The Effects of Part-Set Cuing in Object-Location and Order Memory

by

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The report of the investigation undertaken as a Senior Thesis, to carry two courses of credit in the Program of Neuroscience

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Abstract

Part-set cuing inhibition refers to the counterintuitive finding that hints—specifically, part of the to-be-remembered information—can impair memory performance in free recall tasks. Although inhibition is the standard, in certain situations, researchers have reported hints helping memory (part-set cuing facilitation). The current set of experiments examined part-set cuing in the context of object-location and procedural memory using a novel design and materials. Participants viewed videos of snap circuit object assemblies and either reproduced the object (Experiments 1 and 3) or reconstructed the steps of the procedure (Experiment 2). Results indicate no significant part-set cuing effects in Experiments 1 or 3, although trends in the data suggest possible facilitation. Experiment 2 clearly showed part-set cuing facilitation of procedural information—consistent cues promoted significantly higher performance than inconsistent cues or the absence of cues. These findings represent an important first step towards understanding how part-set cues influence spatial and procedural memory.
Dedication

This thesis is dedicated to my family and friends, who continue to support me endlessly and unconditionally.
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List of Abbreviations

PSC: Part-set cuing
RSD: Retrieval strategy disruption hypothesis
fMRI: functional magnetic resonance imaging
NMDA:
ACh: Acetylcholine
TH/TF:
VSTM: Visual short-term memory
IPS: Intraparietal sulcus
IOS: Intraoccipital sulcus
MTL: Medial temporal lobe
IL: Infralimbic cortex
mPFC: Medial prefrontal cortex
PL: Prelimbic cortex
LTP: Long-term potentiation
OLMT: Object-location memory task
HDAC: Histone deacytelase
TM: Temporal memory
dHip: Dorsal hippocampus
vHip: Ventral hippocampus
RM: Recognition memory
EEG: Electroencephalogram
PRH: Perirhinal cortex
NMDAR: NMDA receptor
I. Introduction

Imagine that you’ve written a 20-item grocery list. On your way to the grocery store, you spill your drink on the list, which renders half of the items unreadable. Would you be better off using the 10 intact items as cues for remembering the 10 missing items, or should you simply ignore the intact items and attempt to remember the entire list without the aid of cues? If given the choice between these two conditions, most people would pick the option with cues (hints), presuming that their performance would increase. However, rather counter intuitively, participants tend to remember a lower percentage of items when provided with part of the set as cues compared to when they are not given cues. This phenomenon is termed part-set cuing inhibition, as the presentation of cues can inhibit recall in the memory task (see Nickerson, 1984 for a review).

Traditional part-set cuing experiments involve participants being given a list of words to remember. Uncued participants are given a free recall task and simply must remember as many words as possible, whereas cued participants are given a random subset of the list and must recall the remaining words. Part-set cuing effects, however, have been studied in a variety of other paradigms as well, such as categorized lists (Basden & Basden, 1995; Parker & Warren, 1974; Rundus, 1973), long-term memory (Brown, 1968; Karchmer & Winograd, 1971), serial memory (Basden, Basden & Stephens, 2002; Kelley & Bovee, 2007; Serra & Nairne, 2000), nonmemory tasks (Peynircioglu 1987), and location memory for chess positions (Drinkwater, Dagnall & Parker, 2006; Watkins, Schwartz & Lane, 1984). Depending on the paradigm, however, both memory impairment and facilitation have been observed with part-set cuing. Key evidence from each of these paradigms is reviewed below.
A. Review of the Part-Set Cuing (PSC) Literature

PSC & Non-categorized Lists

One of the first to study part-set cuing effects, Slamecka (1968) had participants listen to 30-item uncategorized word lists. Participants then attempted recall, either with no cues or with a set of randomly selected cues (given between 5 and 29 cues). Slamecka reported robust \textit{part-set cuing inhibition}, which is a rather counterintuitive finding. In essence, participants were given hints in the form of to-be-remembered list items, but those hints/cues impaired memory. Normally, if given the option between having hints or having no hints, most people would naturally choose the hint condition, but this evidence shows that hints can hurt. Indeed, in most studies of part-set cuing using free recall, part-set cuing inhibition is the standard (e.g., Brown, 1968; Brown & Hall, 1979; Peynircioğlu, 1987; Serra & Nairne, 2000). Subsequent research has shown that \textit{part-set cuing facilitation} is the exception, rather than the rule, and only appears in special circumstances, such as categorized lists or order memory (e.g., Parker & Warren, 1974; Serra & Nairne, 2000).

PSC & Categorized Lists

After Slamecka (1968) showed inhibitory effects of part-set cuing in uncategorized lists, researchers began to examine whether the same effects would be seen while using categorized lists of words. For instance, Parker and Warren (1974) asked participants to read 40 words (20 categories of 2 words each) at a rate of 2 seconds per word. Next, the cued participants read a list of 10 category names at a rate of 2 seconds per word off of index cards before placing down these cards. Uncued participants simply read 10 numbers in place of the 10 category names. All participants, then, were instructed
to recall as many words as possible; the cued participants were told to recall as many words as possible before turning to the cues for help. The researchers predicted that the cued participants should show facilitation for cued categories and inhibition for noncue categories. The results supported this prediction and cued participants recalled more cued categories and fewer noncue categories than uncued participants. Therefore, Parker and Warren (1974) were able to show part-set cuing facilitation is possible with slight modifications of the materials (categorized words) and procedure (attempt free recall first then use cues).

**PSC & Long-Term Memory**

Although much research has focused on the effects of part-set cuing on immediate memory, Brown (1968) explored part-set cuing in long-term semantic memory. Participants were instructed to recall as many United States state names as possible. Before recall, participants either were given a list of 25 states to study (cued) or were given no study list (uncued). Results indicated that the cued participants recalled fewer of the remaining 25 words than the uncued participants. The results were replicated using the 40 counties of England and using the names of counties. All results support the hypothesis that part-set cuing inhibition is seen in long-term memory.

Brown and Hall (1979) assessed whether part-set cuing inhibition would also be present in long-term episodic memory. Participants first wrote four free-association single word responses to 20 word stimuli (e.g. if the stimulus word was “water,” a participant may write down “beach, wave, drink, pool” as her free associates). Two days later, participants were asked to recall their responses from Day 1. Participants were either cued or uncued, and the number of cues also varied. The results showed that part-
set cuing inhibition occurred in all cued situations, regardless of number of cues. Hence, as with free recall in immediate memory, part-set cuing inhibition is robust for long-term semantic and episodic information as well.

**PSC & Nonmemory Tasks**

Although most early research on part-set cuing examined word list memory, Peynircioğlu (1987) explored whether part-set cuing inhibition could be extended beyond memory tasks. Her first experiment had participants find as many two or more letter words from within a single word (e.g. if the word was “intelligence,” potential internal words might be “tell, gentle, in, cent, ignite, ten, gin, and niece”; Peynircioğlu, 1987, 438). Some of these internal words served as cues in the production task, while only noncue words were used in determining the number of words produced. Peynircioğlu (1987) observed part-set cuing inhibition for the cued condition, as well as an increase in inhibition as the number of cues increased.

Similar part-set cuing inhibition was seen in three other experiments using different nonmemory tasks. Experiment 2 asked participants to find differences between images (such as “tip of baseball bat” or “soda can”) and measured the number of differences found with or without cues. Experiment 3 had participants guess the identity of an image at different levels of focus (cues were the two most common incorrect guesses for a given focus level) and the level of focus of correct guess determined the participant’s score. Experiment 4 asked participants to determine plausible identities of nonsense images with or without cues and with number of identities measured. As all four experiments showed part-set cuing inhibition, Peynircioğlu (1987) demonstrated that part-set cuing effects can be seen in nonmemory tasks as well as memory tasks. These
results thus indicate that part-set cuing effects are much more general than originally thought.

