Chapter 2

Effect of Familiarity and Complexity in Visual Working Memory

1 Introduction

A common method to research the architecture of visual working memory (VWM) is to vary the stimuli used in the change-detection task on a single dimension and examining its effect on memory performance. For example, Luck & Vogel (1997) found no change in memory performance when they increased the amount of features that made up the stimuli in the change-detection task, suggesting the VWM system is object-based rather than feature-based. Similarly, in their canonical study, Alvarez & Cavanagh (2004) displayed stimuli of various complexities, such as the more complex random polygons and Chinese characters and the less complex colour squares. Critically, they indexed each stimuli's complexity by conducting a visual search task using those stimuli, in which the observer had to find a target amongst an array. The larger the visual search rate, the additional time it took to find the target with each additional item in the search display, the more complex the object was. Alvarez & Cavanagh (2004) found that change-detection performance was lower for more complex objects, such that the visual search rate, their measure of stimulus complexity, was almost perfectly correlated with working memory capacity (r = 0.992). This finding that stimulus complexity influenced memory performance motivated Alvarez & Cavanagh (2004) to suggest that the VWM system allocates finite resources to storing different stimuli, with more complex items requiring more resources.

Although the object-based "slots" model (Luck & Vogel, 1997) and the feature-based "resources" model (Alvarez & Cavanagh, 2004) have been influential in VWM research, the manner in which object complexity influences VWM processes, a main difference between these models, is still contended. Eng, Chen, & Jiang (2005) found that the visual search rates are better predictors of VWM capacities at shorter presentation durations compared to longer durations. This suggests that stimulus complexity influences perceptual encoding rather than overall VWM capacity. Awh, Barton, & Vogel (2007) suggest that the differences in VWM capacity found by Alvarez & Cavanagh (2004) were not due to sitmulus complexity *per se* but rather because of confusion at the comparison stage in change-detection rather than during encoding. Awh et al. (2007) manipulated whether the changed object in the test array was from the same stimulus set (*within-*

category) or from a different stimulus set (*cross-category*). They replicated the finding of Alvarez & Cavanagh (2004) that change-detection accuracy decreased as complexity increased with within-category changes, but found accuracy was equivalent when changes were cross-category. As objects that were more complex were more visuall similar (high *sample-test similarity*), within-category changes produced more errors made when detecting changes in the test array.

While many researchers have focused on the capacity of visual working memory, the encoding rate of information into VWM also seems to be limited. Vogel, Woodman, & Luck (2006) gradually increased the *stimulus onset asynchrony* (SOA) between the memory array and a backward-mask array in the change-detection task. They found change-detection performance improved with increased encoding duration up to 200 ms, before plateauing. Prior to the asymptote, each colour block too approximately 50 ms to encode. We used this paradigm with stimulus sets of various complexity to examine whether the encoding rate is influenced by stimulus complexity, such that an object with more features takes longer to encode into VWM, as suggested by Eng et al. (2005). Increasing object complexity may slow the rate of encoding into VWM, such that complex objects will require more time to fill VWM capacity. This would confound conclusions made from comparisons of VWM capacity for objects of different complexity with the same memory array durations, such as those found by Alvarez & Cavanagh (2004).

Differing definitions and measures of complexity may have lead to the vastly differing models of VWM architecture. Here, we defined stimulus complexity using *perimetric complexity*, the square of the combined inside and outside perimeters of a letter, divide by its area (Attneave & Arnoult, 1956). As letters increase in perimetric complexity, they are identified increasing inefficiently (Pelli, Burns, Farell, & Moore-Page, 2006). Perimetric complexity is a superior measure of complexity to previous manipulations of complexity because it is objective, measured from the stimulus directly. Additionally, an increase in perimetric complexity reflects an increase in stimulus complexity without the addition of extra feature dimensions. In the present study, we selected letters of the English alphabet and varied the perimetric complexity by presenting the letters in four different fonts (Experiment 1), as well as presented characters from four alphabets that were unfamiliar to our participants (Experiment 2).

