stimuli that presented familiar objects adopted from common conceptual scenes (i.e. house, garden, sea and shop) enabled the researcher to assess the degree to which spatial or semantic information facilitated learning. Such an assessment includes how categorical relationships between objects, which share common characteristics, enable retrieval and learning based on the proximity of spatial associations between these objects. This evaluation would not have been possible with the use of just abstract diagrams.

The most important finding from this experiment was that learning is easiest when both semantic and spatial codings are available in the learning materials and most difficult when none are present. In addition, learning was more facilitated with the presence of semantic information alone than with spatial information, at least for the types of learning material used in this experiment. Although it may seem that the use of the adopted scenes may have a role in learning, the non-significant scene effect indicates that the stimuli structures were actually the most influential factors.

Consistent with the findings from the previous experiment, the L1 < L2 pauses across the stimuli suggest the use of chunks, where participants tend to treat the individual objects as presented. Further pause patterns of L2 < L3a < L3b for the stimuli with divisions suggest that the mental schema structure is hierarchically represented rather than, for example, as a single large chunk representation comprised of all components at one level. It is uncertain, however, whether the Sp stimulus is represented in a similar fashion, as the L2 and L3a patterns were less consistent across the sessions. Similar pause patterns between the Se and SS stimuli provide additional evidence that the objects and divisions in each stimulus are organized at different levels of the hierarchy. Assuming that each separated division of the stimulus is considered as a *slot* (as defined by the notion of schema structure), we suggest that the objects in each area are considered as the *fillers* for these *slots*. Therefore, at a higher level, these divisions can also be considered as chunks. This view is consistent with Palmer's (1977) theory, which he tested through a series of experiments using simple grid patterns. The more complex stimuli adopted in this experiment, where objects vary in the number of elements processed, further confirms that this theory is applicable regardless of the complexity of the learned graphical material. Furthermore, Palmer's prediction that the level of the hierarchy may increase depending on the complexity of the stimulus and task is verified by our experiment. We proposed that, in contrast to Palmer's three levels, at least four levels of detail form the mental schemas related to these types of materials, as shown in Table 6.1.

Table 6.1: Levels of the hierarchy based on the presented stimuli

| **Level** | | **Sp** | **Se** | **SS** |
|---|---|---|---|---|
| **Highest level** | *Level 1* | Whole figure shown on each type of stimulus presentation | | |
| | *Level 2* | Area/location | Conceptual category | Conceptual category & area/location |
| | | (e.g. left, right, top, bottom) | (e.g. bedroom, kitchen, living room, toilet) | (e.g. bedroom, kitchen, living room, toilet in their consistent and prototypical positions) |
| | *Level 3* | Objects | | |
| | | (left) : yacht, cloud, beach ball, starfish<br>(top): anchor, bird, umbrella, castle | (bedroom): bed, lamp, wardrobe, fan<br>(kitchen): vacuum cleaner, iron, microwave, washing machine, kettle | |
| **Lowest level** | *Level 4* | Line segments for each object | | |

Another implication of the increasing pause levels across sessions is that more cognitive processes were involved, as the tasks became more complex. For example, retrieval for objects between two divisions may have required participants to consider all hierarchical levels including lines, objects, and divisions, as opposed to considering only the line and object levels for retrieval between objects within the same division. It is reasonable, thus, to contend that the L3a-transition between divisions pauses would be longer than the L2-between objects pauses. Furthermore, the longer duration of the L3b-return transition pauses may be an outcome of searching for the relevant objects between the divisions.

We further propose that the use of hierarchical organization is effective only if strong relations exist between the different levels of the chunks. According to the principle of *encoding specificity* (Tulving & Thomson, 1973), the hierarchical organization is deemed useful only if a strong association exists between the different levels of chunks or knowledge units. In applying this principle, the SS stimulus may be interpreted as the easiest type of stimulus to learn on account of the stronger association that exists between the category names and the spatial relationship with the constituent objects. This, thus, facilitates the process of retrieval. Conversely, less organized hierarchical structure applies to the NS stimulus presentation because the objects are presented in a random order, eliminating any direct cue on the stimulus to facilitate the organisation of knowledge during learning. This implies weak associations between the higher-level categories and the lower-level objects. As a consequence, the objects or categories are more difficult to recall, resulting in laborious searches and weaker performance overall.

The notion of divisions represented at many levels, at least for the Se and SS stimuli, allows us to propose further that selective attention on the localised divisions is likely to be applied during drawing. This enables the participant to focus only on certain parts associated to the considered branch of a hierarchy, such as the lines within an object and objects associated to the divisions during drawing, rather than paying attention to all objects and their details at once. This is supported by the decreasing and the lowest rate of return to previously visited divisions, indicating that these have a greater chance of being considered individually as a large chunk composed of the specified objects. Again, this supports the claim that the searching technique is the depth-first search strategy.

As mentioned above, learning from the Se stimulus seems easier than from the Sp. The category label on the Se stimulus may provide better cues for retrieval of the constituent objects, which produces a strong activation between the shared attributes among the objects. This is in accord with the results of previous investigators (Cohen & Bousfield, 1956; Tulving & Pearlstone, 1966; Mandler, 1967; Collins & Quillian, 1969), who demonstrated that items from the same category are recalled more easily than items from different categories. Broadbent (1971) further proposed that the attributes of a class are retrieved first, before the group of items, while Cutting and Schatz (1976) showed that items within the same category are processed faster than items between different categories. Both of these effects are present in this experiment, which supports our claim that the Se and SS stimuli are hierarchically organized (see Figure 6.1 (c), (d), (e)).

The SS stimulus was found to be the easiest type of stimulus for learning. This outcome was supported by pause data, the total number of objects drawn and verbal reports, which suggested that the participants were successful in relating the conceptual representation and the spatial relationship of the objects within a division. It is possible that strong associations exist between the semantic category of each division and the spatial context (i.e. orientation, location) of the objects in the hierarchical mental representation, the memory of which is proposed to be strongly influenced by schemas (Biedermann, 1972; Pezdek et al., 1988). The close association between the semantic category and the spatial context may provide strong cues, thus enabling the higher activation of the objects belonging to the particular scene. As a result, this produces easier retrieval and learning for the SS stimulus.

The Sp stimulus may not have the same learning potential as the Se and SS, due to the weak spatial relationship between divisions and objects. In effect, the weak cues hamper retrieval and the unique division structure is not particularly helpful. Both contribute to weaker activation of the objects in the memory. Consequently, poor learning was recorded with this type of stimulus presentation. Therefore, the use of areas or regions in this sort of stimulus presentation as a tool to facilitate learning, as proposed by McNamara (1992), were not very successful. This could imply that the mental representation for the Sp stimulus in this experiment is less structured than in the Se and SS.

The use of hierarchical representations in mental schemas is apparent in the rapidity of learning. This is illustrated by the successful recall of at least half of the objects on each schema by the third session out of a total of six. Such a finding echoes that of Bower et al. (1969), who demonstrated that participants could recall perfectly 112 words, as presented in the actual stimulus, by sessions 2 and 3, owing to the presence of category labels that enabled the retrieval of a large number of items. A similar finding was reported by Cohen and Bousfield (1956), who were successful in testing the recall of 40 words in clusters of 8 categories. Furthermore, this effect is consistent with our earlier observations in Experiment 1. The number of objects finding from this experiment, however, is also consistent with the remarkable learning performance showcased by the participants, as they managed to remember 64 different objects across diverse categories, drawn in unconventional ways (e.g. with gaps between the elements) and in unfamiliar patterns.

By including spatial and semantic information in the learning materials, this experiment has confirmed the findings from experiment 1, whereby it was argued that a stimulus structure that contains such information could enable the formation of a mental structure with a hierarchical representation. Although we have found that the presence of both semantic and spatial information facilitates learning the most, and that semantic information is a better cue than spatial information, the present data is not sufficient to determine to what extent learning is facilitated by these codings. In other words, little is known about whether the level of strength of the stimulus (weak or strong) in regard to the spatial and semantic information it contains, can support learning accordingly. This was investigated in the third experiment.

### 6.2.3 Experiment 3: The effects of spatial and semantic schemas of different strengths in learning

The focus of this experiment was to examine the effects of a strong and weak stimulus structure of spatial and semantic information on learning. Given the limitations of experiment 2, we were interested to investigate the effects of these manipulations on retrieval, as they may suggest the chunk organization of the underlying mental representations. In order to examine the rate of learning more effectively, we used additional measures to those in experiment 2. These included the assessment of the use of divisions on the stimulus (i.e. number of divisions usage and division preferences), which would provide useful details about the structure of information organization of the learned material.