**PSC & Order Memory**

Much of the early part-set cuing research focused on word list memory and employed simple recall procedures that did not require participants to remember the information in its original presentation order. Even the long-term memory research, though not testing a word list presented to the participants, followed a procedure that allowed free recall, in any order. However, more recently, the effects of part-set cuing on order information have been extensively studied (e.g., Basden et. al., 2002; Kelley & Bovee, 2007; Serra & Nairne, 2000).

Serra and Nairne (2000) explored part-set cuing inhibition of order information with a set of three experiments. In Experiment 1, participants were shown a list of eight nouns in a specific temporal order and then were given a reconstruction of order test in which all eight nouns were given again in a new random order on the test sheet. Cued participants were given four of the nouns in their original positions and were asked to reconstruct the positions of the remaining items. Uncued participants, on the other hand, were told that four of the positions were eliminated (marked by X’s) and four nouns were eliminated, yet they were not told which of the eliminated nouns fit with which eliminated position. Thus, both cued and uncued participants reconstructed four positions total (see Figure 1-A). Contrary to the typical inhibitory effect seen in free recall, part-set cuing facilitation was seen as well as a typical serial position curve, with enhanced memory at the beginning and the end of the list.
Figure 1: Part-set cuing tasks

(A) Method of part-set cuing experiment used for memory of words in a particular order. Modified from Serra & Nairne (2000). a-d indicate the words above that will be ordered by the participants; a word in the cued and + in the uncued conditions indicate what needs not be ordered. (B) Overview of types of part-set cuing effects observed in numerous memory and non-memory tasks; separated into part-set cuing inhibition, part-set cuing facilitation, and no part-set cuing effect.
Experiment 2 employed a similar design to Experiment 1 (reconstruction of order task), but with the addition of a free-recall test, in which participants had to recall the original eight words in any order, rather than place the words in the correct serial order. Serra and Nairne (2000) predicted that facilitation would be seen for the reconstruction task (as seen in Experiment 1) and inhibition would be seen for the free-recall task. Results supported their predictions, as there was part-set cuing facilitation for the reconstruction task (as well as a serial position curve) and, at serial positions 1 and 5-8, there was part-set cuing inhibition for the free-recall task.

Serra and Nairne (2000) designed Experiment 3 to study the differences in performance between consistent (cue word placed in appropriate position, as in Experiment 1) and inconsistent cues (where the cue word is not in its original position, yet still not in a target position). While all results displayed the typical serial position curve, they also showed that performance in the consistent cue condition was significantly better than both the uncued and the inconsistent cue condition. Further, performance in the inconsistent cue condition was significantly worse than in the uncued condition. The results of Serra and Nairne (2000) thus demonstrated part-set cuing facilitation with consistent cues and part-set cuing inhibition with inconsistent cues in memory of serial order items, thus significantly broadening the knowledge of part-set cuing effects.

Basden et al. (2002) focused on the role of cue position and cue type when studying part-set cuing effects using a serial recall task in which participants must remember both the word and position, rather than simply the position (as in reconstruction). Experiment 1 was very similar to the experiments of Serra and Nairne.
(2000), with a list of 8 words in serial order (cues were four of the words either in the same order as originally or a different order from the original list) and results indicated facilitation with consistent cues and inhibition with inconsistent cues. In Experiment 2, Basden et al. (2002) explored whether cue order (consistent or inconsistent) would influence free recall, rather than specifically serial recall, using a similar procedure to Experiment 1. Results showed that consistent cues still facilitated recall as they had during Experiment 1, but inconsistent cues did not inhibit recall. Experiment 3 examined the difference between integrated (within the recall blanks) and segregated cues (above the blanks) to test the spatial effect of cues on part-set cuing inhibition. Using a similar design to Experiment 1, the results showed that recall was greater with integrated cues than with segregated cues in addition to facilitated recall with consistent cues and inhibited recall with inconsistent cues. Basden et al. (2002) demonstrated that both cue spatial position (integrated or segregated) and cue type (consistent or inconsistent) affect both serial and free recall in predictable ways.

Kelley and Bovee (2007) extended these earlier studies. In their first experiment, participants were shown word lists of either 8 or 16 words and then were given a reconstruction task, with the list items presented in a random order. Participants were either uncued (an X in the original position), given consistent cues, or given inconsistent cues. Results showed that performance overall was greater for 8-word lists and that the effect of cue type was different in the 8- and 16-word lists. For the 8-word lists, consistent cues and control cues both showed greater reconstruction performance than inconsistent cues and for 16-word lists, inconsistent cues showed worst performance,
followed by control (uncued) with better performance, and consistent cues had best performance.

In their second experiment, Kelley and Bovee (2007) employed a similar experimental design, but used a serial recall task instead of a reconstruction task. The results indicated that consistent cues facilitate serial recall performance, whereas inconsistent cues inhibit serial recall performance. Also, again, performance was more accurate for the 8-word lists than for the 16-word lists. Another finding of their second experiment was that when the data was scored using free-recall criteria (if the correct words were in the list, regardless of order), inhibition was seen for both inconsistent and consistent cues as compared to the uncued participants. Thus, the research of Kelley and Bovee (2007) showed many similar results to that of Serra and Nairne (2000) and Basden et al. (2002), yet continued to enhance the knowledge of part-set cuing effects.

**PSC & Object-Location Memory**

Watkins et al. (1984) explored whether part-set cuing inhibition would occur when remembering the locations of chess positions. In Experiment 1, novice participants (those who had never participated in a chess tournament) were shown a chess board with 24 pieces in position. Next, participants were asked to reconstruct the chess position shown, either with 12 pieces already placed or with no pieces placed, ensuring 24 total pieces placed. The number of critical pieces placed correctly (the 12 not cued) was measured using a strict scoring criterion (exact correct location) and a lenient criterion (any immediate surrounding location). Experiment 2 replicated Experiment 1 with the exception that participants had participated in a chess tournament and had a mean United
States Chess Federation rating of 1902. Results from both experiments showed that part-set cues neither inhibited nor facilitated chess reconstruction performance.

Drinkwater et al. (2006) further explored part-set cuing effects in the reconstruction of chess positions. Participants were either categorized as experienced (Elo rating above 1600) or novice (failure to correctly answer four basic chess questions). They were first shown a partially played chessboard, with 24 pieces on the board. Next, they were given a blank chessboard and were asked to reconstruct the position from memory—placing a total of 24 pieces on the board, even if it meant guessing. Participants were then given a 2-minute distraction task (belief questionnaire) before a second reconstruction attempt, where they were either given no cues, 6 correctly placed pieces, or 12 correctly placed pieces.

Drinkwater et al. (2006) predicted that experienced players would recall more pieces than novice players. This prediction was supported as experienced players placed about double the number of correct pieces as novice players both in first and second reconstruction (the mean for experienced players was roughly 35%, while the mean for novice players was roughly 20%). However, there was no significant effect of cue type and no interaction between experience and cue type on the second attempt. These results therefore indicated the absence of part-set cuing facilitation and inhibition in the reconstruction of chess positions, which is consistent with the results of Watkins et al. (1984). Hence, these results tentatively suggest that spatial memory may be impervious to the effects of part-set cuing.
Explaining PSC

As research on part-set cuing effects (both facilitation and inhibition; see Figure 1B) has expanded into many types of memory and nonmemory tasks, researchers have offered a number of theories to explain these interesting phenomena. For instance, some of the early explanations include: the editing task hypothesis (Basden, Basden, & Galloway, 1977), the increased-list-length hypothesis (Watkins, 1975), the cue-overload hypothesis (Mueller & Watkins, 1977), the competition-at-retrieval hypothesis (Rundus, 1973), the strategy-disruption model (Brown & Hall, 1979), the interference-with-maintenance hypothesis (Epstein, 1969), and the associative sampling-bias hypothesis (Raaijmakers & Shiffrin, 1981). The names of the proposed explanations give a notion into what they suggest. Although researchers have shown some support for particular aspects of each model, the most complete and widely accepted hypothesis is the Retrieval Strategy-Disruption (RSD) hypothesis.