An additional factor that has been shown to influence consolidation and storage in VWM is familiarity. For example, chess experts showed an improved memory performance for chess game positions compared to novices, but equivalent memory performance when the chess pieces were random on the board (Chase & Simon, 1973). More recently, higher

VWM capacities have been found for famous faces over unfamiliar faces (Jackson & Raymond, 2008), as well as for Pokémon (characters from a popular childhood cartoon) from an original generation over a recent generation only for those reporting familiarity with the characters (Xie & Zhang, 2016). Similarly, those familiar showed a higher encoding rate for Pokémon (Xie & Zhang, 2017). Although, these studies do not control stimulus complexity and it is unknown whether these effects of familiarity are independent of stimulus complexity. We examined this in Experiment 3, controlling for stimulus complexity by using the Brussels Artificial Character Set (BACS) (Vidal, Content, & Chetail, 2017). The BACS is designed to have the same number of junctions, strokes and terminations as English letters but is unfamiliar to the observer. Additionally, we matched the perimetric complexity of the BACS to the English letters.

Encoding and capacity limits in VWM might best be described in terms of *objects*, as in the "slots" model or in terms of *features*, as in the "resources" model. If feature intergration limits the encoding rate into VWM, more complex letters will be encoded at a slower rate. If this is not the case, encoding rate will not vary with stimulus complexity. Similarly, if the number of features limits VWM capacity, fewer items will be stored from more complex alphabets. Otherwise, VWM capacity maybe be determined by the number of items, and will not vary with stimulus complexity. These models are shown in Figure 1.

2 References

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*, 106–111. Retrieved from http://visionlab.harvard.edu/Members/Patrick/PDF.files/2005%20pdfs/Alvarez%26Cavanagh(2004).pdf

Attneave, F., & Arnoult, M. D. (1956). The quantitative study of shape and pattern perception. *Psychological Bulletin*, *53*(6), 452.

Awh, E., Barton, B., & Vogel, E. K. (2007). Visual Working Memory Represents a Fixed Number of Items Regardless of Complexity. *Psychological Science*, *18*(7), 622–628. doi:10.1111/j.1467-9280.2007.01949.x

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology*, *4*(1), 55–81. doi:10.1016/0010-0285(73)90004-2

Eng, H. Y., Chen, D., & Jiang, Y. (2005). Visual working memory for simple and complex visual stimuli. *Psychonomic Bulletin & Review*, *12*(6), 1127–1133. doi:10.3758/BF03206454

Jackson, M. C., & Raymond, J. E. (2008). Familiarity enhances visual working memory for faces. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(3), 556.

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

Pelli, D. G., Burns, C. W., Farell, B., & Moore-Page, D. C. (2006). Feature detection and letter identification. *Vision Research*, *46*(28), 4646–4674.

Vidal, C., Content, A., & Chetail, F. (2017). BACS: The Brussels Artificial Character Sets for studies in cognitive psychology and neuroscience. *Behavior Research Methods*. doi:10.3758/s13428-016-0844-8

Vogel, E. K., Woodman, G. F., & Luck, S. J. (2006). The time course of consolidation in visual working memory. *Journal of Experimental Psychology. Human Perception and Performance*, *32*(6), 1436–1451. doi:10.1037/0096-1523.32.6.1436

Xie, W., & Zhang, W. (2016). Familiarity increases the number of remembered Pokémon in visual short-term memory. *Memory & Cognition*, 1–13. doi:10.3758/s13421-016-0679-7

Xie, W., & Zhang, W. (2017). Familiarity Speeds Up Visual Short-term Memory Consolidation: Electrophysiological Evidence from Contralateral Delay Activities. *Journal of Cognitive Neuroscience*, 1–13. doi:10.1162/jocn_a_01188