The findings from this experiment have largely confirmed those of experiment 2. For example, pause analysis showed the L1-within object pause to be the shortest for all stimuli. This verified that the elements of an object were treated together as one chunk. Selection of the elements for a chunk coincided with what was defined as an object, as presented on the stimulus. Moreover, the L1 < L2 pause pattern, which was found for all stimuli, supported the claim that the objects were drawn individually. A more interesting pattern of L2 < L3a pauses, however, that was found for the SeS and SpW stimuli may suggest that these types of material presentation are potentially represented hierarchically, which indicates that the participants were using the divisions' structure presented in these stimuli and were drawing objects as one group in each division. These divisions may form the chunks in the mental representation, which is further deconstructed into individual objects and, subsequently, in the lines for each object in the lower levels. This has once again confirmed the theory that the mental schema is represented hierarchically on multiple levels (Palmer, 1977; McNamara, 1992; Cheng & Rojas-Anaya, 2008). Conversely, the L2 and L3a pause patterns were less obvious for the SpS and SeW stimuli, which implies that the mental schema for these stimuli is either less hierarchically organized or non-hierarchical at all. This indicates that the presented divisions in these stimuli may not have been successfully used by the participants in order to facilitate encoding and retrieval.

These findings from the pause analysis were expected, given that the SeS and SpW may have been considered as strong types of stimuli that enable robust encoding due to the facilitating cues they entail, such as consistent corresponding category labels with the constituent objects and their unique spatial regions. As a result, strong cues are used during retrieval, which strengthens the activation of the relevant objects in memory, producing easier recall and better learning. Furthermore, there is an effect of fast object retrieval for these stimuli made especially obvious by the lowest number of L2 pauses for the SeS stimulus. This can be explained most likely by the strong activation of the object due to priming, where previously recalled objects were used as cues for the next. In addition, each category may represent high frequency objects due to the strong association between the category label and its constituent objects. For example, the 'Noisy' category consists of an alarm clock, a radio, a washing machine and a telephone, all of which are common objects that occur frequently during recall for this particular category. This happens because each of the constituent objects has attributes similar to the super-ordinate category. This finding echoes reports from previous literature, where items from a taxonomic category are better recalled than a comparable group of items of unrelated categories (Tulving & Pearlstone, 1966; Bower et al., 1969; Mandler & Robinson, 1978). This may also indicate that the depth-first search strategy is employed as the dominant retrieval technique. On the contrary, the SpS and SeW stimuli seem to be weak stimuli, providing weaker cues and making retrieval difficult due to the weaker activation they induce in memory, which results in poorer learning. Once more, the theory of *encoding specificity* proposed by Tulving and Thomson (1973) is clearly demonstrated in this experiment.

Given these possibilities, the recall strategy for the stimuli, potentially represented in a hierarchical format, may have taken place in a top-down manner (also known as breadth-first search). For example, evidence to support this theory is that the strong category label, which is at the top level, may have been recalled first, before its constituent parts. This notion supports the findings by Goldstein (1958) and, if applied to our experimental context, it would mean that the category labels from the SeS stimulus would be influential for the retrieval of its members, whereas the category labels, such as Hot, Noisy, Large and Soft, would be retrieved first, prior to their respective members (Broadbent, 1971). This enables closely related items within the same category to be recalled faster than those from other categories (Cutting & Schatz, 1976). Hence, this enables a systematic retrieval strategy. As indicated by Eylon and Reif (1984), the strong relationship between the different levels of knowledge (e.g. the category label at the higher level with its constituent parts at the lower level) in the hierarchical organization facilitates the effective use of the structure. Other measures that further support the claim for effective learning from the SeS stimulus are the greatest number of objects recall, the highest number of divisions usage, the least divisions transition and the least errors produced across all sessions.

Similar to the SeS stimulus, the strategy used to recall objects for the SpW stimulus could also have been organised in a top-down manner. Firstly, what factors could have contributed to the facilitation of learning from the SpW stimulus? As there was no semantic label given to this type of stimulus, the effectiveness of learning may not be purely down to semantic effects. Therefore, there might be a greater likelihood that the use of spatial information, such as area, location and positioning of the objects, would be more influential in facilitating learning, as proposed by Stevens & Coupe (1978), McNamara (1986, 1992), Gattis (2001) and Tversky (2001). Among these attributes, the use of spatial areas is more dominant. Thus, the unique divisions presentation for this type of stimulus may serve as an effective cue during encoding and retrieval. The distinctiveness of these divisions (see Figure 6.1 (a)) compared to the other forms of presentation from other stimuli may have made this stimulus more memorable in the context of this experiment. This finding corroborates the ideas of Goldstein and Chance (1971), who suggested that asymmetric stimuli are recognized, remembered and, hence, retrieved better than symmetric ones. Unintentionally, this finding has made us aware of the coincidence, across experiments, of the unconventional layout (see Figure 3.22 and Figure 6.1 (a), (d), (e)) of the

Rey figure (i.e. 3 group patterns), the SS stimulus (i.e. different regions in the scene) and the SpW stimulus (i.e. 4 areas of different shapes), which may have some role to play in determining the effectiveness of learning, although this remark is speculative at this stage. It may, however, be considered as an area warranting further investigation.

The SpW stimulus that was used in both experiments 2 and 3 may seemingly present contradicting results (i.e. less conducive to learning in experiment 2, more in experiment 3). It is important, however, to note that this stimulus was compared at different levels (or contexts) with the other stimuli. For example, experiment 2 made a comparison between the uses of semantic versus spatial information, while experiment 3 provided more detailed comparisons between strong and weak stimuli. Therefore, the SpW was a more difficult type of stimulus for learning when compared to other, stronger types of semantic stimuli (i.e. Se and SS), as shown in experiment 2, but was deemed more conducive to learning when compared to weaker types of stimuli (i.e. SeW and SpS) or comparable to the SeS stimulus. Therefore comparing the results of the SpW stimulus from these two experiments may not be appropriate. Similarly, the semantic stimuli in both experiments used different contexts (i.e. scene category for Se in experiment 2, adjective category for SeS and colour category for SeW in experiment 3).

We are unsure as to whether the retrieval strategy for both the SpS and SeW stimuli takes place in a top-down manner. It is surprising that the SpS stimulus was found to be the most difficult type of stimulus for learning. Collective findings, such as the greatest pause values used to retrieve objects within and between the same divisions, the fewest objects drawn, the least division usage count, the greatest divisions transition and more errors, provided evidence for this claim. The retrospective verbal reports were also consistent with these results. As noted by Cherry, Park and Donaldson (1993), the matrix-like stimulus representation, which is less visually distinctive, may imply that a strong symmetry stimulus design may not provide effective cues for encoding and recoding. Surprisingly, what we have initially thought of as a highly structured stimulus presentation for the SpS stimulus yielded completely contradictory findings, as the participants did not make successful use of the presented larger grid of the stimulus structure for encoding in the mental structure (see Figure 6.1 (b)). This may have an effect on the strategy for retrieval, where a less organized retrieval plan would be more likely to occur. As a result, participants are able to recall divisions, which results in a less organised mental schema with the configuration described above (i.e. highest division: whole stimulus, levels below: 16 objects), as shown in Figure 6.1 (g). This goes against the prediction shown in Figure 6.1 (b).

Similarly, the SeW stimulus may also have a less robust mental schema, where objects may be retrieved from various conceptual categories, as they do not share common attributes with the colour label super-ordinate category. As a result, the retrieval of the corresponding objects may be more difficult, thus taking longer to process. This effect is supported by higher L2 and L3a pause values than for the SeS and SpW stimuli. This result is consistent with Bower et al. (1969), who argue that inconsistent items for the corresponding category do not facilitate recall, due to poor memory.

Why does this happen? It may be difficult to interfere with the established conceptual knowledge. Taking an example from the SeW stimulus, the ‘Emerald’ category consists of the following objects: a slice of toast, a lamp, a ghost and an envelope. None of these objects represents attributes of the colour green because each is more strongly associated with other conceptual categories. Therefore, assigning objects, which have stronger associations with particular categories, to one which is inconsistent with their attributes may prove inefficient. Consequently, this contributes to the difficulty in learning.

With regards to the depth of the mental hierarchical structure, based on the obtained data, we propose that the SeS, SeW and SpW stimuli are each represented in four levels, as initially described. Palmer's (1977) argument of a complex stimulus potentially being represented in more detailed levels is confirmed by the findings in this experiment. The SpS stimulus, however, may be represented across two levels: the whole stimulus at the highest level, followed by all 16 objects (1 object from each smaller cell) at a level below, above the lines level, as shown in Figure 6.1 (g). This representation is likely, as the participants could have not treated the larger boxes as a division for another hierarchical level.