The RSD explanation of part-set cuing suggests that cues disrupt an individual’s strategy of recalling information, which, in turn, inhibits free recall. Although the RSD explanation was originally designed to explain inhibition, its basic concept can be adapted to explain some facilitative effects as well. Basden and Basden (1995) performed a set of experiments that showed that when participants organize information into categories and are then cued in a way consistent with the categories, the expected part-set cuing inhibition is diminished presumably because strategy disruption is reduced with this design.

The RSD hypothesis also can account for inhibitory effects, such as those described earlier from Brown (1968). In this study, participants who had been given a
random set of 25 US states recalled fewer of the remaining 25 than control participants who recalled all 50. According to the RSD hypothesis, each participant has a distinct method of retrieving stored information (in this case, states). By providing some of the states as cues, in a random order, the cues disrupt the natural retrieval method of the information, yielding inhibition. The RSD hypothesis can also explain facilitation. For instance, in the study described earlier by Serra and Nairne (2000), participants who received consistent cues of order information demonstrated part-set cuing facilitation. In this case, the RSD hypothesis would explain that the method of retrieval of order information is structured based on the order; thus, when cues are consistent with the order of information presented, there is no disruption of the retrieval method by the presentation of cues.

Though the RSD hypothesis is the most widely accepted explanation for part-set cuing, it does have some faults. The major fault to the explanation is the ability to predict what cues will disrupt and what will not. The hypothesis is very good at elucidating data that has already been collected; it explains that if there is inhibition, then there was disruption, while if there is facilitation, then there was no disruption. However, the a priori predictive abilities of the RSD hypothesis are limited, as it is not always apparent whether disruption will occur. Until a better hypothesis is presented that can predict the effects reliably, however, the RSD hypothesis, with its keen ability to explain the current set of part-set cuing effects, remains the accepted view on part-set cuing.

**Gaps in the PSC Literature**

Clearly, part-set cuing facilitation and inhibition are consistently robust and widespread phenomena. Unfortunately, part-set cuing has not been thoroughly examined
or explained in some areas, such as with spatial and object-location memory. To date, only two studies have examined location part-set cuing in chess and it is not possible to form conclusions from their null results. Further, no studies have examined procedural memory directly. Although one might assume that the effects of part-set cuing on order memory might relate to procedural memory, since order is inherent in a procedure, these order studies have primarily utilized word list stimuli, which are very different than the stimuli used in procedural studies. The current set of experiments set out to resolve these gaps in knowledge. However, before looking to the present experiments, it is important to understand more about how research is conducted when studying these areas of memory, as well as to understand how (and where) the brain processes these types of information.
B. Object-Location & Spatial Memory

Spatial memory refers to the memory of physical objects in space, whereas object-location memory is used when remembering a specific object and where it is located in space. Thus, the latter is more than simply remembering the spatial location of an object, as the object’s identity must also be remembered. This distinction was demonstrated in a set of experiments by Kohler, Moscovitch, and Melo (2001). In Experiment 1, participants were either asked to remember a list of displays, rank the displays according to their semantic value, or make judgments about the displays locations. The displays were sets of three line drawings of objects that had no semantic relation (e.g. sweater, airplane, and wine glass). Next, participants performed a 30-minute distractor task, after which they performed a memory task. In the memory task, participants were shown two displays, one of which was the same as the test display and one of which was altered in some way (e.g. one object moved to a new location, two object locations switched, one object replaced with a new object, or one object replaced with a familiar object from a different display). Results showed that recognition memory performance for both spatial and identification memory in participants who made judgments about location was significantly lower than in the other two locations, indicating the possibility of domain-specific encoding processes between the memory for locations and for identity of the displays. That is, the memory for object locations and for identity of objects is dependent on the way that information is processed: either through location or identity representations.

The second experiment employed four participant conditions: no encoding (baseline), spatial encoding (making location judgments), object encoding (making
object-attribute judgments), and combined encoding (both spatial and object judgments). Additionally, participants were asked to assess which target object was missing from a display shown to them and were asked to mark where missing objects of the displays should be located. Results indicated that on the object-identification task and the object-location task, performance was significantly lower after spatial encoding than after object or combined encoding. Thus, no enhancement of memory for object-location was seen after spatial encoding.

In the third experiment, Kohler et al. (2001) explored whether memory for object location requires encoding of object identity. The design of this experiment was similar to Experiment 2, but now with slightly different encoding conditions: spatial encoding without naming (location judgments without naming objects), spatial encoding with naming (location judgments and referring to names of objects), object encoding (value judgment and judgment about number of straight lines in object), and no encoding. Results indicated that spatial encoding with naming yielded performance on the object-identity task that was between the performance level after object encoding and after spatial encoding without naming. Additionally, on the object-location task, spatial encoding with naming once again showed increased performance as compared to spatial encoding without naming. These results thus seem to indicate that the identity of the object is necessary for tasks of both object-identity and object-location memory. Such distinctions have also been shown at a neural level (e.g., Assini, Duzzioni, & Takahashi, 2009; Bachevalier & Nemanic, 2008; Bird & Burgess, 2008; Gilbert & Kesner, 2004; Piekema, Kessels, Mars, Petersson, & Fernández, 2006).
Biological Origins of Object Location Memory

Gilbert and Kesner (2004) examined the role of the hippocampus in object-place associations using hippocampal lesions in Long-Evans rats. Before surgery, a shaping procedure taught rats to displace an object to receive a food reward. Rats received either an electrolytic-induced lesion of the dorsal and ventral hippocampus or they received a control lesion in the cortex (1 mm below the dura) but in the same coordinates as the hippocampal lesion. A behavioral test was administered after surgery to assess the object-place memory after lesioning. Behavioral results showed that the hippocampal lesioned rats initially performed more poorly than the control rats after surgery, but they quickly regained the object-place associations. These results indicate that the hippocampus is involved in the initial learning of object-place associations, but other brain regions also take part in the retrieval of such memories.

As there was still much confusion as to the nature of which brain structures contribute to object-location memory, Piekema et al. (2006) set out to examine the brain while conducting short-term object-location memory tasks with human participants. In this study, fMRI imaging was used during a simple memory task—namely, the delayed-match-to-sample task. In this task, participants viewed a set of information that either required them to retain information about the location of the object, the color of the object, both the identity and the location, or both the identity and the color. Next, participants were shown items and were instructed to note if the items were part of the current set of information, while brain activity was recorded by fMRI. The fMRI results seemed to indicate that the right hippocampus, in particular, is important in short-term memory that involves both spatial and non-spatial components (such as color and
location associations). The right hippocampus is not shown to hold such importance, however, in tasks involving only non-spatial components (even when multiple things are to be remembered such as color and number) or single components (only color, number, or location). These results are indicative of the specific role of the right hippocampus in object-location studies, a focal point in the current study.

