The Pennsylvania State University
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INFLUENCE OF CONCEPT OR SEMANTIC RELATION OF ITEMS IN REMEMBERING PERCEPTUAL DETAILS

A Thesis in

Psychology

by

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ABSTRACT

Visual working memory (VWM) – an important cognitive memory system for online storage and maintenance has always been contested for its representational capacity. Prior studies generally suggest discrete slots model (Luck and Vogel, 1997), resource pool model (Bays and Husain, 2008) as well as a hybrid type of model (Swan & Wyble, 2007). However, all three converge on the basis that working memory is of limited capacity and representation of items depends on such capacity. We investigate the usefulness of chunking – the association of items derived as a concept from long-term memory and how this helps structure memory. Chunking helps utilize available capacity to organize items into coherent unit such that limited available capacity can be efficiently utilized and this in turn helps improve recall. In a series of experiments, we showed that this organizational facility of chunking does exist, however the nature of chunking to preserve visual details bounded within the chunk (Allen et al, 2021) remained open to investigation as we failed to find an effect of chunking on memory for visual detail. In experiment 1 and 2, we utilized chunked letters to show that memory benefit existed in recalling letters, but this benefit was not translated in recalling the style of letters. In the next two experiments, we used object grouping as an extension of chunking to real-world objects, also provided a similar effect. We also showed objects were better recalled and their size easily discriminated when objects were semantically paired, however, the same memory effect in size was not found when objects were flipped.

List of Figures

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TABLE OF CONTENTS

Chapter 1. INTRODUCTION

The world we see is filled with rich and intricate visual information, conveyed to our minds through sensory and cognitive systems. The processing of enormous visual information requires a memory system that encodes, stores, and manipulates information according to its utility. Such a memory system should not only be able to incorporate information during eye movements, but also direct attention to specific areas as well as preserve details about things that they see. For example, a driver driving on a crowded highway must deal with a lot of visual information – different vehicles, lane markings, signs, directions, etc. The driver must incorporate information coming from their visual field – roads, lanes, cars, warning signs, weather, etc. and utilize this information where to speed up/slow down, change the lane, take the exit, make a hard stop, etc. However, not every information that comes to the eye can be processed by the mind. Other information such as landscapes outside the road can be secondary or even unnecessary to driving. Thus, there is a need to direct the attention according to the immediate goal. Also, drivers can organize the information using their knowledge. They can use the knowledge of speeding up or slowing, the distance between vehicles in the vicinity, exit signs, and light indicators, and associate them to take the exit from the road. Such organization of information by association of knowledge of working items in hand helps remember details or make decisions without getting overwhelmed. The memory system responsible for actively storing, organizing, and manipulating visual information for perception has been termed visual working memory (VWM).

Working memory

In cognitive memory systems, two distinguishable memory systems are thought to be interacting with each other during cognitive processes: short-term memory (STM), is perceived as having limited capacity for current information, while long-term memory (LTM) is perceived as having seemingly limitless storage (Atkinson & Shiffrin, 1968). Initially, it was thought that repeated maintenance of information on the STM was required for encoding information into the LTM. Atkinson and Shiffrin brought the concept of working memory: where information was not just maintained for immediate tasks but also could be manipulated, organized, and then rehearsed for the necessary goal.

(Baddeley & Hitch, 1974) revised the initial STM with a multi-component working memory model of interacting sub-systems: phonological loop – maintaining verbal information, visuospatial sketchpad– maintaining visual information, and central executive -performing higher level cognitive functions such as decision making, planning, allocating attention, etc. as well as directing the activities of the phonological and visuospatial sketchpad (Figure 1). This multicomponent model also laid the groundwork for a contemporary understanding of working memory (WM). Temporarily held information is manipulable for a current task and such manipulation differs from processes that help facilitate the transfer of information to permanent storage in LTM. This model also brought modality specific information transfer by introducing the notion of phonological loop and visuospatial sketchpad. Whilst traditional WM studies focused dominantly on verbal aspects of encoding and retrieval, the introduction of the visuospatial sketchpad has helped studies to test WM retrieval for visual or visuospatial information such as objects and scenes (McAfoose & Baune, 2009).

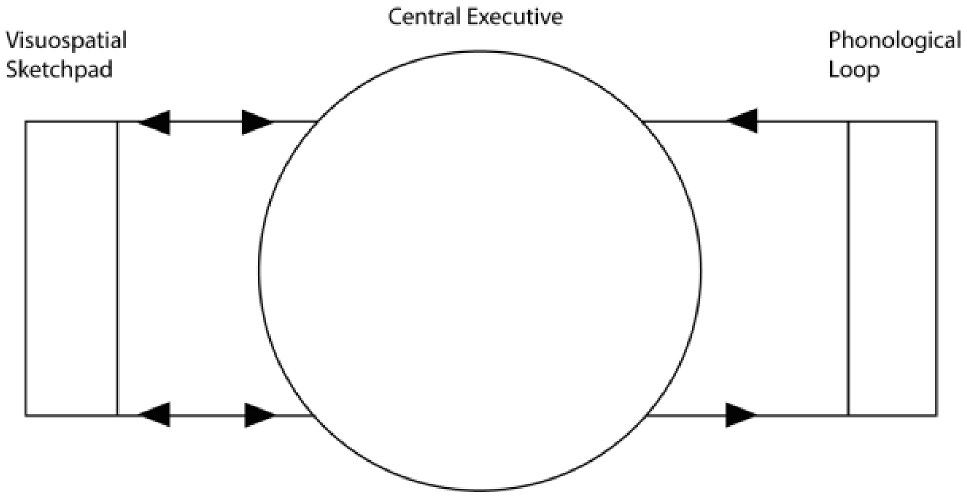

Figure 1.1 Initial Multicomponent working memory model.
Source: Baddeley and Hitch (1974)

Capacity of working memory

Visual working memory has been considered a capacity limited system that can only incorporate a small amount of visual information (Baddeley & Hitch, 1974; McAfoose & Baune, 2009). There's been a consensus among influential studies upon a fixed capacity limit that supports only a certain number of objects – usually three to four (Awh, Barton, & Vogel, 2007) that can be remembered or that there's only a fixed resource pool to distribute across items (Bays, Catalao, & Husain, 2009; Swan & Wyble, 2014). Luck and Vogel (1997) conducted a study trying to measure the capacity limitation of visual working memory by using a standard change detection paradigm. An array of colored square boxes was presented for a brief interval to participants. The participants were then probed whether a second display of an array of square boxes identically matched the first display or not. It was observed that the participants performed well when the number of items to be remembered was within the capacity limit of 3 to 4 items or slots. However, as the number of items exceeded this limit, participants' accuracy in detecting changes decreased significantly. This suggested that there is a finite capacity for the number of objects that can be efficiently stored and processed in visual working memory.