Another important finding from this experiment relates to the rapidity of learning demonstrated across the four sessions employed in this experiment, which was the least number of sessions across all prior experiments. Although we were not able to study return transitions between divisions due to the limited sessions, more importantly, the participants were successful at achieving adequate learning by retrieving almost perfect numbers of objects for the SeS stimulus and at least half of the total for the other stimuli by the fourth session. This was expected, as with practice and supported by effective cues, learning can occur in a short period of time.

## 6.3 Implications for the use of pause analysis

The results of the pause analysis, using the GPA method to probe the nature of the underlying mental representation, are consistent with those arrived through other methods, such as reaction time, qualitative scores of drawings and verbal protocol analysis (Egan & Schwartz, 1979; van Sommers, 1984; Karmiloff-Smith, 1990; Koedinger & Anderson, 1990; van Mier & Hulstijn, 1993). The GPA provides an improved method of analysing drawing behaviour as it employs easier analysis, accurate data recording, as pauses are captured using the computer's clock, modern techniques of drawing on a graphics tablet and an economical method of capturing rich data of natural drawing actions.

Building on previous research that used GPA largely in writing tasks, such as recalling number sequences, writing familiar and unfamiliar word phrases, copying mathematical formulae and assessing writing abilities among dyslexic children (Cheng & Rojas-Anaya, 2005, 2006, 2007; van Genuchten & Cheng, 2009, 2010), the present study exploited the use of GPA in complex drawing tasks. This study is a continuation of work conducted to evaluate the effectiveness of the GPA method in drawings by Cheng et al. (2001). They assessed the effects of drawings using simpler geometric figures. All three experiments reported in this thesis coupled the successful use of GPA with findings that support and extend those of past research.

For example, the use of pause analysis allows for an investigation of the nature of chunk properties with regards to drawing data. This is achieved by evaluating the pause duration, where increasing pauses imply objects drawn at different levels, such as L1 pauses (within object), L2 pauses (between objects of the same division) and L3a pauses (between objects from different divisions). Based on these data we have determined that (1) drawings patterns are chunked; (2) groups of elements within an object are retrieved as chunks; (3) the grouping of elements and objects is based on that specified by the Gestalt principles; (4) these chunks form the hierarchical representation of the mental schema. These characteristics corroborate the findings of a significant number of previous works in the area of chunk properties (Miller, 1956; Tulving, 1962; Pollio et al., 1969; Buschke, 1976; Reitman, 1976; Egan & Schwartz, 1979; Reitman & Rueter, 1980; Pammi et al., 2004; Sakai et al., 2004).

Another implication of the use of pause analysis is that it enabled us to specify that at least four hierarchical levels are present in learning from graphical materials. Although different levels of hierarchy, ranging from three to five, were found in the previous GPA studies (e.g. three for writing familiar and jumbled sentences (Cheng & Rojas-Anaya, 2006), four for copying artificial sentences (Cheng & Rojas-Anaya, 2008), five for writing sentences (van Genuchten & Cheng, 2009), these differences, including the results from our own experiments, could be due to the nature of the tasks in question. This is because writing has more levels that range, in descending order of size, from paragraph to character stroke (i.e. paragraph → sentence → word → alphabetical character → stroke for each character), while drawings may have fewer levels, ranging from groups of patterns to single elements of a pattern (e.g. collection of objects → object → element of an object).

GPA has pioneered the use of transition matrices to investigate the kinds of chunk patterns produced during retrieval. At present, the author has not found any previous literature, which has applied this method, especially on the Rey Figure, in order to assess the successive transitions between patterns in an effort to evaluate the sequential behaviour of retrieval across the boundaries in question. This has offered an alternative method for evaluating these kinds of data, other than the extant ones. Although some parts of the analysis were largely done automatically, these procedures could have been improved in order to allow for a fully automated analysis. Thus, further related research in this area is worth pursuing.

Finally, another measure that was made possible through pause analysis was the error analysis. Across all experiments, we have evaluated the types and frequency of the errors produced over time. This provides additional evidence for the rate of learning that occurs among the participants. Although we have not focused our present analysis on the assessment of the participants' accuracy of drawings, compared to the presented stimulus, further in-depth analysis is possible and would be welcomed in the future. This type of measure will be able to evaluate the participants' learning performance more accurately.

## 6.4 Scope, limitations and future work

The studies reported in this thesis focused on the role of chunking in relation to the use of spatial and semantic schemas induced from the presented stimuli structure. While various methods, such as recall of word lists and recognition tasks, can be used to investigate how these effects are reproduced in the underlying mental representation, we have made use exclusively of drawing tasks for this purpose. This activity has produced not only consistent findings, but has introduced the benefits of drawing tasks for such studies.

In experiment 1, we demonstrated the effects of chunking and spatial schemas with the use of a single stimulus, the Rey Figure. Another approach of conducting experiment 1 is to adopt different types of abstract figures, such as those by Bouaziz and Magnan (2007), in order to evaluate whether similar findings will be presented. From another perspective, the hypothesis and questions from experiment 1 could have been applied to conceptual diagrams, such as electronic circuits or probability diagrams. The present findings are not able to provide detailed suggestions about the differences in terms of chunk organization in the mental schema between the drawing tasks.

In experiment 2, a few of the participants reported that they were unable to recognise some of the drawings. Although this did not affect the data adversely, it is important to ensure that consistency or familiarity with the objects is monitored. Furthermore, performing the experiment with different sets of objects and scenes and with more participants will produce more accurate findings, which would verify if the manipulated spatial and semantic information on the stimulus structure is producing effects similar to those found in the present data. This will enable us to determine the effectiveness of learning from drawings in relation to the use of semantic and spatial factors.

In experiment 3, there were only four types of stimulus presentation given to the participants. Evaluation of other types of divisions presentations in relation to the use of strong and weak spatial and semantic information would verify the present findings more accurately. Similar to the suggestions from experiments 1 and 2, more participants would provide more representative results. Furthermore, this experiment could have been performed with more sessions to assess the number of transitions between divisions, which would enable a more detailed evaluation of the use of chunks in the mental schema.

Across all experiments, we have employed only in-house software that was developed for the demands of the analysis. This has taken a reasonable amount of time in which additional research could have been conducted. The use of specialised software could also have reduced the potential of human error during the analysis. Given the types of data produced in the experiments, the bulk of the analysis had to be done manually. Therefore, as we have emphasized, the use of improved automated software for analysing the data (perhaps from a closely related research in the field of software engineering) is worth considering.

A number of findings have emerged which could be explored in future research. Firstly, in experiment 1, a similar research question could be applied on other types of conceptual learning material. This enables us to determine more precisely the effects of chunking and spatial schemas on abstract yet conceptually meaningful diagrams, such as the UML and electronic circuit diagrams. More detailed analysis is important to evaluate chunk development (i.e. whether chunks amalgamate and if so how) as learning progresses. This is possible by having numbered labels for each element during data collection. Furthermore, a recognition test, such as drawing circles around the patterns which participants feel should belong together, as practiced by Egan and Schwartz (1979) is another potential method of analysis.

Secondly, in relation to experiment 2, a potential future study is to investigate the relationship between items with consistent and inconsistent schemas. For example, a cake in the birthday scene would be a consistent schema (i.e. in accordance to expectations), whereas encountering a toothbrush in the birthday scene would be an inconsistent schema. This will enable us to determine the strength of the underlying conceptual knowledge (i.e. meta-knowledge) about an object, scene or event. For example, it may well be that participants are better at remembering unique or inconsistent objects as reported by Bower, Black and Turner (1979), Goodman

(1980), Pezdek et al. (1989), and Sakamoto and Love (2004) rather than consistent ones. Spalding and Murphy (1996) reported that participants were unlikely to group items from the same category into one large group when the category members contained inconsistent information. This implies that the category is less likely to be treated as a large chunk, but as smaller chunks instead. Following from that, a potential research question could be how well remembered are items violating the regularity of existing knowledge. A potential evaluation to test this is to investigate which items are often learned first from the material, namely whether easy or more difficult items (i.e. consistent vs inconsistent items) are given more attention during the early stages of learning.

