Abstract

Introduction

A common method employed by visual working memory (VWM) researchers is to manipulate the stimuli used in the change-detection task and examine the resulting effect on memory performance. A major point of contention central to the current debate over the architecture of VWM is the influence of stimulus complexity on VWM processes. However, an overlooked influence on the VWM system and on the complexity of a stimulus is the observers' familiarity with the stimulus. This chapter examines influence of stimulus complexity and familiarity on two parameters of VWM, the encoding rate and capacity.

Complexity and architecture of VWM

Opposing findings regarding the influence of stimulus complexity on VWM capacity inspired the two conflicting models of VWM architecture that have shaped much of the research in VWM, the *slots* model and the *resources* model. Proponents of the *slots* model suggest the information capacity limit of VWM is defined stricly by the number of *items* to be stored, regardless of the complexity of the stored items. In their paper that established the *slots* model, @luck_capacity_1997 increased the complexity by increasing the amount of relevant features to the to-be-remembered stimuli. For example, the memoranda included various conjunctions of colour, orientation, size and the presence or absence of a gap. They found no change in VWM performance with the increased amount of relevant features that made up the stimuli in the change-detection task, suggesting the VWM system is object-based rather than feature-based.

Similarly, @alvarez_capacity_2004 used various stimlus sets, ranging from the more complex random polygons and Chinese characters to the less complex colour squares, in a change-detection task. Critically, they indexed each stimuli's complexity by conducting a visual search task with those stimuli. In the visual search task, observers had to locate a target object amongst an array of 4, 8 or 12 objects from the same stimulus class. They then quantified complexity as the visual search rate, the additional time it took to find the target with each additional item in the search display. That is, more complex objects were those that made visual search slower with each added object. @alvarez_capacity_2004 found that change-detection performance was lower for more complex objects, such that the visual search rate was almost perfectly correlated with working memory capacity ($r = 0.992$). This finding that stimulus complexity influenced VWM performance motivated @alvarez_capacity_2004 to propose the *resources* model, which suggests that the VWM system allocates a finite pool of resources to storing stimuli. As more complex items require more resources, less items can be stored in VWM.

Although the object-based "slots" model [@luck_capacity_1997] and the feature-based "resources" model [@alvarez_capacity_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. Additionally, the results that these models are based upon have not been perfectly replicated. @hardman_remembering_2015 attempted to replicate the critical result of Luck and Vogel [-@luck_capacity_1997]

In their direct replication of @luck_capacity_1997, @hardman_remembering_2015 found an effect of feature load on change-detection performance where @luck_capacity_1997 had not. This rules out the pure *slots* account where the number of items is the sole factor limiting VWM performance, but @hardman_remembering_2015 found strong evidence that the number of items is a significant contributor to the capacity limit of VWM.

Stimulus complexity may influence VWM processes at an early stage, when items are being consolidated into VWM. @eng_visual_2005 were able to replicate @alvarez_capacity_2004, finding that visual search rate negatively correlated with VWM capacity with brief memory display presentations (500 and 1000 ms) and longer presentations (3000 ms). However, they did not replicate the near perfect negative correlation found by @alvarez_capacity_2004, and found the visual search rates were better predictors of VWM capacities at shorter presentation durations compared to longer durations. If capacity was purely determined by the complexity of the stimulus, it should not be influenced by duration presentation. Thus, @eng_visual_2005 suggests that increased stimulus complexity limits perceptual encoding rather than overall VWM capacity.

@awh_visual_2007 suggest that the differences in VWM capacity found by @alvarez_capacity_2004 were not due to stimulus complexity *per se* but rather because of confusion at the comparison stage in change-detection rather than during encoding. @awh_visual_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 similarly replicated the finding of @alvarez_capacity_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 visually similar (high *sample-test similarity*), within-category changes produced more errors made when detecting changes in the test array, lowering estimates of VWM capacity.

Encoding rate

Like the capacity of visual working memory, the encoding rate of information into VWM is similarly limited. The encoding rate was first quantified by @vogel_time_2006. @vogel_time_2006 presented four colours for a fixed duration (100 ms) to observers in a change-detection task. VWM processes creating a durable representation of those colours were then interrupted with a backward mask. @vogel_time_2006 varied the *stimulus onset asynchrony* (SOA), the duration allowed for VWM processes prior to the onset of the backward mask. They found change-detection performance improved with increased encoding duration up to 200 ms, before plateauing. Prior to the asymptote, each colour block took approximately 50 ms to encode.

Although the encoding rate reflects early processing creating durable VWM representations, it is often ignored by researchers despite the possibility influences on early VWM processing might vary VWM capacity estimates. In our study, we adpoted the @vogel_time_2006 paradigm with various stimulus sets to examine whether the encoding rate is influenced by stimulus complexity. This allows us to determine whether a stimulus set with items containing more features (more complex) takes longer to encode into VWM. Increasing object complexity may slow the rate of encoding into VWM, such that complex objects will require more time to saturate 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_capacity_2004.

Defining complexity

Inconsistent definitions, measures and manipulations of complexity may have lead to the vastly differing models of VWM architecture. For example, @luck_capacity_1997 manipulated stimulus complexity by increasing the number of relevant features in the stimuli, whereas @alvarez_capacity_2004 varied stimulus sets and measuring their visual information load using a visual search task. In the present chapter, we defined stimulus complexity using *perimetric complexity*, the square of the combined inside and outside perimeters of a letter, divide by its area [@attneave_quantitative_1956]. As letters increase in perimetric complexity, they are identified increasing inefficiently [@pelli_feature_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).

Familiarity

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_perception_1973]. More recently, higher VWM capacities have been found for famous faces over unfamiliar faces [@jackson_familiarity_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_familiarity_2016]. Similarly, those familiar showed a higher encoding rate for Pokémon [@xie_familiarity_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_bacs:_2017]. The BACS is designed to have the same number of junctions, strokes and terminations as English letters but is unfamiliar to the observer. Another critical aspect of the BACS characters is that they match the similarity between characters found with English letters [@vidal_bacs:_2017. Additionally, we matched the perimetric complexity of the BACS to the English letters.

It is unclear how different qualities of the stimulus in terms of complexity, familiarity and similarity interact and contribute to VWM performance. The experiments presented in this chapter attempt to explicate the interaction by focusing primarily on familiarity.

Modelling VWM performance

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.