The capacity limitation also influences the content in working memory when the demand for remembering visual information increases. For example, change detection in perceptually similar objects is easier with just one item but becomes harder when the number of objects increases. The chance of detecting the change in perceptual content (e.g., shades on each side) of a single 3D cube is higher than detecting the change in multiple 3D cubes (Alvarez & Cavanagh, 2004). Storing multiple cubes increases information storage demand for memory precision. The capacity limitation therefore affects the representation of each cube when incorporating visual information for multiple cubes. A single cube can be represented in working memory with higher resolution than multiple cubes in which each cube competes with each other for representation. Alvarez and Cavanagh (2004) introduced a resource model where multi-feature objects compete for resources. This competition between visual items tends to exhaust the available pool of resources for encoding and storage as the number of separable features among them increases or the complexity of visual stimuli grows. However, such a representation also is prone to noise as more information is cramped into a limited space (Bays & Husain, 2008).

Chunking

Brady et al. (2009) found that when regularities among items were introduced and learned during an experiment, memories can be efficiently organized for advantageous recall. In a set of two experiments, their studies had two colors were regularly paired either within objects i.e. two colors consistently paired in two concentric circles forming one object or across objects i.e. two colors consistently paired two neighboring objects. It was found that in either case, the regularities provided memory compression for colors in patterned condition and therefore memory benefit in remembering the cued colors which can be observed through improved recall from the results in both experiments. Ngiam et al. (2019) interpreted that the ease in remembering information was not just due to the fact that the regularities helped compress information in memory and facilitated capacity, but the strong associations between items enabled from LTM contributed to the improved recall. This posits that conceptual information helps arrange and organize in WM during online storage and maintenance and thus provide mechanism for memory benefit during WM tasks.

Chunking has been conceptualized as a strategic associative learning mechanism (Baddeley & Logie, 1999). Miller (1956) refers to chunking as the process of grouping individual pieces of information into larger, more manageable units. Miller proposed in his paper that on average seven chunks could be held in human working memory. A mechanism to overcome the capacity constraints of working memory and enhancing the storage and retrieval could be achieved by utilizing chunking of information. Drawing knowledge from long-term memory, chunking utilizes a conceptual understanding of associated items to parse relevant information necessary to perform the task (Huang & Awh, 2018). For example, multiple items can be associated with each other to form a unit that matches a concept stored in our long-term memory (e.g., three distinct letters ‘C’, ‘O’, ‘W’ forming a label “COW” or a word chunk). One can assume that this chunk, which is a meaningful attribute, therefore might provide a benefit for memory of the individual letters. Since “COW” is a concept that one might have learned as a label for an animal, it serves memory to extract individual letters easily.

To support the usefulness of chunking, Allen et al. (2021) showed that using a word chunk facilitated memory performance not only to remember individual items but also their visual details. They presented a set of eight letters in the display which on random trials either formed two-letter word (or chunk) pairs or random letter pairs. Participants were then probed for a random letter in a 4-AFC task. They found that chunking structured memory not only to identify letters more accurately than non-chunked letter pairs but also facilitated memory to represent the font style of letters in the display. Their result shows that semantically paired items help serve memory preservation for perceptual visual detail for each item. This outcome is also supported by the claim from Norris et al. (2021) study that verbal chunking utilizes data compression by recoding inputs into different code in STM as well as preserve representations underlying that code. However, one drawback from Allen et al. (2021) result is that the effect demonstrating that chunking improves both letter knowledge and font detail was weak and has not been replicated yet.

In contrast to these results, the memory for visual details such as font might be more precise when items are not linked semantically (e.g., ‘C’, ‘O’, ‘W’ arranged as “O-W-C” rather than the chunk word “COW”). During encoding of chunks, information might be compressed during representation in working memory (Brady, Konkle, & Alvarez; 2009). This arrangement provides flexibility in the capacity to store additional chunk units, but the compressed nature of each chunk might degrade the resolution of visual details information about items within the chunk. Figure 2(a) shows the representation of a chunk word – COW – composed of individual letters, ‘C’, ‘*O*’, ‘**W**’, with different fonts (visual detail). In this example, the chunk word as a knowledge unit is stored in one slot of working memory compressing detail information about each letter. Figure 2(b) shows that the random word “**X***T*Y” is not encoded in compressed format, but each individual letter takes up a discrete slot resulting in better representation of detail information. In this model, a non-chunked word has enhanced memory precision for individual letters but results in less availability of space capacity in working memory to encode additional letters.

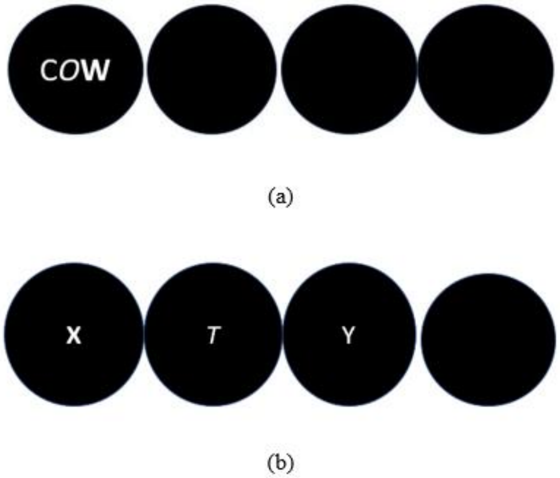

Figure 1.2 (a) Representation of a chunked word in working memory. The generic "COW" occupies a slot in compressed format and ties visual information about individual letters in a hierarchical format in remaining slots (b) Representation of random letters in working memory.

O'Donnell et al. (2016) found that memory for items benefited from both semantic and functional relationships amongst the items. Their study showed that the semantic grouping of objects (with functional interaction) provided better memory for remembering items. The stimuli consist of items in a regular semantic and functional configuration called action-pairs. An example is a swinging golf club aimed rightly at a golf ball. A non-action pair would be two semantically unrelated objects, like a fire extinguisher and a wrench. The improved effect of functionality only depended upon the semantic relatedness among objects.

However, visual working memory can be influenced by the type of visual information that has to be stored. A study from Asp et al. (2021) shows that working memory performance can be enhanced for meaningful stimuli (Asp, Stormer, & Brady, 2021). When meaningful information (i.e., face-level features) were extracted from ambiguous Mooney faces, this higher-level interpretation helped preserve memory for low-level features, aiding better recognition memory for Mooney faces against both scrambled Mooney faces, and inverted Mooney faces in separate experiments. Then, we can also ask whether such preservation for low-level features can be expected when stimuli in memory can be integrated or associated with each other based on prior conceptual knowledge about integrated units. Can semantically paired (e.g., individual letters forming a word) items aid individual item identification as well as enhance memory precision for visual details for each item?