Another direction of research motivated by the findings of experiment 2 relates to the investigation of the spatial relationship between objects, such as location versus spatial composition. In spatial location, terms such as facing, left, bottom, right would potentially provide information related to the structural organization of the graphical information, as opposed to that shown on the actual stimulus. In spatial composition, investigation may focus on the differences between the drawings in terms of areas filled with drawings versus empty spaces, which were intentionally or unintentionally produced. This may be achieved by replicating the study by Mandler and Johnson (1977). While their experiment focused on recognition rather than drawing tasks, they have introduced 5 distracters, such as the manipulation of objects in different sizes and shapes, the conceptual replacement of different objects, the conceptual replacement of similar objects but different in appearance, the removal of objects from the actual stimulus and the change of the spatial positioning of the objects. These kinds of manipulations can be adopted to assess the effects produced by spatial cognition (i.e. location versus composition). As for the SS stimulus, assessment for the spatial relations and meaning between objects will provide evidence on how strongly these codings affect learning. Furthermore, it would be interesting to investigate the effects of other spatial properties in learning. Thus, the materials could manipulate attributes such as size, location and relative distance of the objects.

Finally, in experiment 3, it would be beneficial to have a better working definition of ‘strong’ and ‘weak’ spatial and semantic information. This will improve the stimulus design to which the attributes from these forms of information can be applied more accurately. A better definition of these terms would provide more reliable and detailed comparative results. Furthermore, the investigation of the effect of division distinctiveness from other types of design may verify whether unique material presentation really facilitates learning.

## 6.5 Conclusion and recommendations for graphical material design

Our experiments have emphasized the importance of considering spatial and semantic information with the design of graphical materials to ensure effective learning. In experiment 1, we propose that spatial information is more influential over semantic information for drawing abstract diagrams, such as the Rey Figure. With the involvement of conceptual knowledge, however, experiment 2 showed that the presentation of both spatial and semantic information together has the greatest beneficial effect on learning. In a more focused comparison, experiment 3 further demonstrated that use of semantic information most strongly related to the context in question resulted in most effective learning performance.

Across all experiments, we have recognized that semantic coding may have a larger role to play in learning over spatial coding. This could mean that conceptual knowledge is more robust (structured) and is organized more coherently in memory than spatial knowledge. The use of spatial coding, however, is effective when the stimulus is presented in an unconventional manner. As we have noted, the unique layouts of the SpW, the SS and the three groups that constitute the common drawing pattern in the Rey Figure may have been effective for learning. Therefore, we propose that if the material uses semantic information only, it is best represented in a class-categorical membership manner, whereas if the material uses spatial information only, it may be beneficial to present the data in a unique layout. Conversely, if both semantic and spatial information are available, the best approach of designing the material would be to represent them in a fashion most familiar to the participants' existing knowledge. Further work is needed, however, in order to verify these claims fully.

The findings from these experiments are particularly beneficial in a learning situation where the learner is required to group together or categorize information that shares similar characteristics or functions. This may involve the consideration of using semantic and spatial information to facilitate learning. The use of meaningful categories that is consistent with their contents would aid this process. If the materials to be learned, however, do not have consistent category labels for their contents, a strategy, such as presenting the contents based on spatial groupings, may be more useful in ensuring effective learning. Perhaps learning would be more facilitated if the spatial groups of the contents were arranged in a unique presentation. For example, in chemistry, it may be difficult to learn the various forms of molecules with their complex Latin names, as these diagrammatic icons may not have memorable names. Classifying these patterns of molecules according to categories in an irregular tabular presentation, rather than the regular tabular format may, nevertheless, produce easier learning.

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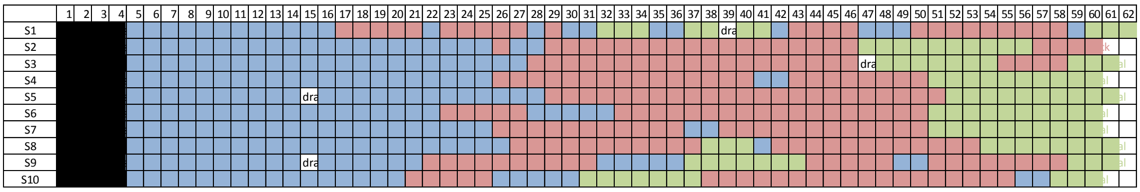
# Appendices

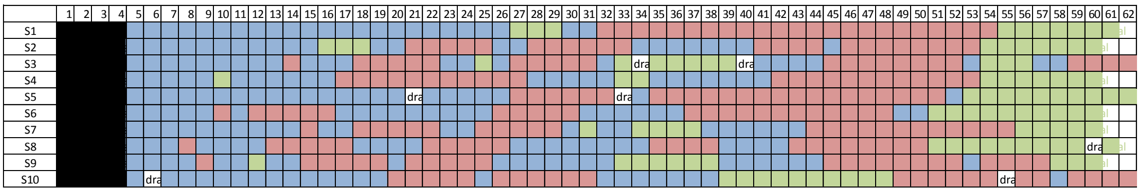
## A. A complete set of drawing patterns for Experiment 1: Rey Figure

### Tracing task

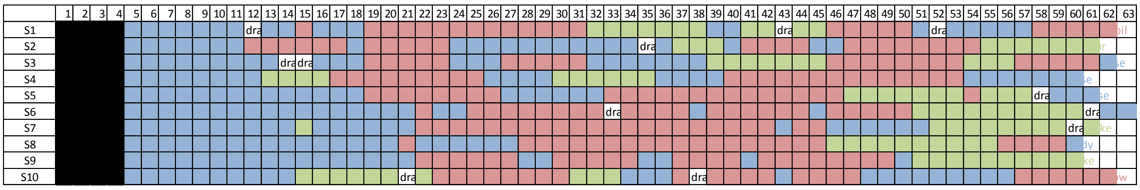
*G1-Tr*



*G2-Tr*



*R-Tr*



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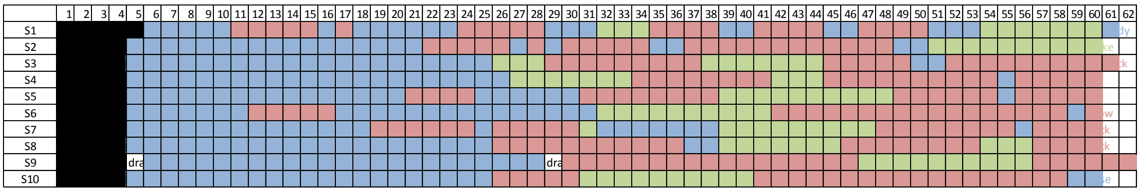
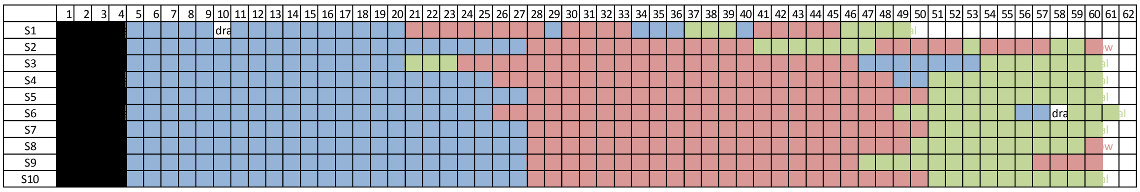
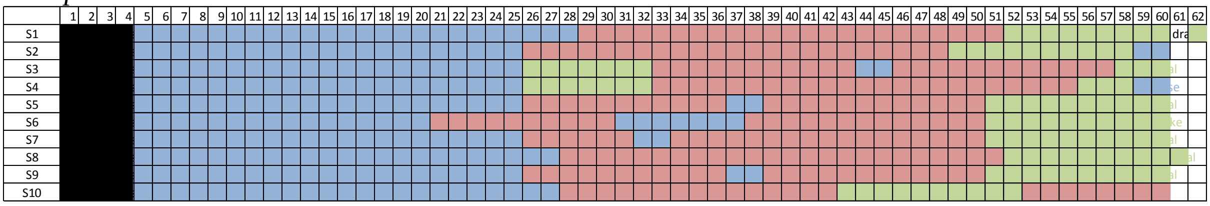