Further studies continue to implicate the hippocampus as playing a key role in object-location memory. For instance, Assini et al. (2009) demonstrated the role of the hippocampus in the object-location memory of mice by testing drugs’ effects on the hippocampus during object-location memory tasks. In this task, mice were placed in a field with objects interspersed throughout and mice were allowed to explore the objects. Next, the mice were removed and one object’s location was changed. When the mice returned to the field, the time spent exploring the old and the new objects was recorded and the identification of object-location by the mice could be studied. Results from this study indicated that CA1 receptors of the hippocampus play a key role in object-location memory tasks. Inactivation of CA1 receptors with lidocaine produced significantly impaired object-location task performance in mice (accuracy dropped from about 60% to about 45%). Additionally, NMDA receptor antagonists and muscarinic ACh receptor antagonists significantly impaired object-location task performance, while NMDA receptor agonists and cholinesterase inhibitors improved object-location task performance. Thus, not only does this study help support the role of the hippocampus in object-location memory tasks, and further specifies the role by implicating CA1 receptors, it also allows for the possibility of further exploration into glutamate and acetylcholine and their roles in spatial memory tasks.
Although there have been numerous studies supporting the role of the hippocampus in object-location memory, the necessity to look toward other brain regions also exists. A study by Bachevalier and Nemanic (2008) used monkeys to look toward the hippocampus, parahippocampal areas TH/TF, and the perirhinal cortex and their effects in spatial memory. The researchers lesioned primate brains in these areas and looked at performance on spatial location and object-in-place VPC tasks. In the spatial location VPC task, monkeys were shown an image on a screen. Next, they were shown the same image in the same location, but with another identical image in a novel location on the screen. In the object-in-place VPC task, monkeys were shown a set of five images on a screen. Next, the images were rearranged in one of three possible rearrangements (differed by difficulty). The time spent looking at the stimuli in general and at the novel stimuli was recorded. Results indicated that hippocampal lesioned primates and perirhinal cortex lesioned primates had impaired performance on object-in-place tasks, but not spatial location tasks, while TH/TF lesioned primates showed impaired performance on both tasks. However, the perirhinal lesioned primates’ performance could be attributed to a “more global difficulty in encoding and retrieving complex visual stimuli,” (Bachevalier & Nemanic, 2008, p. 74) rather than spatial memory problems in particular.

Brain regions other than the hippocampus have been implicated in recent studies. Harrison, Jolicoeur, and Marois (2010) examined the role of the intraparietal sulcus (IPS) in both object-location and object-identity of visual short-term memory (VSTM). They employed an fMRI study to examine the brain regions activated during what they termed “what” and “where” tasks. Results indicated that the IPS and the intraoccipital sulcus
(IOS) are more greatly affected by a load on “where” information than by “what” information. In fact, the researchers mentioned that the IPS/IOS is mainly concerned with representing spatial information about objects in VSTM. Although differing results have been noted as to the nature of the role of the IPS/IOS in “what” information (Xu & Chun, 2006), Harrison et al. (2010) provide compelling arguments linking the IPS/IOS to object-location memory.

More recently, a study by Buffalo, Bellgowan, and Martin (2006) explored the medial temporal lobe (MTL) and its contribution to object-location memory. Buffalo et al. (2006) performed fMRI experiments to explore the roles of the perirhinal cortex and the parahippocampal cortex in object-location and object-identity, using “spatial” and “object” tasks, respectively. The results indicated that the “anterior parahippocampal cortex was significantly more active during the spatial task than during the object task” (Buffalo et al., 2006, p. 639). Additionally, the researchers found that the perirhinal cortex was activated in both tasks during the recognition phase, while the parahippocampal cortex was not activated in either task during the recognition phase. These results therefore implicate the parahippocampal cortex as being an important region in object-location memory.

Another region of the brain currently being linked to object-location memory is the infralimbic (IL) cortex of the medial prefrontal cortex (mPFC). Nelson, Cooper, Thur, Marsden, and Cassaday (2011) performed lesions in the prelimbic (PL) and IL cortices of rats to test for object recognition and object-location memory. Results showed that IL lesions did not affect object recognition; however, these lesions caused significant disruptions in object-location memory of the rats. Additionally, PL lesions did not lead
to any significant change in object-location memory. These results thus implicate the IL cortex as being important to object-location memory, which is consistent with previously known information that the IL of the mPFC receives neural signals from the hippocampus (thus returning to the hippocampus once again).

**Molecular Mechanisms of Object Location Memory**

As mentioned earlier, research has supported the notion that the hippocampus (and regions such as the IPS/IOS, parahippocampal cortex, and IL cortex) plays a key role in object-location memory. However, a big question still remains: how exactly does object-location memory work? Recent studies have begun to further study the molecular mechanisms of object-location memory (see Figure 2C).

Using the knowledge that the hippocampus is important to object-location memory, Prut, Prenosil, Willadt, Vogt, Fritschy, and Crestani (2010) looked to a GABA receptor in the hippocampus for more answers. As it was already known that GABA<sub>A</sub> receptors that contain α5 subunits are found in CA1 cells and Assini et al. (2009) demonstrated that CA1 receptors of the hippocampus play an important role in object-location memory, the wish to study these GABA receptors is natural. Using transgenic mice, Prut et al. (2010) studied behavior of these mice in object-location memory-dependent tasks. Results showed that in the transgenic mice, there was a decrease in α5 subunits of the GABA<sub>A</sub> receptors, yet all other subunits remained at normal levels. Results from behavioral tasks indicated that the transgenic mice exhibited a “failure in encoding object location information” (Prut et al., 2010, p. 485). As a decrease in α5 subunits in the hippocampus is linked to a decrease in the ability of mice to employ
object-location memory, it seems that these α5 subunits play an important role in object-location memory.

In addition to receptors being studied for links to object-location memory, endogenous molecules also have been explored. Specifically, ghrelin has been implicated as important to memory processes, most notably in areas including the hippocampus, and hippocampal long-term potentiation (LTP). As the hippocampus is consistently linked with object-location memory, Jacoby and Currie (2011) studied the effects of ghrelin on object-location memory. Rats were injected with either vehicle or ghrelin and were tested on a typical object-location memory task (OLMT). Results indicated that rats with ghrelin performed significantly better on the OLMT and that dopamine receptor antagonists (specifically, SKF 83566) block this effect. Thus, both ghrelin and dopamine appear to be important for object-location memory tasks.

Another route for further understanding the molecular mechanisms underlying object-location memory is to look at DNA modifications. As was noted by Hawk, Florian, and Abel (2011), DNA modification is necessary for long-term learning. One important type of this modification is acetylation of histone proteins. Hawk et al. (2011) desired to study whether the inhibition of histone deacetylases (HDACs) would contribute to the enhancement of long-term object-location memory. In the experiment, mice were trained on an object-location task and then were either injected with an HDAC inhibitor (TSA in Experiment 1, MS275 in Experiment 2) or vehicle into the hippocampus before being tested. Results showed that the mice injected with both HDAC inhibitors showed enhanced object-location memory as compared to the mice
injected with the vehicle. These results indicate that HDACs play a role in memory formation and further research should occur to identify specific ones involved.

Summary of Biological and Molecular Mechanisms

Object-location memory has been implicated in numerous brain regions (see Figure 2A). The hippocampus seems to play a large role in object-location memory (Assini et al., 2009; Gilbert & Kesner, 2004; Piekma et al., 2006). Other brain areas have also been shown to play a role in object-location memory, such as the intraparietal and intraoccipital sulci (Harrison et al., 2010), the parahippocampal cortex (Buffalo et al., 2006), and the infralimbic cortex of the medial prefrontal cortex (Nelson et al., 2011). In contrast, the hippocampus seems to not be as important in nonspatial components of memory (Piekma et al., 2006). Additionally, object-identity memory and object-location memory seem to yield differences in brain activity across hemispheres, even when activating the same area, such as the entorhinal cortex (Bellgowan, Buffalo, Bodurka, & Martin, 2009).
Figure 2: Biological Basis of Object-Location and Order Memory

(A) Schematic of the brain structures involved in object-location memory. (B) Schematic of the brain structures involved in temporal order memory. (C) List of molecular and anatomic mechanisms that seem to be involved in both object-location and order memory. All of these mechanisms have been linked to activity in areas of the brain noted in (A) and (B).