Two approaches to assess the effects of semantically paired items will be used in my project. We will perform four experiments which look at how conceptual knowledge of semantically paired items guides memory by assessing performance for remembering individual items and their visual detail. There can be two outcomes – either the semantic pairing facilitates the memory by helping to encode details in addition to the item information, like the memory advantage for details in Asp et al. (2021) and Allen et al. (2021) or, alternatively the semantic pairing sweeps away the visual detail by compressing every item to form a unit during encoding. Of these two alternatives I propose that semantic pairing of items provides a memory advantage for remembering individual items, but it comes at the expense of memory precision for visual details i.e., visual detail information about items from pairs is compressed which degrades memory precision but facilitates additional paired units to be incorporated.

Chapter 2. EFFECT OF CHUNKING & GROUPING ON MEMORY FOR DETAILS

Effect of chunking on memory for visual details

Experiments were undertaken to understand the effect of the nature of chunking on memory for visual detail. Drawing inspiration from the pre-learned chunks (well-known words were utilized as chunks) experiment from Allen et al. (2021), the effect of chunking on memory for individual letters as well as memory for the letter types (two font styles – bold or italic) was tried to replicate in the Experiment 1 of my study to see if it fails my hypothesis.

Experiment 1: Two-letter chunked word.

Participants: 22 participants were recruited from The Pennsylvania State University undertaking introductory psychology courses out of which 21 participants data was utilized. A criterion was set before analysis that the participants who performed with an average accuracy below the chance for both memory tests were to be excluded. One participant was excluded for not meeting the criteria and one participant was excluded for a higher number of missed trials.

Stimuli and Procedure: An encoding display of 2000ms was presented with two sets of two-letter words. The chunked words ("WE", "TO", "AS", "IF", "UP", "MY") were drawn up from Allen et al. (2021) experiment 2. Non-chunked words ("SP", "EF", "YM", "TI", "WU", "AO") were created by randomly and appropriately shuffling the 12 alphabets from chunked words set so that there is no long-term conceptual association between two letters in a word. The individual letters were extracted from the EMNIST dataset (Cohen et al. 2017) consisting of thousands of handwritten letters to provide the stimulus variability and complexity as shown in Figure 3.

Figure 2.1 Examples of EMNIST letters.
Source: Cohen et al. (2017)

The motive was to provide an information rich stimulus – visual letters set of different handwriting styles providing variability in presentation.

Figure 2.2 Two letter chunk experimental setup. The left figure shows the memory display where pairs of two letters are shown on either side of the screen. The right figure shows the response screen where an asterisk marks the letter that is being probed.

Participant performed a total of 160 trials of the two-chunked letter working memory experiment. In the memory display, two sets of letter pairs were always presented on either side of the fixation point as shown in Figure 4. No letter pairs were repeated in the same trial. Encoding was followed by a 700ms blank period, and the participants were probed for a random letter in a 4-AFC test. In the response display, an asterisk provided a cue to recall a particular letter. Both label memory and style memory were tested on a single trial. In the 4 alternative forced choice scheme, there were two versions of the correct letter out of which one was an exact replica of the letter being probed. The remaining two were different styles of a letter not shown in the memory display. The experiment was configured such that both chunked and non-chunked trials were presented in equal proportion.

Result: It was found from this experiment that there was no memory benefit when a chunk comprised of two letters were presented. The participants did not have significant advantage at remembering individual letter from chunked trials (*M* = 0.94 and *SD* = 0.07) over non-chunked random trials (*M* = 0.94 and *SD* = 0.076) with t(20) = 1.60, p= 0.125. Similar memory effect was seen for writing style for chunked trials (*M* = 0.67 and *SD* = 0.11) over random trials(*M* = 0.66 and *SD* = 0.10) with t(20) = -0.73, p = 0.473.

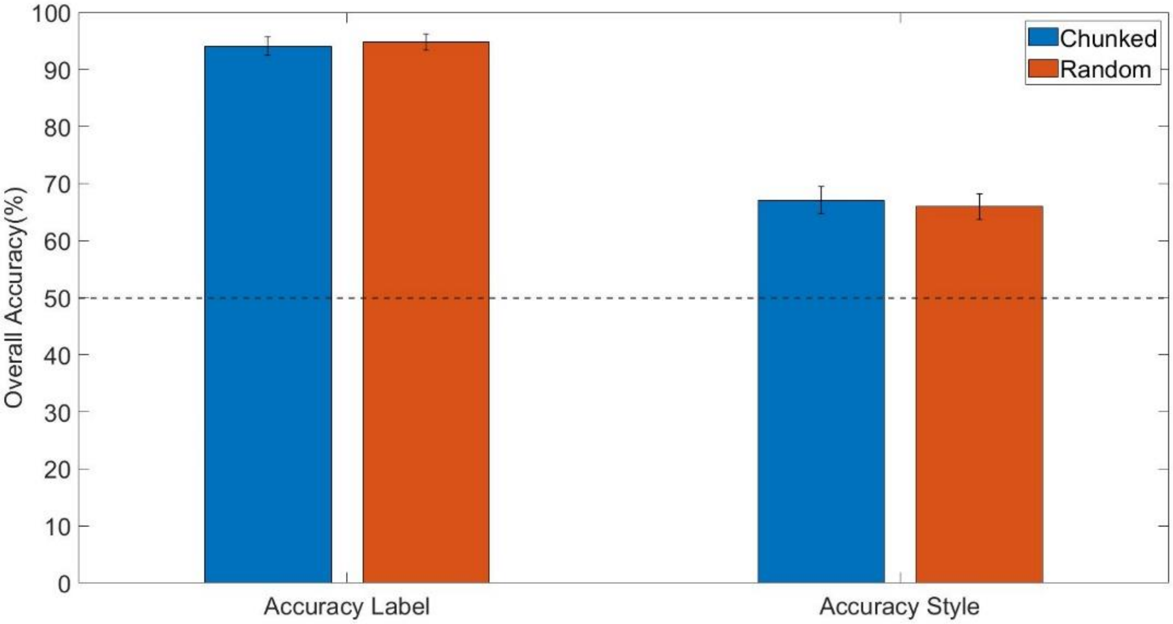

Figure 2.3 Experiment 1 results. Chunking shows no improvement either for letter label or for style. Error bars indicate the standard error of the mean.