*F-Tr*

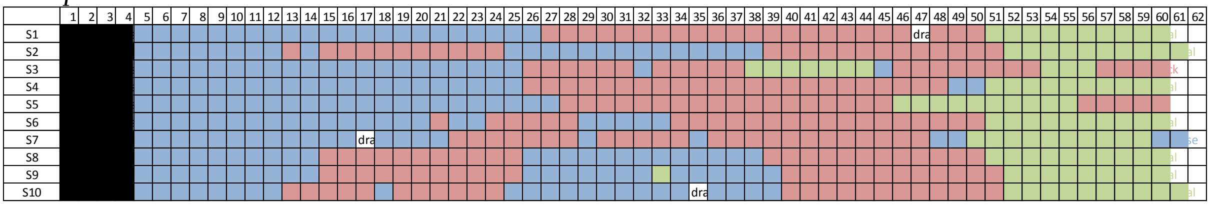


## Copying task

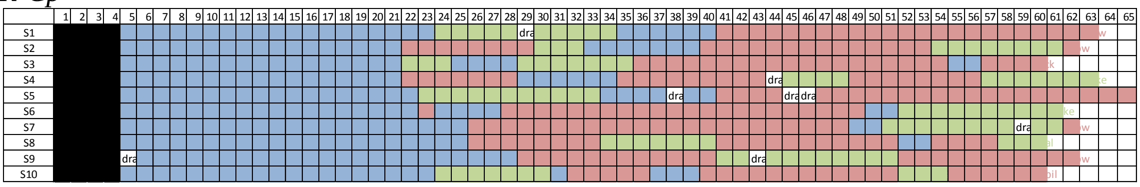
*G1-Cp*



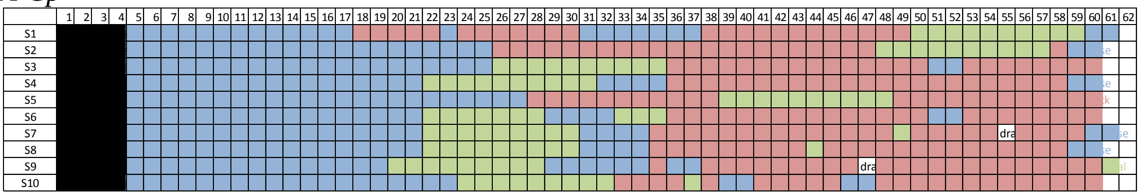
*G2-Cp*



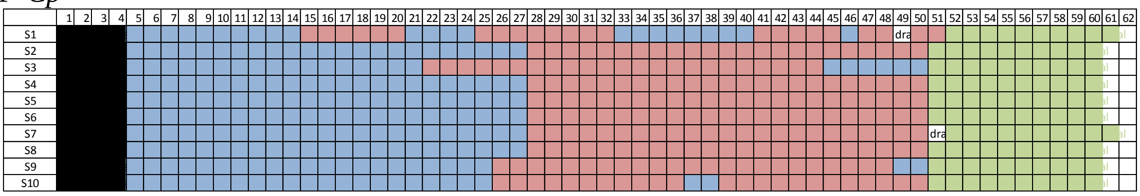
*R-Cp*



*A-Cp*

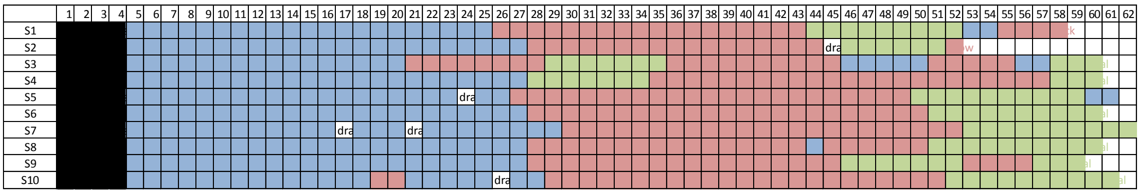


*F-Cp*



## Immediate recall

### *G1-Ir*

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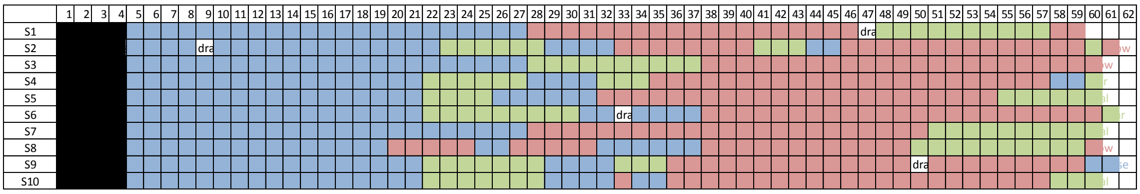


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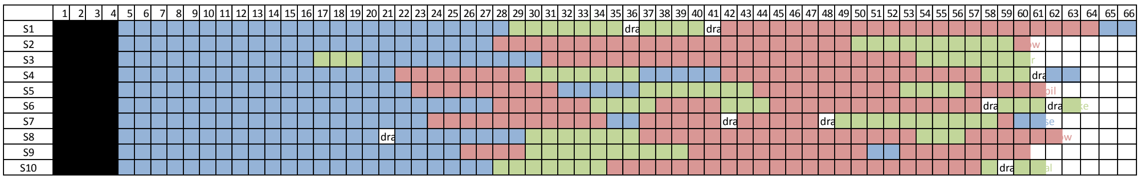
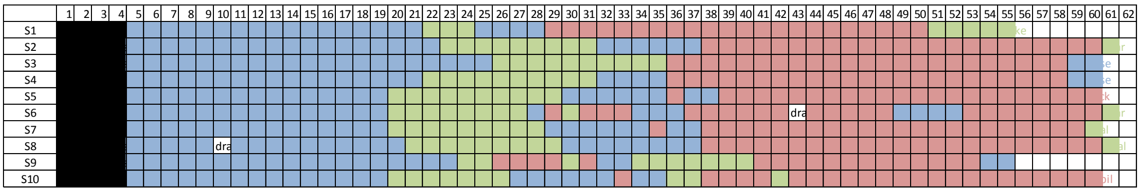
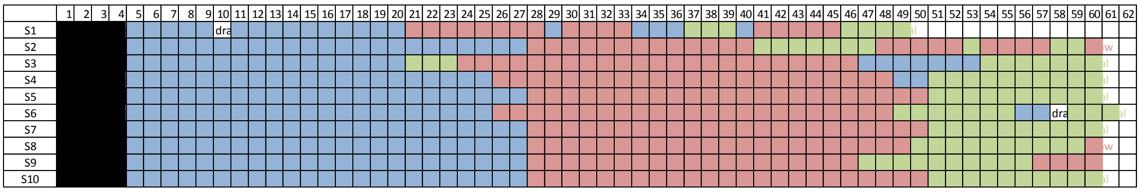