Brain image from http://accidentalmind.org/_Media/halfbrain-3.jpeg
C. Procedural, Temporal & Order Memory

Procedural, temporal, and order memory are all related processes, with small nuances that differentiate them. Procedural memory refers to the memory of a specific procedure or task (e.g. riding a bike, tying one’s shoes). One example of a method for studying procedural memory is the mirror-drawing task (Cavaco, Anderson, Allen, Castro-Caldas, & Damasio, 2004). In the mirror-drawing task, participants draw an object while looking at it through a mirror, rather than directly. As time passes, performance generally improves. Thus, researchers can determine problems in procedural memory when participants do not improve on the task. Order memory refers to the memory of items in a specific serial order. As previously described, one of the most common methods for studying order memory is to present a list of words presented in a specific order and have participants perform a serial recall or reconstruction of order task (Kelley & Bovee, 2007; Serra & Nairne, 2000). Finally, temporal order memory has been described as “maintaining a representation of the order in which events or items have been experienced over time” (Hannesson, Vaca, Howland, & Phillips, 2004, p.274). A way to study temporal order memory is to look at rats’ preference of arms in a radial arm maze between newer and older familiar arms. Overall, procedural memory tends to look at tasks and actions, order memory tends to be associated with verbal information, and temporal order memory tends to be associated with the order of presentation of more spatial information. However, all three types of memory probably recruit similar mnemonic processes.

Many biological studies have been performed in an effort to implicate different brain regions and mechanisms in the processes of temporal order memory (Barker &
Warburton, 2011; DeVito & Eichenbaum, 2011; Hannesson et al., 2004; Howland, Harrison, Hannesson, & Phillips, 2008; Hsieh, Ekstrom & Ranganath, 2011; Schäble, Huston, Brandao, Dere, & de Souza Silva, 2010). These studies have noted a subset of brain regions in the hippocampus and medial prefrontal cortex as being important in order memory.

**Biological & Molecular Origins of Order Memory**

The search for anatomical structures in the brain that correlate to order memory has long been a priority for researchers. Hannesson et al. (2004) explored the medial prefrontal cortex (mPFC) as a possible structure important in specifically spatial temporal order memory. The goal of their Experiment 1 was to develop a way to study spatial temporal memory (TM) that relied on spontaneous behavior in the context of a radial arm maze. In the radial arm maze, rats explored two arms of the maze placed in different locations across training trials. At test, an object-location task should yield rats’ preference for the newest arm location introduced, while a TM task would yield rats’ preference for the oldest familiar arm location presented. The results from Experiment 1 showed that in the TM task, rats prefer the old familiar arm to the new familiar, indicating that the task does, in fact, test TM. In Experiment 2, rats that received lidocaine injections in the mPFC performed significantly poorer on the TM task than control rats. These results indicate that the mPFC is involved in some aspect of TM.

The hippocampus also has been shown to be involved in temporal order memory. In a study by Howland et al. (2008), the differences between the roles of the dorsal hippocampus (dHip) and ventral hippocampus (vHip) in memory were tested. A radial arm maze procedure, similar to that Hannesson et al. (2004), was used in their study.
Results showed that rats infused with lidocaine in the dHip showed significantly poorer performance on an object recognition memory (RM) task as compared to sham injection, while rats infused with lidocaine in the vHip exhibited significantly poorer performance on a TM task, but not the RM task. These results thus implicate the vHip as playing an important role in temporal order memory, specifically.

To further explore anatomical regions linked to order memory, DeVito and Eichenbaum (2011) tested the abilities of mice to remember the orders of odors presented to them. Mice either received lesions to the hippocampus, to the mPFC, or sham lesions. Next, mice were tested on an order memory task. On this task, mice were exposed to two sets of five odors while digging for chocolate sprinkles; each odor was presented three times with a three-hour lag between the two sequences. Then, during testing, mice were presented with two of the odors from either one list or both lists. The time spent digging when exposed to the odors was recorded, and the mice’s preferences for specific odors were calculated from these times. Results indicated that both hippocampal-lesioned and mPFC-lesioned mice did not exhibit preference for earlier odors from a list, whereas sham operated mice did. These results were also found with a time lag. Additionally, no mice showed a preference between odors from different presentation groups, indicating that the memory was for a set of odors, rather than relative time the odors were presented throughout a day. These results thus demonstrate that both the hippocampus and the mPFC are important for remembering the order of items within specific sequences, further supporting previous findings.

Given that the hippocampus is important in TM, Schäble et al. (2010) wished to study whether neurokinin NK₂ receptors of the septo-hippocampal cholinergic system, a
system whose primary influence is the hippocampus, play a role in TM. In this experiment, rats either received a NK₂ receptor antagonist or vehicle and behavior was tested to examine object recognition memory, object location memory, and temporal order memory. Results showed that injection of the vehicle into the medial septum had diminished TM and location memory, while injection of the NK₂ receptor antagonist re-established TM memory, but not location memory. The researchers suspected that this might occur due to the NK₂ receptors’ role in stress-induced activation of the hippocampal cholinergic system, though they mentioned that further studies are needed before firm conclusions can be drawn.

In addition to specific receptors, research has also attempted to understand the types of brain activity attributed to TM (see Figure 2C). Hsieh et al. (2011) used EEG to study the neural mechanisms of TM and how they differ from object identity memory. Participants performed order and item memory tasks while being recorded by EEG. Results indicated that order trials induced more theta oscillations, which were localized to sources in the medial and lateral PFC (consistent with aforementioned anatomical studies). Additionally, they reported that item trials induced more alpha oscillations, which were localized to sources in the left posterior parietal and lateral occipital cortex. These results demonstrate that working memory for TM and for object-identity rely on different mechanisms and are localized to different areas of the brain.

Looking back to the mPFC, researchers wished to study the role of glutamate and dopamine on TM and their role in the perirhinal cortex (PRH)-mPFC circuit (Barker & Warburton, 2011). To do so, rats received drugs to disrupt neurotransmission within this circuit and researchers measured the effects on behavior. The results from this set of
experiments implicated both the PRH and the pre-limbic and infra-limbic cortices (PL/IL) of the mPFC in TM. Additionally, the researchers suspect that the PRH is involved in encoding familiarity of items, whereas the PL/IL is involved in memory of the order of items. Also, results indicated that NMDAR and muscarinic receptor neurotransmission is important to these order memory processes. However, most interesting is the apparent neural circuit involving the PRH and the PL/IL that is vital to temporal order memory.

**Summary of Biological Mechanisms**

Thus, several brain regions have been implicated in order memory (see Figure 2B). Like most memory types, the hippocampus seems to play a role in order memory; specifically, the ventral hippocampus and perhaps the NK$_2$ receptors and their role in the hippocampal cholinergic system seem to be important to order memory in particular (Howland et al., 2008; Schäble et al., 2010). In addition to the hippocampus, however, the medial prefrontal cortex (mPFC) appears to play a role in temporal order memory (Hanesson et al., 2004). In fact, researchers were able to be even more precise, locating the pre-limbic and infralimbic cortices of the mPFC as locations important for order memory (Barker & Warburton, 2011).
D. Purpose and Experimental Design of the Present Investigation

To date, the majority of part-set cuing research has been focused on types of memory using words as cues. Although multiple paradigms have been employed using verbal stimuli, spatial memory tasks involving nonverbal stimuli are rare in the part-set cuing literature. Indeed, the two existing studies exploring part-set cuing of chess positions produced null results, leading to a necessity for further research into that type of memory. Further, none of the part-set cuing studies have examined memory specifically for procedures (i.e., steps in a process), although a fair amount of research exists on remembering sequences of words with part-set cues. Thus, the current set of experiments employed a novel methodology to explore part-set cuing effects of object-location memory and procedural memory.