The findings as interpreted by Figure 5 show that in the case of two letter pairs, chunking did not provide any advantageous benefit to remember both the letter identity and writing style. This finding is inconsistent with the result from Allen et al. (2021) paper that chunking helped organize memory to retrieve both letter identity and font style with significant effect. However, in my experiment, the memory for letter identity suffered ceiling effect for both chunked and random trials. This effect might have been observed because in this experiment only two sets of letter pairs consisting of four different and distinct letters were presented. Instead, the original experiment by Allen and Brady (2021) had 8 letters organized as 4 letter pairs. It might have been easier to encode all items in the available capacity resulting in ceiling effect for identity memory and no significant difference for style memory in both conditions.

Experiment 2: Three-letter chunked words.

Experiment 2 utilized six individual letters instead of the four letters in experiment 1. The motive was to bring accuracy down from ceiling for label memory and maintain style memory above chance level.

Participants: 16 participants were recruited from The Pennsylvania State University undertaking introductory psychology courses. A criterion was set before analysis that the participants who performed with an average accuracy below the chance for both memory tests were to be excluded. No participants violated the exclusion criteria.

Stimuli and Procedure: Experiment 2 followed the same mechanism as experiment 1 with small design changes. Six sets of letters were utilized in Experiment 2 forming two item sets of three letters. A three-letter frequent wordlist was downloaded and curated to remove words consisting of letter replication (e.g., ALL), undesired characters (e.g., N'T), anagrams (e.g., ARM = RAM), and abbreviations (e.g., FBI). The two sets of three letters were aligned vertically with each on either side of a fixation point located in the middle.

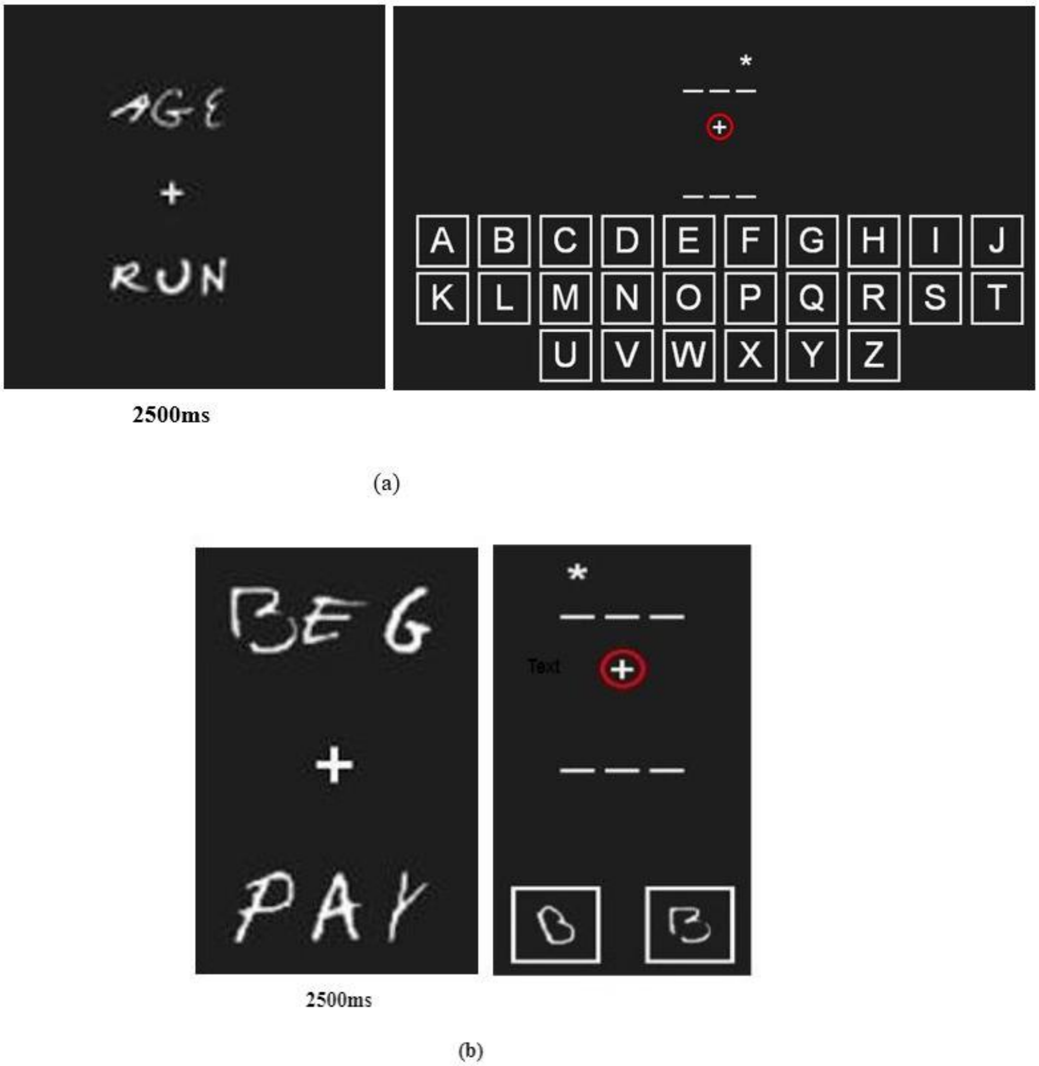

Figure 2.4 Three-letter chunk experimental setup. Panel (a) shows the memory display where two sets of three letters are displayed on the upper and lower part of the fixation point. It follows with a response display for letter label being probed marked by asterisk sign. Panel (b) shows the displays for trials where participants are probed only for style memory marked by asterisk sign in a 2AFC task.

Participants performed a total of 160 trials of the three-letter chunked words working memory experiment. In the memory display, two sets of three letters were always presented on the upper or lower side of the fixation point as shown in Figure 6. No letter pairs were repeated in the same trial. The encoding period was increased to 2500ms which was followed by 700ms blank period. Another design change was that instead of probing letter identity and style in a single test, participants were trial-wise randomly probed either for letter identity in a 26-AFC task or letter style separately in the

2-AFC task. This aspect was introduced to assess the performance for identity and style independent of each other. The experiment was also configured such that both chunked and non-chunked trials were presented in equal proportion.

Result: In this experiment, participants did show a significant advantage for remembering individual letter label when three letters formed familiar words(M = 0.92 and SD = 0.09) than for random letters(M = 0.97 and SD = 0.09) with t(15) = -4.01, p = 0.001). However, the memory test for writing style had accuracy that was low and showed no reliable difference.