### *A-Ir*

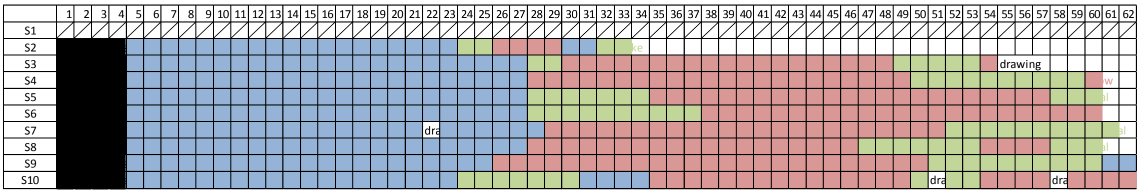



### *F-Ir*

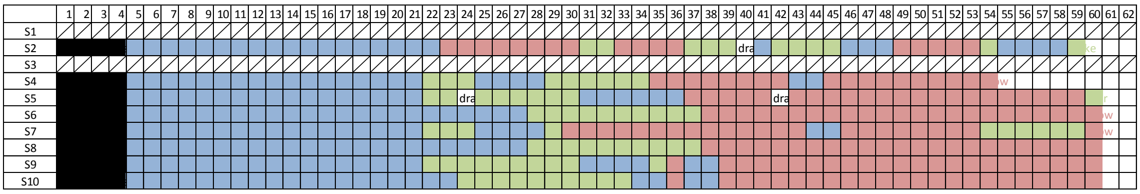


## Delayed recall

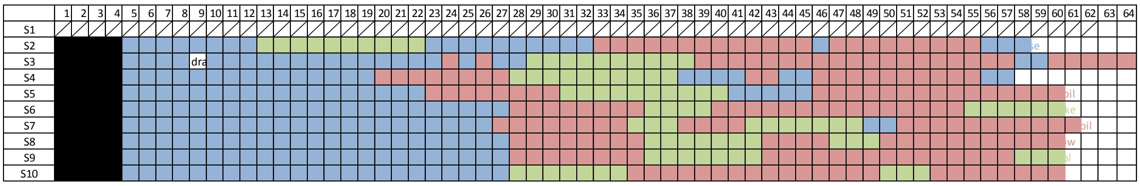
*G1-Dr*



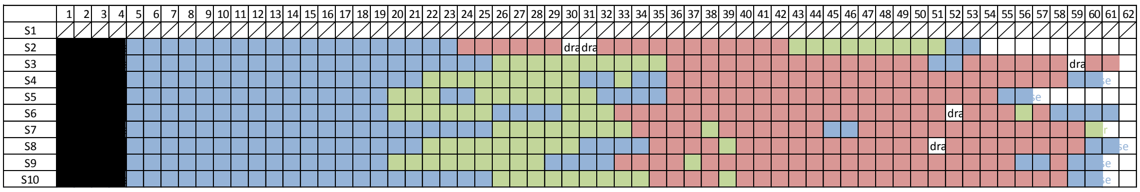

*G2-Dr*



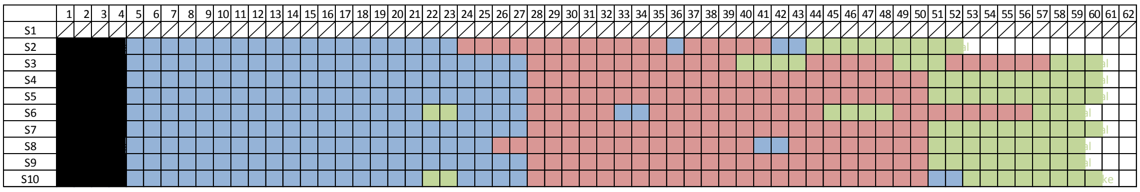

*R-Dr*




*A-Dr*




*F-Dr*



B. List of Publications

# Graphical Production of Complex Abstract Diagrams: Drawing Out Chunks and Schemas

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**Abstract**

What cognitive processes and strategies are used to reproduce complex abstract diagrams? Over ten sessions, a complex diagram was traced, copied, drawn immediately from memory and drawn after a delay. The five adult participants rapidly learned to make near perfect productions of the diagram. They converged on an approach that exploits chunks, which was used across all the modes of drawing, rather than a strategy that minimizes motor effort. They appear to use an overarching spatial schema to organize their access and production of the chunks.

**Keywords:** chunks, spatial schemas, drawing, tracing copying, graphical protocol analysis, Rey figure

## Introduction

Drawing is a common human activity that has been rather neglected by Cognitive Science. Compared to the extensive studies on the nature of writing or the work on perception, reasoning and learning with diagrams, our understanding of the mechanisms underlying production of graphical artifacts at the cognitive level is relatively meager. There have been some notable studies. The classic work of van Sommers (1984) explored and described some of the underlying processes of drawing and Goel (1995) examined the more fluid nature of sketching particularly in the task of design problem solving. Some studies have used drawing as a means to investigate other aspects of cognition such as children's increasing flexibility in their use of schemas during cognitive development (Karmiloff-Smith, 1990) or the impact of alternative representational systems on conceptual leaning (Cheng, 2003).

Nevertheless, there are many questions and issues to be addressed concerning the underlying processes of drawing. The experiment reported here concerns well-structured diagrams. This experiment examines four modes of drawing: (a) *tracing* by drawing directly over the target diagram; (b) *copying* by transcribing the target diagram on to an adjacent blank sheet; (c) *immediate drawing from memory* when there has been exposure to the target diagram just prior but not during production; (d) *delayed drawing from memory* when the target has not been seen for some time. In this experiment what changes as the same diagram is drawn many times over an extended periods of many days is investigated, rather than, say, how generic drawing abilities change with cognitive development. How does the drawing process vary when the diagram does or does not have rich semantic content for the drawer? Van Sommers (1984) showed the interpretation that participants possessed influenced the order of production of the graphic elements in simple line drawings (consisting of about 5 lines and no more than two chunks). A complex abstract diagram without particular conceptual content was used as the stimulus in this experiment, which is shown in Figure 1. To what extent does drawing invoke the same cognitive structures and processes that are commonly implicated in other types of tasks? This study will consider the role chunks and use of schemas. Are there generic task strategies for drawing? If so what are they and how do they interact with the factors associated with the preceding questions?

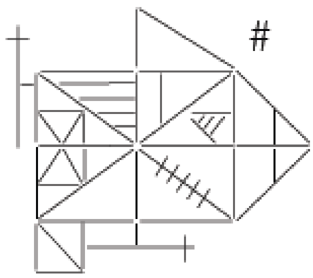


Figure 1: Modified Rey figure used in the experiment.

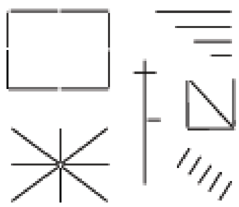

Figure 2: Six example patterns (not to scale).

The diagram in Figure 1 is a modified version of the Rey-Osterrieth Complex Figure (Meyers & Meyers, 1995). The original figure is used in a well-validated test of memory function. The modifications make it more suitable for our *graphical protocol analysis* approach to the study of graphical production, which is described below. The modifications include: inserting a space between the end of all lines, replacing circles and dots with lines, and breaking up long lines into shorter segments. The diagram has 56 lines (excluding the #).

Figure 2 shows a selection of the patterns of lines that appear to correspond to putative perceptual chunks, based on the normal scoring scheme used for the original Rey figure. The six patterns are shown in Figure 2 but Figure 1 incorporates 13. We presume that if participants are using chunks then the chunks may correspond to these patterns, which seem like plausible candidates, for example on the basis of the Gestalt principles of perception.

More precisely this experiment examines three sets of related questions in an exploratory fashion. First, to what extent is the process of drawing dominated by chunking? The use of an abstract diagram allows strategies that are not reliant on chunks to be manifest, as the stimulus does not have given semantic content that relates specific configurations of diagrammatic elements to particular conceptual chunks. The four modes of drawing were chosen in order to vary the likely use of chunks. Delayed drawing from memory is the most likely to involve chunking, because the lines of the diagram that share similar characteristics could be encoded as perceptual chunks. At the other extreme, one may expect that participants instructed to trace the target diagram 'as quickly and as accurately possible' might adopt a strategy that minimizes unnecessary movements of the pen by selecting successive lines that are in close proximity. If such a strategy is strictly used it will operate independently of whatever chunks the drawer perceives or retrieves from the memory. One might predict that the extent of chunk use in the copying mode of drawing will fall somewhere between that of the tracing mode and drawing from memory modes, as the stimulus is present but components must still be briefly remembered.

The second question: Is there a generic strategy (or strategies) for drawing complex abstract diagrams? Humans naturally adapt their behaviour in order to reduce the cognitive and physical effort expended on tasks, so one might expect that even moderately experienced drawers will adopt some generic approach to drawing that (to some extent) rationally organizes the process of graphical production. If the participants are not drawing in a haphazard or random fashion, what are they doing? One possibility, if they are not relying upon chunks, is some strategy that operates at the level of individual lines, such as selecting the nearest neighbouring line to be the next one to draw in order to minimize pen/hand movements and the need for higher level sequential planning.

The third set of question concerns learning. How will the process of drawing gradually change over time with improvements to the accuracy of the reproductions? To address this, the participants did ten repeated sessions of drawing each separated by a number of days. With repeated reproductions of the same complex diagram does the use of chunks change (if they are used) and how are the overall drawing strategies affected?

One means for probing chunking processes in drawing will be the *temporal chunk signal* that we have found in our studies using *graphical protocol analysis*. Our previous experiments on writing and drawing have demonstrated the existence of this signal that reveals the structure of chunks in memory. The signal has been found in the writing of simple sentences (Cheng & Rojas-Anaya, 2006) and artificial sentences (Cheng & Rojas-Anaya, 2008), in the writing of number sequences (Cheng & Rojas-Anaya, 2005), in the copying of mathematical formulae (Cheng & Rojas-Anaya, 2007), and in the production of simple geometric figures (Cheng, McFadzean & Copeland, 2001). The temporal chunk signal is based on the pause between successive pen strokes (i.e., the time between lifting the pen from the paper at the end of the previous mark and placing it down to begin the current mark). Significant differences between the duration of pauses at different levels of the hierarchy of chunks possessed by the participants were found across all types of task. The pauses for elements within a chunk (e.g., letter level, *L1*) are smaller than the pauses for the chunk itself (e.g., word level, *L2*). This finding is consistent with classic findings on chunking processes, for example, in chess (Chase & Simon, 1973), go (Reitman, 1976), electric circuits (Egan & Schwartz, 1979) and word lists (Bushke, 1976). However, the temporal chunk signal in graphical production is (remarkably) strong and robust with significant differences found between the chunk levels in the data for individual participants on a single trial; i.e., with no aggregation into groups. *Graphical protocol analysis* (GPA) is the term we use to describe our method for studying cognitive processes involving free-hand writing and drawing using the temporal chunk signal.

Another means for probing chunk structure, which also provides evidence on drawing strategies, is to examine the particular sequence of production of the elements within the different patterns of the target diagram. This will involve the analysis of whether drawing progresses in a consistent fashion with all the elements of each pattern being drawn together, or whether transitions occur between partially completed patterns.

## Method

### Participants

The participants were graduate students and research assistants at the University of Sussex. Each had a moderate amount of experience of drawing diagrams typical of graduates in technical subjects. One of the six participants originally recruited for the experiment was unable to complete the trials due to unrelated commitments. One participant was left-handed the rest were right-handed.