In the present experiments, *Elenco Snap Circuits*—a children’s toy that allows people to build electrical objects—were used as stimulus materials, rather than chess boards in previous studies. The decision to not use chess pieces was made in an effort to minimize participants’ familiarity with the materials and to reduce potential confounds of (a) being able to use prior knowledge (as opposed to memory) when constructing the to-be-remembered objects and (b) simply remembering the whole object, as opposed to the individual pieces. Indeed, for most participants, the snap circuits were completely novel stimuli and to further ensure that there weren’t potential expertise confounds (e.g., participants with extensive knowledge of circuitry), the objects participants were asked to create did not contain a power source and were not connected into a fully functional circuit-like design. Moreover, the snap circuits allowed one to study both object-location and procedural memory using the same stimuli and methodology. That is, participants
could view an identical video of an object being built and then later, one could test either their object-location or procedural memory for the same video.

As the snap circuit stimuli have never been utilized in a memory study, there were many options available for presentation of the stimuli, type of cue used, and scoring of the complete reconstructions of the participants. Due to these potential ambiguities, multiple pilot studies were performed to assess the strengths of these various aspects of the experimental design. These pilot studies were performed during Summer 2011 and used Richter Scholars and other Lake Forest College student researchers as participants.

The pilot work indicated that two visual presentations of stimuli with 8-10 objects and 8-10 connections were optimal to ensure the appropriate level of performance. With this procedure, overall accuracy was in the 30-60% range, which allowed room for either facilitation or inhibition in performance and to make the present study consistent with uncued performance levels from previous experiments (Basden et al., 2002; Kelley & Bovee, 2007). Additionally, the type of cue was tested during pilot studies by asking participants opinions about the utility of the cues for the test. Ultimately, the most effective cue type from these studies was used (see Experiment 1). Thus, due to the novel nature of the snap circuit stimuli, many aspects of the experimental design were decided during pilot studies the summer preceding data collection. Further pilot testing was performed before Experiments 2 and 3 to ensure the minor changes made to the experimental design would be optimally effective.

In all of the experiments, the participants viewed a video of an object consisting of snap circuit pieces being constructed. After the completion of the object, participants were asked to either reconstruct the object (Experiments 1 and 3) or reconstruct the
procedure (sequence of steps) of the placement of the snap circuit pieces (Experiment 2).
In all experiments, participants were either given no cues and asked to complete the task, or were given some form of to-be-remembered items as cues; the cues differed across experiments and will be explained further within the context of each experiment (see Figure 3).
PSC effects with object-location memory?

Snap circuit PSC with procedural memory?

Object-location PSC with stronger cues?
Figure 3: General Methodology for the Present Investigation
The current set of experiments utilized the presentation of a snap-circuit video, after which participants were asked to provide information about the video they viewed—either reconstruction or order information. Participants either received no cues prior to providing such information or they were cued in various ways. The two major questions driving these experiments are whether part-set cuing effects can be seen in reconstruction of object-location information and whether part-set cuing effects can be seen in order memory of object-location information.
II. Experiment 1

The first experiment was designed to examine the effects of part-set cuing on the reconstruction of a snap circuit object. This experiment explored only object-location memory. In this experiment, participants twice viewed an assembly of a snap circuit object and were then asked to reconstruct the final object (by hand). Participants were either given cues, which consisted of photos of the connections between colored pieces, or were uncued and simply asked to reconstruct all the pieces and connections. With this experimental design, one could imagine that part-set cuing effects would be absent, as seen in the chess studies (e.g. Drinkwater et al., 2006). Alternatively, given the prevalence of part-set cuing inhibition in free recall tasks, one could argue that inhibition is the most likely outcome (e.g. Slamecka, 1968).

Methods

Participants & Setting. Sixty-nine introductory psychology students received extra credit for participating in this experiment (47 females, 22 males). Participants performed the experiment individually while sitting in a cubicle with a computer and the stimulus materials.

Materials. *Elenco Snap Circuits* (SCM-400) were used to create a snap circuit object that served as the to-be-remembered stimulus. The object consisted of a clear board, several colored circuit pieces, and several blue connector pieces of varying lengths (for example, see Figure 4). Although snap circuits are designed to create actual electric circuits, the to-be-remembered object did not resemble a true circuit so as to avoid the
Figure 4: Experiment 1 Final Object
A 16-piece snap-circuit object was built consisting of a clear board, 8 colored pieces, and 8 blue connector pieces of varying lengths. This object was used as the stimulus material for Experiment 1.
possibility of remembering due to physics knowledge rather than object-location memory.

Cued participants received a sheet of cues that they were asked to refer to during assembly of the final snap circuit object. The cue sheet contained four pictorial cues, which represented half of the total connections in the snap circuit object. Each cue consisted of two images and each image showed part of a colored circuit piece and part of a blue connector piece, giving enough information to denote which two colored pieces were connected and in what general orientation (see Figure 5 for an example).

**Procedure.** Participants viewed a short video, lasting 1 min 4 sec, in which a pair of hands assembled a snap circuit “object.” The object contained 8 colored and 8 connector pieces. During assembly, each piece was placed individually with a 3 second lag between placements. The placement of the pieces was sequential in the building of the object: two colored pieces were placed, then a connector piece, then another colored piece, then a blue connector piece, and so on. After complete assembly, the final object remained on the screen for 6 seconds. Participants viewed the video two times in immediate succession and then were instructed to raise their hand once the video finished.

After the presentation phase, participants were asked to replicate the object seen in the video. They were not responsible for reproducing the temporal order of assembly, but instead they were just instructed to reproduce the final object placement by any means necessary. All participants received a blank snap circuit clear board and only the individual pieces necessary for completion of the final object. Uncued participants were simply instructed to recreate the object with the materials. Cued participants, in addition
In Experiment 1, cued participants were given cues that resembled the two images that appear to the right of the arrow. These two images were designed to give the participant characterizing information about the connection enclosed in red, without revealing excess information about the placement on the board.

Figure 5: Experiment 1 Cues
to the aforementioned items, received the cue sheets, which indicated half of the connections between colored snap circuit pieces.

All participants were given unlimited time to complete the task. All participants finished the entire experiment within 25 minutes and most finished within 15 minutes. After completion, participants were given a debriefing sheet and left the study, while their snap circuit objects were photographed for scoring and data analysis.

**Scoring.** Placement of pieces was scored in both a strict and lenient fashion. Strict scoring required pieces to be placed in the exact correct location and orientation on the snap circuit board. Lenient scoring allowed pieces to be moved one space either up, down, left, or right on the snap circuit board, while remaining in the correct orientation.

Scoring of connections occurred in the same fashion as colored pieces. A connection (blue) piece was scored as strictly correct if it was in the exact correct location, regardless of the two colored pieces it connected. A connection was scored as leniently correct if the blue piece was one space in any direction away from the correct location on the snap circuit board, in the correct orientation.