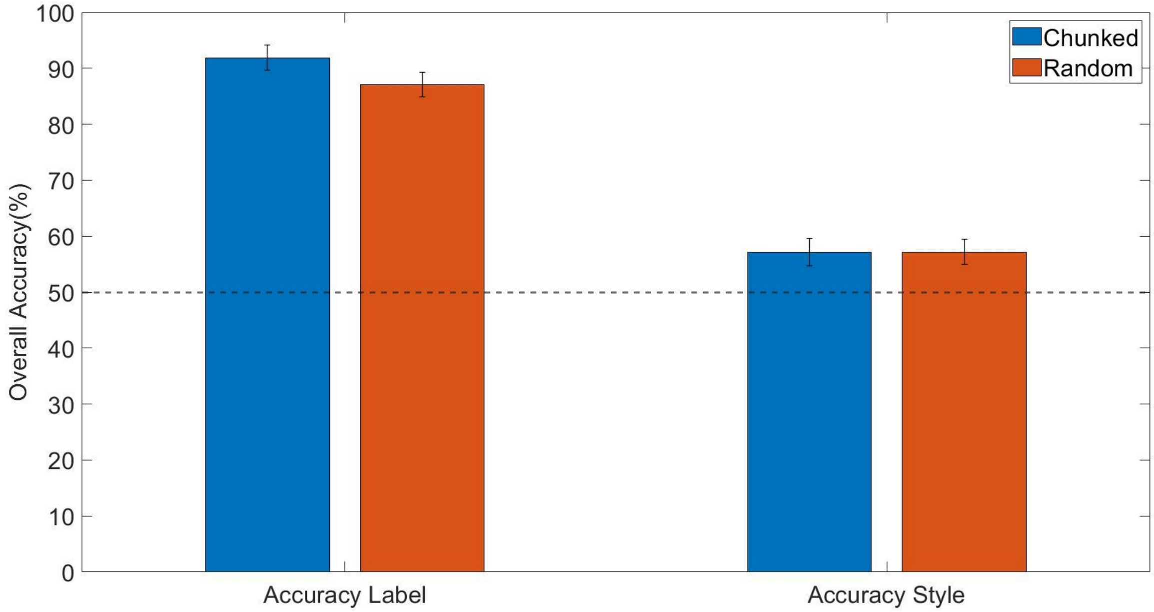

Figure 2.5 Experiment 2 results. Chunking improves letter knowledge but accuracy for writing style shows no effect. Error bars indicate the standard error of the mean.

The result interpreted by Figure 7 suggests that most participants might have often been guessing the letter styles rather than judging from memory content. This was likely due to the need to remember 6 different letter styles rather than 4 in Experiment 1. The increase in memory load might have caused the resolution of representation for visual details to degrade. Another reason might be that the close similarity of items between target and foil might have prompted the participants to guess rather than base their judgement on memory. In the 2AFC task, the target item might have been perceptually similar to the foil item on many trials. This might have caused confusion between the two options since participants had difficulty matching either with the representation in the working memory and thereby opting to guess.

Effect on object grouping on memory for visual details.

Findings from Balaban and Luria (2016) contended that feature information from different objects (e.g., color and orientation) are hard to integrate as a unit in working memory unlike different features of the same object (Luck and Vogel; 1997). However, O'Donnell et al. (2016) found that memory for items benefited from both semantic and functional relationship amongst the items. Their study showed that the semantic grouping of objects (with functional interaction) provided better memory for remembering items. The stimuli consist of items in a regular semantic and functional configuration called action-pairs. An example is a swinging golf club aimed rightly at golf ball. A non-action pair would be two semantically unrelated objects, like a fire extinguisher and a wrench. The benefit of relatedness primarily depended upon the semantic relatedness among objects and less so their physical orientation.

Drawing inspiration from their study, I ran two experiments which tried to assess the effect of object grouping on memory for objects as well as the perceptual details of individual objects from each pair. The primary question addressed by this experiment is whether semantic relatedness affects memory for details. One motive is to replicate the finding of O'Donnell et al. (2016) experiment 1 which showed memory benefit for remembering items from semantically related interacting pairs. Additionally, another motive is to test the hypothesis that memory for perceptual detail of objects in action pair are worse off than non-action pair despite advantage to remember object.

Experiment 3: Object grouping with size varied.

Participants: 30 participants were recruited from The Pennsylvania State University undertaking introductory psychology courses. A criterion was set before analysis that the participants who performed with an average accuracy below chance for both memory tests were to be excluded. No participants violated the exclusion criteria.

Stimuli and Procedure: Object pairs constituting action pairs and non-action pairs are adapted from O'Donnell et al. (2016) study. The objects for the pairs are selected from the Snodgrass and Vanderwart (1980) images. There was a total of 18 different objects which were organized into two pools of distinct action pairs and non-action pair sets. That is, no objects were repeated in pairs in either pool. Four sets of object-pairs were randomly chosen for a given trial from either action-pair or non-action pair sets. The experiment was configured such that two conditions – semantically paired objects (consisting of action pairs only) and non- semantically paired objects (consisting of non-actin pairs) were presented in equal proportion for each subject.

Figure 2.6 Four different object pairs experimental setup. The left figure shows memory display with two set of object pairs appearing either side of fixation point. The right figure shows a test display of 4AFC task where participant must select one matching object.

An encoding display was presented for 3000ms which was followed by a blank period of 1000ms. The encoding display contained two sets of object pairs on either side of the fixation point as shown in Figure 8. The participants were then probed for remembering one of these objects in a 4-AFC task where the target and foil will be different objects and of two different sizes. That is, within each trial, participants were tested for memory for the objects compared between action pair and non-action pair, as well as memory for the size between two groups on different trials. Both the memory for objects and memory for remembering perceptual size of objects were tested in equal proportion during the experiment.

Result: It was found that participants had a significant advantage in remembering both the individual objects as well as the perceptual size of the object being tested. Participants were able to discriminate the perceptual size of the object given that they correctly identified the object. Accuracy was higher on the semantically paired trials (*M* =0.92 and

SD = 0.07) over non-semantically paired trials (*M* =0.85 and *SD* = 0.08) for identifying the object (t(29) = -4.17, p < 0.01). A similar effect was seen for semantically paired trials(*M* =0.76 and *SD* = 0.12) over non-semantically paired trials(*M* =0.65 and *SD* = 0.11) for discriminating size (t(29) = -6.06 and p<0.01).