### Apparatus

The single target stimulus is the complex abstract diagram in Figure 1. All drawing occurred with an inking pen on a sheet of paper taped to a standard graphics tablet (Wacom Intuos[2®]). Specially designed drawing/writing analysis software, TRACE (Cheng & Rojas-Anaya, 2004), was used to record the writing actions, to extract the pen positions and times, and to compute the duration of pauses between drawn elements. Participants were instructed to produce drawings that largely filled an A4 page in landscape orientation. For the tracing mode, a copy of Figure 1 with faint grey lines was used. For the copying mode, a copy of Figure 1 was placed near the tablet for the participant to refer while drawing.

## Procedure

There were ten sessions each lasting about 30 minutes. They were spaced no less than two and no more than seven days apart, with the precise timing dependent on the individual participant's availability. The time between the first and last sessions was between 3 and 10 weeks (No evidence was found that the different durations affected the overall results). In the first session the participant traced the diagram, then copied the diagram and finally drew the diagram from memory (immediate recall drawing). In the second and subsequent sessions the participant first drew the diagram from memory (delayed recall drawing). Then it was copied and traced, the order of which alternated with session. Finally an immediate recall drawing was done. For all drawings the participant first drew the hash (#) at the top right of the diagram to ensure that they were fluently drawing before any of the elements of the target was produced. The participants were told not to practice between sessions.

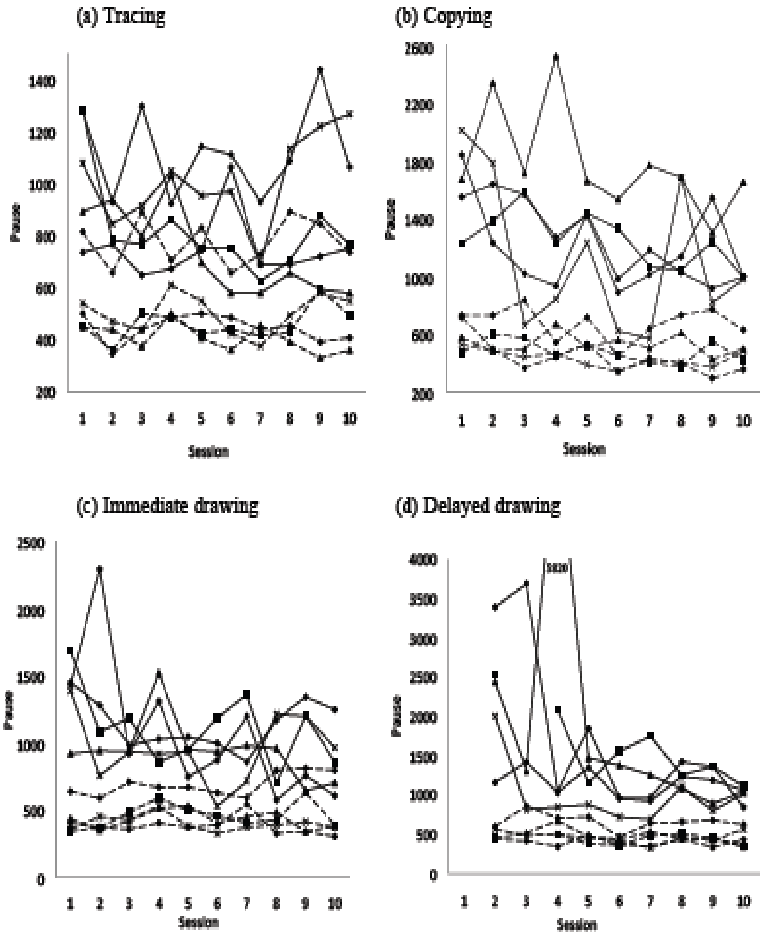


Figure 3: Median L1 within (dashed) and L2 between pattern (solid) pauses for each mode of drawing. (Each symbol type is a particular participant.)

# Results

## Overall performance

Participants overall success at producing the diagram was initially assessed by coding the errors made in their drawings in terms of omissions, commissions and structural (misshapen) errors at the level of whole patterns and elements within patterns. The structural errors are minor compared to the omissions and commissions errors. Except for the omission of one element by one participant in the very first session there were no errors with the tracing mode. In the copying mode there were slight structural errors in six of the drawings. For the immediate recall drawing mode there were (remarkably) few errors even in the first session. The worst participant omitted three patterns and six elements, but by the third session just two participants each made one structural error. With the delayed recall mode (beginning in the second session) the number of errors also declined from about 10-20 to near perfect drawings by the second or third attempt. The rapidity of reaching ceiling level performance was unexpected.

## Between and within pattern/chunk pauses

On the assumption that if the participants were chunking the diagram they may be doing so in terms of the default patterns (Figure 2), each drawn line was coded either as *L2-between* or *L1-within* a pattern. A between pattern element is the first occurrence of any line of a particular pattern. All subsequent lines of the same pattern are within pattern elements. Figure 3(a)-(d) show the median values of the pauses for all the between and within pattern lines, for every participant, in every session, for all four modes of drawing. (There is no data for delayed recall drawing in session 1 and data for immediate recall drawing for one participant is missing due to experimenter error.) The solid line corresponds to L2 between pattern pauses and the dashed line to L1 within pattern pauses.

Simple visual inspection of the graphs reveals that in all 194 drawings the median of the L2 between pattern pauses is greater than the median of L1 within pattern pauses. If either were equally likely to be larger, then the probability of L2>L1 for all the 10 drawings of one participant in one mode is $p=0.5^{10}=.0001$, by the Binomial theorem. Separate t-test (one-tail, paired) comparisons of the L1 and L2 pauses over the 20 sequences of drawings for the 5 participants in the 4 modes were significant (p<.05 once; p<.01 once; 18 at p<.001). Further, t-test (one-tail, paired) comparisons of the pauses over the five participants for the 39 sessions (10 sessions by 4 modes minus 1) are significant, in all but two cases (p>.05 twice, p<.05 three times, p<.01 34 times.) (The outcomes of an ANOVA test is consistent with these results.) As longer pauses are associated with chunks (see above), it is clear that: (1) the participants are using chunks in the drawings in all modes; (2) these chunks largely correspond to the default patterns, some of which are shown in Figure 2.

The medians of the L1 within pattern/chunk pauses are similar across participants, sessions and modes of drawing. The L2 pauses are more variable. Overall, they are largest for delayed recall drawing, then for copying, immediate recall and least for tracing, respectively, 1453, 1336, 1047, 885 ms. Figure 4 shows the mean of the participants' median pauses. If there is a ¼ probability of any one of the modes being the shortest in any given session, then by the Binomial theorem, the chance of the tracing mode having at least nine of the smallest values is p=.00001. The mean of immediate recall drawing mode falls between the tracing mode and the other two modes in seven of the ten sessions, which by the Binomial theorem has as chance of p=.0031. T-tests (paired, one tail) of the between pattern pauses for all the pairs of modes across all the sessions were computed. The L2 pauses for tracing was shorter than each of the other three modes (p<.01 in all three). The L2 pauses for immediate recall drawing are shorter than for copying (p<.001) and for delayed drawing (p<.01). The difference between delayed drawing and copying is not significant. In summary, tracing has the shortest L2 pauses, immediate drawing the next, and copy and delayed drawing comparably long pauses.

The within pattern pauses are relatively constant over the sessions. There is an apparent decline of the magnitude of the between pauses over the sessions. The curves in Figure 4 show that the median L2 between pattern/chunk pauses declined over sessions. This is confirmed for the copying, immediate drawing and delayed drawing modes by the t-tests (one tail, paired) of the difference between the participants' first and last session median pauses (at p<.05 for each one). The particularly large drop between the second and third session magnitude of the delayed drawing model parallels the drop in the errors between the same sessions.

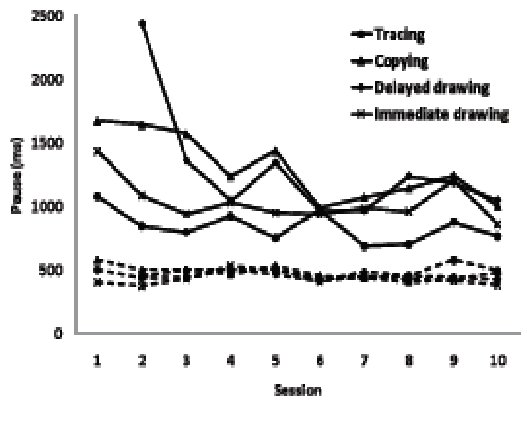


Figure 4: Mean of the L1-within (dashed) and L2-between (solid) pattern median pauses for all modes of drawing.