**Results & Discussion**

To assess the differences in performance between the cued and uncued participants, each participant’s reconstruction was scored for accuracy. Specifically, participants could have placed between 0 and 8 colored pieces and blue connectors in their appropriate locations. Figure 6 displays the mean performance for piece placement of uncued and cued condition for lenient and strict scoring of colored and connector pieces. Four separate independent samples t-tests were performed, for strict color
placement, $t(67) = -.314, p > .05$ (uncued $M = 2.9714$, cued $M = 3.1765$), lenient color placement, $t(67) = -.089, p > .05$ (uncued $M = 3.9143$, cued $M = 4.2941$), strict connector placement, $t(67) = -.572, p > .05$ (uncued $M = 3.2571$, cued $M = 3.3235$), and lenient connector placement, $t(67) = -.732, p > .05$ (uncued $M = 3.9429$, cued $M = 4.118$). The statistical analyses thus indicated no significant differences between the means of the uncued and cued conditions, using both strict and lenient scoring of color and connector placement.

The finding of no significant results is not particularly surprising. Although inhibition is seen in most cases of word-list part-set cuing studies, the studies most similar to this experiment, namely the chess studies performed by Watkins et al. (1984) and Drinkwater et al. (2006), found no significant effect of cues as well. Thus, the possibility that cues do not affect object-location memory tasks must be considered. However, limitations to the study could have also contributed to the null results observed. As no previous studies have used snap circuits as test items, nor have spatial cues been used in part-set cuing experiments, it is feasible that the cue type used in this experiment was simply not strong enough to elicit significant differences in performance or that participants simply did not use the cues while reconstructing the object. Indeed, visual inspection of the data revealed a slightly, but not significantly, greater mean in all of the cued conditions. Thus, a repetition of this experiment using a different cue type could perhaps yield significant results (see Experiment 3 for a follow-up).
Figure 6: Mean Number of Correct Piece Placements as a Function of Cue Type

Mean number of correct placements for both the uncued and cued conditions. There were no significant differences between conditions in either the lenient or strict scoring of colored or blue piece placement.
III. Experiment 2

Experiment 2 was designed to assess memory for the step-by-step procedure of the snap circuit assembly. As in Experiment 1, videos of snap circuit objects were shown to participants. Then, participants recalled the procedure of the object placement with or without cues. Cues were either consistent or inconsistent, as described in the Serra & Nairne (2000). Given the potential similarities between remembering sequences of procedures and sequences of words, one might expect that consistent part-set cues would facilitate recall as compared to control, while inconsistent part-set cues would inhibit recall.

Methods

Participants & Setting. 55 introductory psychology students (18 male, 32 female) received extra credit for participation in this experiment. Participants performed the experiment in an individual computer cubicle.

Materials. As in Experiment 1, Elenco Snap Circuits were used to create the to-be-remembered object, which did not resemble a true circuit so as to avoid the possibility of remembering due to prior physics knowledge.

Unlike Experiment 1, in Experiment 2, participants were not instructed to reconstruct snap circuit objects. Rather, they were given photos of completed snap circuit objects and asked to note the order in which pieces were placed. There were blank squares next to each colored snap circuit piece of the complete assembly image, which participants used to fill out order information (see Figure 7).
Participants were given a version of this test sheet to record the order of placement for the snap-circuit assembly. Depending on condition, half of the blank squares were either filled with Xs, the correct order number of placement, or the incorrect order number of placement.
Procedure. Presentation of the instruction and materials was controlled by a PowerPoint presentation. Participants were instructed that they would view a snap circuit assembly video twice and then be asked information about the assembly. Unlike Experiment 1, participants were not asked to replicate the final snap circuit object. Instead, their knowledge of the order (steps) of assembly was tested. Each participant viewed a total of six different snap circuit object assembly videos (each approximately 2.5 minutes in length), with 10 colored and 10 connection pieces each. Given the nature of this new procedure and the results of a pilot test, the number of pieces was increased from Experiment 1 because performance was near ceiling with an 8-piece assembly.

After viewing of each video, participants raised their hands to receive a test sheet. Participants were asked to fill in the blank spaces on the test sheet with the order of placement of colored pieces (1, 2, 3,…,10), some trials were cued and some were uncued. Specifically, three conditions were used to test order memory: (a) uncued trials, in which 5 colored pieces were designated with X’s and participants were instructed to fill out the order of the other 5 pieces; (b) consistently cued trials, in which 5 colored pieces were marked with the correct order number and participants completed the order of the other 5 pieces; and (c) inconsistently cued trials, in which 5 colored pieces were marked with the incorrect order number and participants completed the order of the other 5 pieces.

Cues and the to-be-remembered positions were balanced (using a Latin square) across participants such that a total of 6 conditions were present: uncued even, uncued odd, consistent even, consistent odd, inconsistent even, and inconsistent odd. All participants received one of each condition.
Participants were not timed when marking the order of the assembly and they proceeded through the procedure at their own pace. Most participants finished each trial within 5 minutes. After completion, participants were given a debriefing sheet and left the study.

**Results & Discussion**

Participants reconstruction of the sequence of steps yielded a score between 0 and 5 correctly ordered steps (keep in mind that half of all placements were given or marked with an X). Figure 8 displays the mean percentage of correctly assigned order values for the uncued, consistent cued, and inconsistent cued conditions. A one factor repeated measures analysis of variance (ANOVA) compared memory performance over three cue conditions (uncued, consistent cued, and inconsistent cued). The ANOVA indicated a significant main effect of cue condition, \( F(2,51) = 13.473, \ p < .05 \).

Sidak post hoc tests were performed to test which conditions differed significantly. Post hoc tests revealed a significant difference between the means of the consistent cued condition (M = 0.796) and uncued condition (M = 0.617), as well as a significant difference between the consistent cued condition (M = 0.796) and inconsistent cued condition (M = 0.585). There was no statistically significant difference between the inconsistent cued condition and the uncued condition.

The results of this experiment generally mesh with previous part-set cuing studies examining the order of word lists. Specifically, the finding that consistent cues aid in the retrieval of order information is congruent with all previous part-set cuing order studies.
Figure 8: Proportion of Correctly Ordered Objects as a Function of Cue Type
Mean percentage of correctly ordered pieces across the three conditions: uncued, consistent cued, and inconsistent cued. The consistent cued condition yielded significantly higher performance than both the uncued and inconsistent cued conditions.
(e.g., Basden et al., 2002; Kelley & Bovee, 2007; Serra & Nairne, 2000). As consistent cues are given in the same manner in which they were encoded, according to the strategy-disruption hypothesis of part-set cuing, they should always help in retrieval of other order information.

Interestingly, in the current experiment, performance in the inconsistent cue and uncued condition did not differ significantly from one another. These findings are not congruent with previous studies, which typically demonstrate poorer performance in the inconsistent cued condition as compared to both the uncued and consistent cued conditions. Analysis of the raw data sheets revealed that many participants “corrected” the inconsistently cued order information with the appropriate numbers while completing the test. Others seemed to cross out the inconsistent information, which suggests that they might have ignored the information completely. These data might explain the non-significant difference between the inconsistent cued and uncued conditions. If the participants changed or disregarded the cue numbers given in the inconsistent condition, then the inconsistent condition may have acted merely as another control condition, similar to the uncued condition. Thus, as the participants treated both conditions as control, the finding that the mean performance between the two was not significant is not surprising.
IV. Experiment 3

The main objective of Experiment 3 was to revisit the question of whether part-set cues influence object-location memory. The present study used a different type of cue in an effort to enhance the efficacy of the part-set cuing manipulation. In this experiment, the cue was an image of the snap circuit board with half the pieces placed in their appropriate locations. Participants reconstructed the object either with this set of cues or with no cues. Given that there was a nonsignificant trend towards cue facilitation in Experiment 1, it was predicted that these cues would yield part-set cuing facilitation.