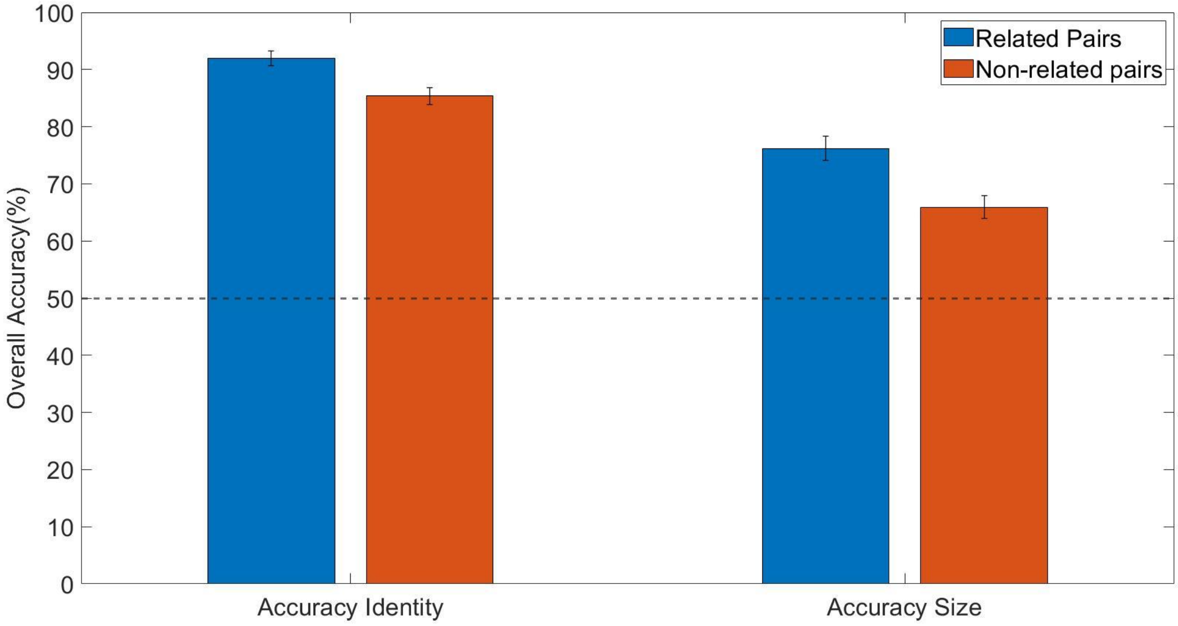

Figure 2.7 Experiment 3 results. Object Grouping does show memory benefit in identity and size. Error bars indicate the standard error of the mean.

This result as seen in Figure 9 shows that when objects are grouped together in a semantically and functionally interacting manner, there is a memory benefit in remembering the individual items as well as correctly discriminating the size. The effect was similar to Allen and Brady (2021). This suggests that chunking benefits can be translated to real-world objects by grouping them in semantic manner.

Experiment 4: Object grouping with flipped representation.

Participants: Experiment 4 was conducted to replicate the effect seen in experiment 3 with a different form of visual detail. Instead of varying size, object pairs were flipped randomly to see if the semantic pairing preserves object detail during flipping. 24 participants were recruited from The Pennsylvania State University undertaking introductory psychology courses. A criterion was set before analysis that the participants who performed with an average accuracy below the chance for both memory tests were to be excluded. No participants violated the exclusion criteria.

Stimuli and Procedure: Experiment 4 used the same stimuli and followed the same procedure as experiment 3 with the exception that this experiment replaced the memory judgement for the perceptual size among object pairs with horizontal object flips as shown in Figure 10. As stated earlier in experiment 3, the action pair might bias relative size among objects. To test whether this effect replicates, the experiment tests memory for whether objects have been horizontally flipped or not in the memory display under the two conditions (action pair and non-action pair). In this experiment, the set size has also been increased to 6 from 4.

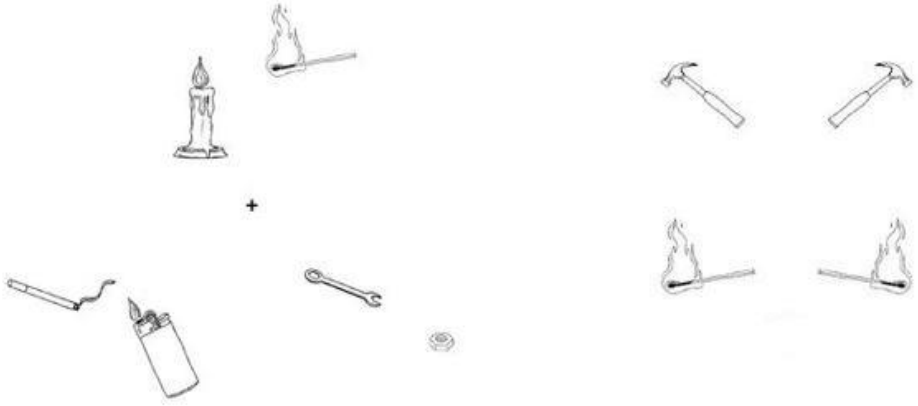

Figure 2.8 Object grouping for flip experimental setup. The left figure shows memory display with three set of object pairs arranged in different spatial locations. The right figure shows a test display of 4AFC task where participant must select one matching object.

Three pairs were shown at different spatial locations. The pairs were randomly flipped horizontally. The three pairs from memory display were presented for 3000ms and then a delay of 1000ms. The participants were probed for both identity and orientation of an object in a 4-AFC task. The 4-AFC choices consisted of a target, a distractor with the same identity as the target but the opposite horizontal orientation, and two foils with the same identity and flipped both ways.

Result: It was found that participants had a significant advantage in remembering the objects from semantically related pairs, however, memory for flipped representation of objects showed no benefit when objects were semantically paired over non-semantically paired ones. Participants were able to remember objects from the pairs (t(23) = -2.26 and p=0.033) with semantically related pairs (*M* =0.79 and *SD* = 0.09) having significant advantage over non-semantically related pairs (*M* =0.75and *SD* = 0.09). However, there was no advantage for semantically related pairs(*M* =0.57 and *SD* = 0.13) over non-semantically paired ones (*M* =0.54 and *SD* = 0.11) as participants were not able to discriminate the flipped representation in either condition (t(23) = -1.19 and p=0.244)