## Sequences of drawing individual patterns

Another measure of whether the participants were treating the patterns as chunks is the number of times within a particular drawing that a switch occurs from the production of an element in one pattern to an element from another. The minimum possible number of switches is the number of patterns minus one (i.e., 12). The number of switches above this will be called the *transition count*, which is a measure of excess number of switches between patterns. When this is zero each and every pattern will have been drawn as a separate group that presumably are distinct chunks.

To obtain a sense of the transition count when chunks are not being used for drawing, the nearest neighbour drawing strategy was examined. It minimizes pen movements between lines using a strategy that selects the next line to draw 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 that is closest to the pen. The strategy was applied to the diagram using five different obvious starting points in Figure 1 (e.g., top left, centre) giving a mean transition count of approximately 12. Values less than this suggest of the use of chunks.

Figure 5 shows the mean transition counts across participants for the four modes across the sessions. By the second drawing in every mode the transition count has dropped to approximately half the value for the nearest neighbour strategy. A decline in the transition counts for each mode is apparent in Figure 5 and t-tests (one-tail, paired) between the first and last session over participants indicates that the drop is significant for the copying, immediate recall and the delayed recall drawing modes (p<.05, all modes), but not for the tracing mode.

## Sequences of drawing groups of patterns

Inspecting all of the lines for each drawing over the ten ses-

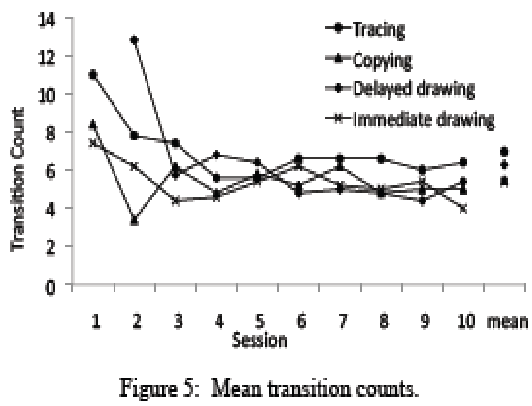


Figure 5: Mean transition counts.

sions, the groups of patterns are (very) often drawn together suggesting an amalgamation process of the individual patterns as drawing progresses over the sessions. One such group that often appeared in the drawings will be called the *frame* group, which consists of the large rectangle, triangle to the right, the top triangle and the lines radiating from the centre. The patterns within and beyond the large rectangle also appeared sometimes to be drawn as groups. To test whether these groups really have a substantive role in drawing, group transition counts were obtained for every drawing, in a fashion similar to the patterns but at the aggregated group level. Applying the nearest neighbour drawing strategy with different starting points gives transition counts in the range of 6 to 16.

Figure 6 shows the mean transition count over participants for each mode of drawing. The group transition count is substantially less than that for the nearest neighbour strategy indicating that the groups may have had a meaningful role. The measure is relatively constant for each mode with the exception of tracing. A t-test (one-tail, paired) on the first and last session of this mode has a large variance so the difference is not significant (p=.095).

Closer inspection of the sequence of patterns reveals that patterns from the frame group were always the first to be drawn in every diagram without exception. Twenty-three lines constitute the patterns of that group. For the tracing, copying, immediate and delayed recall modes the mean number (and range) of lines produced from the frame group before the start of any other groups were, respectively, 16.1 (11-21), 18.9 (16-21), 19.7 (18-22) and 19.8 (17-21). This suggests that frame group of patterns had a primary role in all of the modes of production, including the tracing mode but to a lesser extent than the others.

## Discussion

With regard to the drawing of complex abstract diagrams using four modes of drawing, the questions posed for this experiment concerned: the role of chunking in graphical production; the existence and nature of generic drawing strategies; and the effects of learning over multiple sessions of reproducing the diagrams.

The experiment provides converging evidence that chunks have a central role in the drawing of one instance of a complex abstract diagram. The coincidence of longer pauses before the production of lines between the default patterns compared to pauses for lines within the patterns indicates that the participants were treating the patterns as chunks. The relatively low level of transitions counts also supports the claim that chunks had a causal role in the production of the diagram, because the participants on the whole tended to complete each pattern before moving to the next.

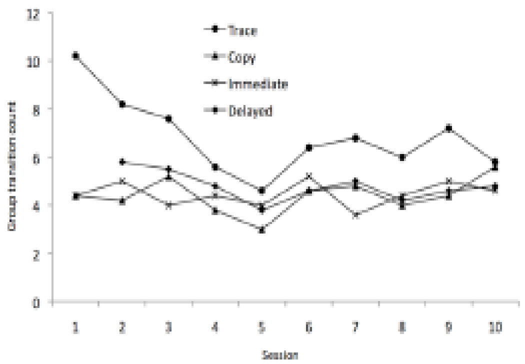

Figure 6: Transition count for groups of patterns.

The strong and robust temporal chunk signal that was found in other writing and drawing tasks using the Graphical Protocol Anaysis (GPA) method (Cheng & Rojas-Anaya, 2005, 2006, 2007, 2008; Cheng, McFadzean & Copeland, 2001) was also clearly found in this experiment. This extends the scope of the GPA for studying the nature of chunk-based phenomena in Cognitive Science. The magnitude of the L1 within chunk pauses was approximately 500 ms across all of the modes of drawing and fairly constant across sessions. In the latter sessions, the L2 between chunk pauses were approximately 900 ms. These times are longer than those found in the drawing of simple geometric figures in which L1≈400 ms and L2≈600 ms (Cheng, McFadzean & Copeland, 2001). Possible reasons for the difference are the great complexity of the stimulus in the experiment and the larger physical scale of the drawing.

As with the previous studies, the constancy of L1 pauses and the variability of L2 pauses suggest that the drivers of the observed effects are largely occurring at the chunk level. Tracing had the shortest L2 pause times, then immediate recall drawing, with copying and delayed recall drawing equally longest. A plausible explanation for why the immediate recall drawing L2 pauses is shorter than those for delayed recall drawing is the more recent and presumably greater activation of the chunks in memory for the former mode. The need to switch attention between the target diagram and drawing is one explanation for the greater L2 pauses for copying than immediate recall drawing. Tracing is the mode that one would expect to be the most different to the others, because the recall of chunks is not strictly necessary and shifts of attention to a remote target are not needed. Nevertheless the difference between L2 and L1 pauses indicates that chunking has an important role in the tracing mode. Notice in Figure 4 that the magnitude for copying converges with the immediate recall drawing line, which is consistent with the participants using their remembered chunks in the copying mode in later sessions. At a high level, chunks are being used substantially in the process of drawing as indicated by both the between pattern pauses being greater than the within pattern pauses and the low transition count (Figure 5). This raises an intriguing question for further research: Is the use of chunks during tracing (in the later sessions) somehow a more effective strategy than the nearest-neighbour strategy, even though the recall of chunks is strictly unnecessary, as all the required information for production is present in front of the participant? Alternatively, is this a case of the processes of chunking interfering with a potentially more efficient strategy, because the propensity of the mind to retrieve known chunks of information cannot be intentionally suspended?

As the participants are using chunks the overall approach to drawing cannot be the nearest neighbour line strategy or some other that primarily operates at the level of individual lines. The early dominance of the frame group of patterns suggests that a strategy based on a spatial schema or template (Gobet & Simon, 1996) was being used. The participants draw the frame first, which then provides spatial locations (or slots) as cues for the retrieval of particular chunks. This interpretation is preferable to a strategy in which the order of production of patterns/chunks is in terms of their perceptual salience or memorability. There are other patterns/groups that appear more salient than the frame group, which is relatively diffuse and masked by other patterns.

In the early sessions the transition count data suggests that the patterns/chunks had less of a role: the initial few drawings may have used something akin to the nearest neighbour strategy. Learning is occurring over the sessions in the experiment. What is surprising is how quickly the participants were drawing near perfect versions of the diagram consisting of 13 patterns and 56 lines. The effects of learning are seen in the declines in the pause data (Figure 4) and transition counts for the patterns (Figure 5), and suggested by the transition counts for the groups in the tracing mode (Figure 6). The rapidity may be explained by the likely use of the spatial scheme drawing strategy. The spatial schemas provide a systematic way of organizing the information that does not require production to follow a single rigid sequence of elements that is vulnerable to breaking down as a whole if any one subsequence is forgotten. Further, although the diagram is supposed to be abstract, it is possible that the participants may have impose a meaning on the diagram for themselves (e.g., fish, rocket) and thereby adding semantic information that associates particular patterns to specific locations as part of the schema. It would be interesting in future work to manipulate the presence of the overall spatial schema and the degree of semantic content.

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