Methods

Participants & Setting. 69 introductory psychology students (18 male, 51 female) received extra credit for participation in this experiment. Participants performed the experiment in an individual cubicle with a computer and stimulus materials.

Materials. As in Experiments 1 and 2, Elenco Snap Circuits were used to create the to-be-remembered object, which did not resemble a true circuit so as to avoid the possibility of remembering due to prior physics knowledge.

Also, as in Experiment 1, participants received a sheet of cues and to use while completing the final snap circuit assembly. The cue sheet differed from that of Experiment 1, however, in that they now consisted of an image of the complete snap circuit board with 5 colored pieces correctly placed on the board (See Figure 9 for an example).
Figure 9: Experiment 3 Cue Sheet
An example of the cue sheet that participants received in Experiment 3. 5 of the 10 colored pieces were shown in their correct locations. Counterbalancing occurred so that all 10 pieces were used as cues; either the oddly placed pieces or the evenly placed pieces made up one of two cue sheets.
Procedure: Presentation of the instruction and video was controlled by a PowerPoint presentation. Participants were instructed that they would twice view a video of the construction of a snap circuit object. The video consisted of the assembly of a snap circuit object containing 10 colored pieces and 10 blue connector pieces (see Figure 10 for complete object). Participants were also informed that they would be asked information about the snap circuit object following the presentation of the video.

After viewing the video, participants were instructed to replicate the snap circuit object, to the best of their ability. Half the participants were simply given the board and pieces to reconstruct, and half the participants were cued. The cued participants were given a sheet of paper containing 5 of the colored pieces in their correct locations; the cued condition was counterbalanced so that all 10 pieces appeared on one of the cue sheets—either all odd-placed pieces or all even-placed pieces were cued. The completed reconstructions were collected and photographed for later scoring and participants were debriefed.

Scoring. With regard to the assembly task, the same scoring method was used as in Experiment 1 with one exception: only colored pieces were scored. The same strict and lenient conditions were used when scoring the colored stimuli. Further, since cues consisted of actual pieces placed, only the noncue items were scored. Participants from the uncued condition were randomly assigned to one of two conditions for scoring as well. Thus, each participant’s reconstruction score was a number out of 5, regardless of cue condition.
Figure 10: Experiment 3 Final Object
This image is the complete 20-piece object that participants viewed being assembled, and were required to reconstruct, in Experiment 3.
Results & Discussion

As aforementioned, scoring of snap-circuit reconstructions led to a possible score between 0 and 5 for each participant. Figure 11 displays the mean performance percentages for piece placement of the uncued and cued conditions for lenient and strict scoring of colored pieces. Two separate independent samples t-tests were performed, for strict placement, \( t(67) = -1.172, \ p > .05 \) (uncued M = 0.3222, cued M = 0.4061), and for lenient placement, \( t(67) = -1.328, \ p > .05 \) (uncued M = 0.4056, cued M = 0.4909). The statistical analyses thus indicate no significant differences between the means of the uncued and cued conditions, using both strict and lenient scoring of colored pieces.

The results of this experiment are consistent with those of Experiment 1. Although in previous studies, part-set cuing effects have been seen in a myriad of different memory types, the non-significant findings that appear in this experiment and in Experiment 1 are consistent with chess studies. Thus, the possibility that the mean performances do not significantly differ between the cued and the uncued conditions can possibly be explained by the type of memory being studied. However, since these data are not significant, no conclusions can be drawn. Further, the data show a similar trend, albeit larger but still non-significant, as seen in Experiment 1. This leaves open the possibility that the present design simply was not powerful enough to detect a significant difference. Perhaps more participants or an even stronger cue manipulation are needed.
Figure 11: Proportion of Correct Pieces Placed as a Function of Cue Type
Mean percentages of correctly placed colored pieces for the uncued and cued conditions. There is no significant difference in performance between the two conditions.
V. General Discussion

The results from this set of experiments demonstrate two important findings. First, part-set cuing of procedures is consistent with the findings reported in the part-set cuing of order literature (Basden et al., 2002; Kelley & Bovee, 2007; Serra & Nairne, 2000). In Experiment 2, consistent cues led to significantly higher performance—part-set cuing facilitation—than both control and inconsistent cues. Though typical order studies have shown part-set cuing inhibition with inconsistent cues, in this study, participants often ignored or corrected the inconsistent cues, which made them functionally equivalent to a second control condition. In the future, by modifying the way the cues are presented (to avoid ignoring and correcting by participants), it might be possible to find part-set cuing inhibition for inconsistent cues, just as seen in the word-order literature.

Further, it would be fascinating to study the biological nature of part-set cuing in order memory. Although the hippocampus and mPFC play a role in temporal memory, none of these brain regions have yet been studied during part-set cuing tasks and an important next step in the part-set cuing literature is to examine the anatomical basis for these effects. It is quite possible that during part-set cuing tasks of order memory, one of the aforementioned brain regions has more or less activity. Simply using fMRI to look at activity during a modified order part-set cuing task could provide great insight into the brain regions that are important not only in the type of memory itself, but in facilitation and inhibition of that memory.

Second, both Experiment 1 and 3 yielded no significant differences between cued and uncued conditions on an object-location reconstruction task. Although limited conclusions can be drawn from null results, these findings are consistent with the part-set
cuing chess studies (Drinkwater et al., 2006; Watkins et al., 1984). Still, the
nonsignificant trends in the data suggest that part-set cuing facilitation of object location
is a real possibility and future research is needed. The simplest way to follow-up this
study is to simply increase the statistical power of the study by adding more
participants—perhaps then, the nonsignificant trends will reach statistical significance.
One could also explore the biological side of part-set cuing, as suggested earlier. Using
biological tests during part-set cuing tasks could lend insight into brain activity that
changes across conditions during typical part-set cuing tasks, but does not during object-location tasks. That is, if part-set cuing inhibition and facilitation are associated with
specific changes in brain activity, and those changes are nonexistent during part-set cuing
of object-locations, then one would be more confident in concluding that part-set cuing
does not influence object location memory. Looking to brain regions such as the
intraparietal and intraoccipital sulci, parahippocampal cortex, and infralimbic cortex of
the medial prefrontal cortex could provide explanation as to why part-set cuing effects
were not seen in this set of experiments.

However, one cannot rule out the possibility that these nonsignificant object-location findings are due to the design of the experiment itself. Snap circuits have never
been used in the literature to test object-location memory (or any type of memory, for that
matter). It is possible that the strength or utility of the cued stimuli used in these
experiments was simply not enough to elicit the typical part-set cuing response. Or,
maybe the procedure of using the cues was not appropriate. By continuing to tweak
aspects of the experimental design, as was done between Experiment 1 and Experiment 3
by the changing of the presentation of cues, there is a possibility that definitive part-set
cuing effects will be produced in the future. Thus, in addition to looking toward the anatomical basis of the effects seen, it will be important to continue to study the behavioral effects while making small changes to the stimuli in an effort to increase their strength.
VI. Conclusions

This set of experiments lent new insight into the effects of part-set cuing. It is now apparent that the serial order effects seen with word-list memory, namely that consistent cues lead to facilitation, are extended into memory for the sequence of steps in an object-building procedure. Additionally, no part-set cuing effects have been noted in object-location memory, both in this study and in previous chess studies. The inability to find significant results from object-location tasks could be due to a number of things (e.g., inadequate power, design issues, or that part-set cues simply do not influence object-location memory) so additional research is required. Moreover, research on the differences in brain activity, with or without part set cues, in object-location, procedural, free recall, and order memory tasks would be instructive. Future studies should be designed to address these possibilities and further elucidate the mechanisms behind part-set cuing in different types of memory.
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