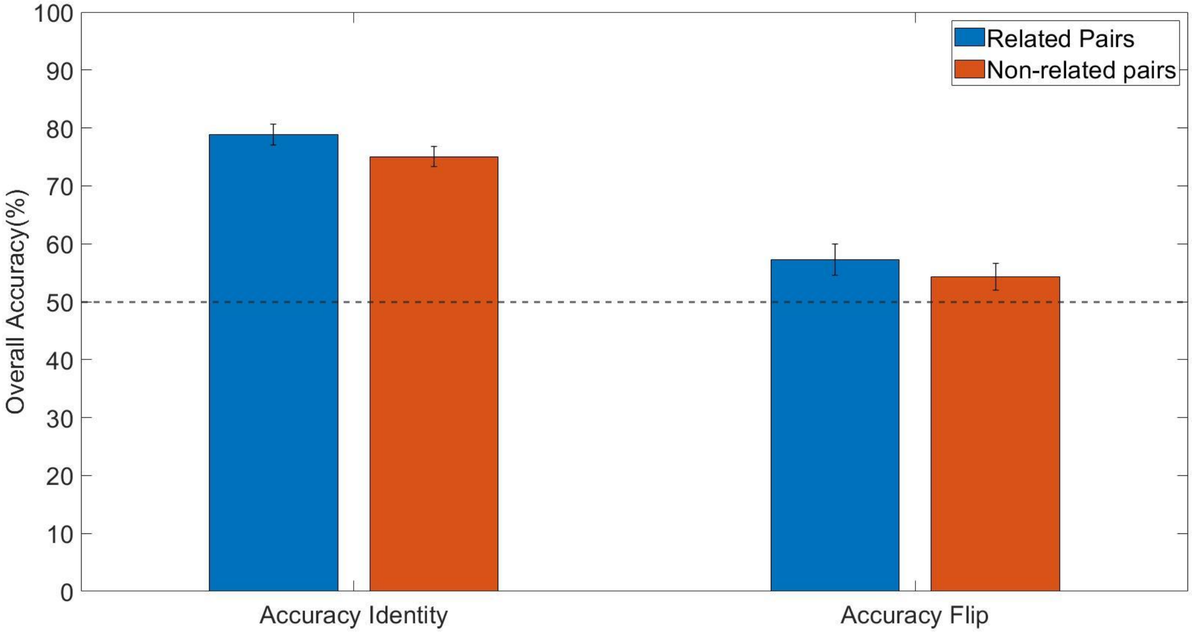

Figure 2.9 Experiment 4 results. Object Grouping produces a memory benefit in identity but not for flips. Error bars indicate the standard error of the mean.

The result interpreted by Figure 11 shows that when objects pairs were increased from two different pairs to three different pairs, the memory benefit in remembering individual objects still exists when objects were semantically paired. However, the memory was not able to discriminate the orientation of the object from the memory display. There was no significant benefit in semantically pairing objects to support memory in helping determine the object’s orientation.

Chapter 3. DISCUSSION

This study examined whether memory organization and improved recall performance can be achieved when visual information is processed and maintained using a strong association among items in the form of chunking and object grouping. More specifically, we tested whether chunking helps to preserve the perceptual details embedded within the items bounded by the chunk in the VWM. Most influential studies only focused on the organizational benefit of chunking identity information in working memory (Cowan, 2010; Mathy and Feldmen, 2012; Norris, Kalm, and Hall, 2019). These studies showed the single-level representational benefit in chunking by recoding redundant items into a coherent unit or compressed format. Such organization in memory was shown by an advantage of recalling items effectively. However, these studies omitted the depths into which the nature of chunking can be studied. Brady et al. (2011) began studying visual memory in a more structured representation than just an item-based representation. They concluded that in either simple displays (e.g., a simple colored shape or ensemble of such colored shapes) or in real-world displays (e.g., any real-world object or a scene comprising of objects and context), information is distributed in a parallel interacting processing stream across items. Other work showed that regularities (Brady, Konkle, and Alvarez; 2009) as well as strong association from LTM (Ngiam and Brissenden; 2019) interacted with VWM to provide a hierarchical and distributed memory representation (Allen, DiStefano, and Brady; 2021).

In this study, our goal was to see if conceptual information from LTM helped working memory to compress items and improve memory for visual details. The effect was seen in Allen et al. (2021) experiment 2 where recall for both letter identity and its form (bold or italic) showed significant advantage during chunking condition over random association. However, the effect observed was small and detail preservation might have existed due to the clear categorical distinction i.e. to simply remember whether the letter was bold or italic. Similar benefits of letter-based chunking can be translated to everyday objects when they are grouped semantically and functionally interacting (O’Donnell et al. 2016). It was found that such semantically related objects helped subjects to remember objects presented in memory display better than unrelated ones. This effect was similar to chunking helping recall items by strategically organizing them in memory. However, the study did not check if details had similar advantageous effect during semantic pairing as was seen in Allen et al. (2021) study.

In a series of experiments, we studied if chunking and object grouping show memory benefits by structuring items into hierarchical and distributed representation and therefore replicate the effects in the Allen et al. (2021) and O'Donnell et al. (2016) studies for item-level information. We hypothesized that both chunking and semantic pairing of items provides a memory advantage for remembering individual items, but at the expense of memory precision for visual details. In other words, visual detail information about items from compressed pairs would be degraded allowing additional items to be stored. In the first two experiments, we tried to study the nature of chunking and replicate the findings of Allen et al. (2021) using letters that form words. Experiment 1 utilized two sets of letters with rich visual detail. The letters were taken from the EMNIST dataset consisting of more than 1000 handwritten letters by different writers. The result provided a ceiling effect for letter identity for both chunked and non-chunked random condition. Since only two pairs were utilized, the visual memory capacity was large enough to incorporate each letter. Nothing significant could be derived from this experiment. Experiment 2 increased the memory load by introducing two sets of three letters. We also studied the memory for identity and writing style (visual detail) separately with half of trials for each condition testing memory for identity and the other half testing memory for style. The result showed participants having an advantage in recalling letters during chunked condition, but the writing-style memory was very low. The style memory for either condition was close to chance suggesting that either encoding of perceptual features of items wasn't robust enough or the target items suffered interference from competing items. It can also be true that the experiment design to test two memory effects separately contributed prominently towards identity memory by making participants discard perceptual detail to only favor retrieving items. Moreover, the two candidate items (target and foil) were clearly not distinct enough to allow participants to recall the difference. One future aspect to this experiment can be discarding the separate memory test and introducing 4AFC test with targets and foils perceptually distinct from each other to avoid interference.

Experiment 3 used object pairing instead of letters to determine if perceptual detail in the form of varied object sizes is preserved or not. The result did not support our hypothesis that perceptual details are lost during semantic pairing and exhibit better recall during non-semantic pairing. In fact, the experiment replicated the finding of experiment 2 of Allen et al. (2021) study and showed that memory is organized hierarchically, and conceptual organization preserved the perceptual content of items. Semantically paired object biased memory not just for identity but also for size such that observers demonstrated higher memory in discriminating object size for action pairs over non-action pairs. To see if the effect replicates, we set up experiment 4 where memory load was increased to three different pairs and object pairs were randomly flipped in trials. Participants were still able to significantly recall more individual objects from memory during semantic pairing condition however no significant difference was seen for the memory of whether the object was flipped or not between the two conditions. This was an interesting finding because the flipped orientation did not matter unlike varied size might have mattered in experiment 3. Participants were also able to discriminate flipped objects with reliable accuracy and the findings suggest that semantic relatedness had no effect for the horizontal flip memory judgement. However, it still did not support our hypothesis that visual details for objects in non-semantic pairing should have an advantage over semantically paired objects.

The present studies still lacked the proper design to completely test memory. As mentioned earlier, a follow up of experiment 2 can be elaborated further by removing the separate test for identity and introducing more perceptually distinct letters as foils. This would help introduce variability and avoid confusion among competing items in test display. The result might still go either way and the memory advantage for both identity and details might be observed for chunked condition. Or the visual detail might be reduced during the chunking condition but get encoded item-wise with greater precision during non-chunked condition. For the object grouping experiments, especially for object flip experiment, we can further test memory effect for detail by varying set sizes within block or across blocks and see if same effect is still replicated from experiment 4. Also, if we randomly flip one object rather than the object pairs, could semantic relatedness effects persist? Another extension to this idea would be to see using EEG if flipped object pairs are treated similarly when they are interacting with each other in semantic relatedness condition. We could use contralateral delay activity (CDA) amplitude to see if objects pairs exhibit similar behavior from observers when one of the objects in a semantic pair is horizontally flipped vs when they are positioned so as to be interacting (e.g. the axe blade facing towards a tree rather than away from it). If CDA amplitude is similar between flipped and non-flipped conditions, it will show that the object pairing is similar and will also validate O'Donnell et al. (2016) result that functional interacting is a secondary effect to semantic relatedness. However, for the result from experiment 4, it might suggest that during the 4AFC task, participants could not match orientation template to their VWM and opted for guessing during semantic related trials. But, if the CDA amplitudes do not match, the result suggests that object pairs are treated differently suggesting flip might break semantic relatedness property of the object.

One thing is certain from the set of results obtained here is that letter chunking and semantically paired object grouping facilitates item/identity recall. This supports the nature of chunking in organizing contents in VWM through an interaction with LTM for remembering the objects advantageously. There are obvious individual differences in working memory capacity, but it can be accepted that chunking helps maintain information efficiently given the capacity. The interesting and somewhat controversial aspect of chunking helping to preserve the visual detail by structuring memory to hierarchical representation is still open to investigation.

References

1. Allen, M., DeStefano, I., & Brady, T. (2021). Chunks are not “Content-Free”: Hierarchical Representations Preserve Perceptual Detail within Chunks. *Proceedings of the Annual Meeting of the Cognitive Science Society*, 43. https://doi.org/10.1167/jov.21.9.2312

2. Alvarez, G.A., Cavanagh, P. (2004). The capacity of visual short-term memory is set both by visual information load and by number of objects. *Psychological Science.* 15(2):106-111. https://doi.org/10.1111/j.0963-7214.2004.01502006

3. Asp, I.E., Stormer, V.S., Brady, T.F. (2021). Greater visual working memory capacity for visually matched stimuli when they are perceived as meaningful. *Journal of Cognitive Neuroscience*. 33(5): 902-918. https://doi.org/10.1162/jocn_a_01693

4. Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. *Psychology of Learning and Motivation*, 89–195. https://doi.org/10.1016/s0079-7421(08)60422-3

5. Awh, E., Barton, B., Vogel, E. K. (2007). Visual working memory represents a fixed number of items regardless of complexity. *Psychological Science*. 18(7):622-8. https://doi.org/10.1111/j.1467-9280.2007.01949.x.

6. Baddeley, A.D., Hitch, G. (1974). Working memory. *Psychology of Learning and Motivation*. 8, 47-89. https://doi.org/10.1016/S0079-7421(08)60452-1

7. Baddeley, A. D., & Logie, R. H. (1999). Working memory: The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 28–61). Cambridge University Press. https://doi.org/10.1017/CBO9781139174909.005

8. Balaban, H., Luria, R. (2015). Integration of distinct objects in visual working memory depends on strong objecthood cues even for different-dimension conjunctions. *Cerebral Cortex.* 26:2093-2104. https://doi.org/10.1093/cercor/bhv038

9. Bays, P.M., Catalao, R.F.G., Husain, M. (2009). The precision of visual working memory is set by allocation of a shared resource. *Journal of Vision*. 9(10):7.1-11. https://doi.org/10.1167/9.10.7

10. Brady, T. F., Konkle, T., & Alvarez, G. A. (2009). Compression in visual working memory: Using statistical regularities to form more efficient memory representations. *Journal of Experimental Psychology: General, 138*(4), 487–502. https://doi.org/10.1037/a0016797

11. Cohen, G., Afshar, S., Tapson, J., van Schaik, A. (2017). EMNIST: an extension of MNIST to handwritten letters. *ArXiv:1702.05373 [Cs]*. https://arxiv.org/abs/1702.05373

12. Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why? *Current Directions in Psychological Science, 19*(1), 51–57. https://doi.org/10.1177/0963721409359277

13. Huang, L., Awh, E. (2018). Chunking in working memory via content-free labels. Scientific Reports. 8. https://doi.org/10.1038/s41598-017-18157-5.

14. Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature, 390*(6657), 279-281. https://doi.org/10.1038/36846

15. O'Donnell, Ryan & Clement, Andrew & Brockmole, James. (2018). Semantic and functional relationships among objects increase the capacity of visual working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 44. https://doi.org/10.1037/xlm0000508.

16. Mathy, F. and Feldman, J. (2012) What's Magic about Magic Numbers? Chunking and Data Compression in Short-Term Memory. Cognition, 122, 346-362. https://doi.org/10.1016/j.cognition.2011.11.003

17. McAfoose, J., & Baune, B. T. (2009). Exploring visual–spatial working memory: A critical review of concepts and models. *Neuropsychology Review, 19*(1), 130–142. https://doi.org/10.1007/s11065-008-9063-0

18. Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*(2), 81–97. https://doi.org/10.1037/h0043158

19. Norris D., Kalm K.(2021) Chunking and data compression in verbal short-term memory. Cognition. 208:104534. https://doi.org/10.1016/j.cognition.2020.104534

20. Norris, D., Kalm, K., & Hall, J. (2020). Chunking and redintegration in verbal short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 46*(5), 872–893. https://doi.org/10.1037/xlm0000762

21. Ngiam W.X.Q., Brissenden J.A., Awh, E. "Memory compression" effects in visual working memory are contingent on explicit long-term memory. J Exp Psychol Gen. 2019 Aug;148(8):1373-1385. https:// doi.org/10.1037/xge0000649.

22. Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory, 6*(2), 174–215. https://doi.org/10.1037/0278-7393.6.2.174

23. Swan, G., Wyble, B. The binding pool: A model of shared neural resources for distinct items in visual working memory. *Atten Percept Psychophys* 76, 2136–2157 (2014). https://doi.org/10.3758/s13414-014-0633-3